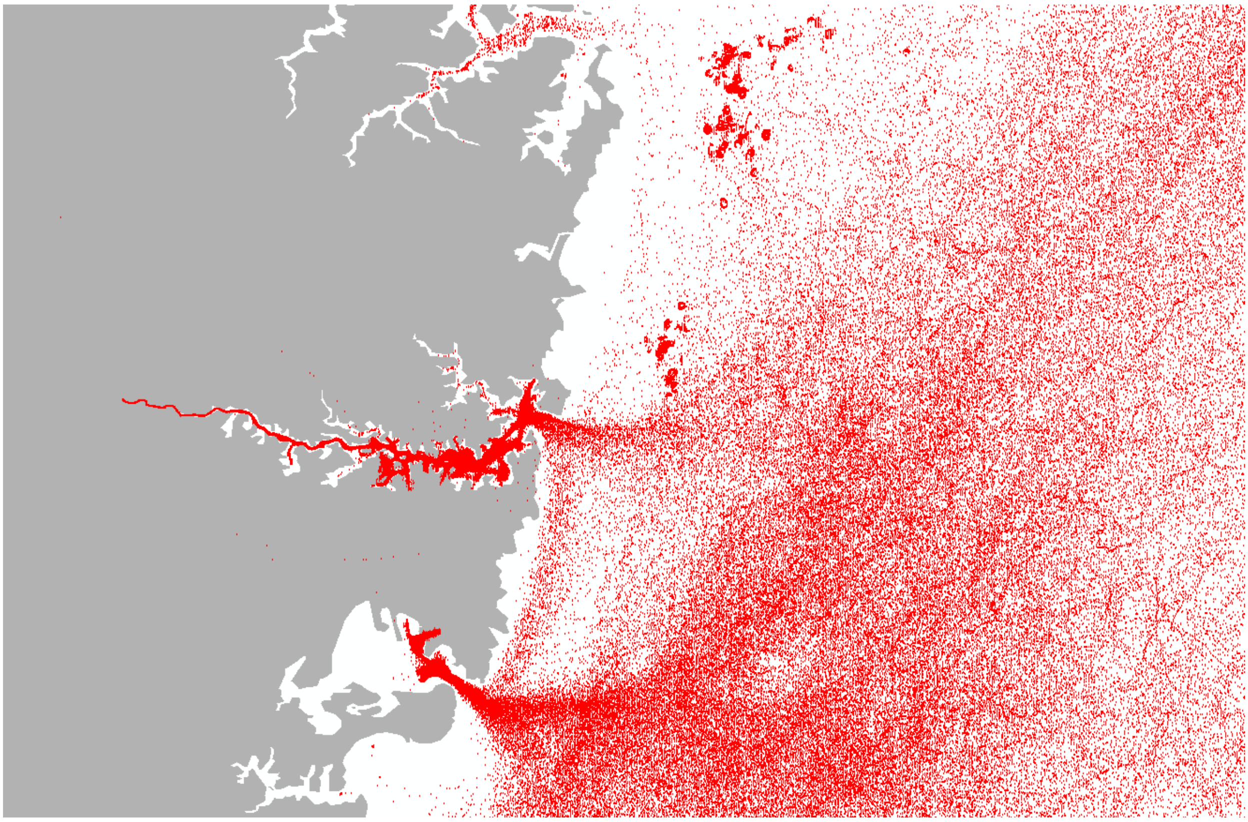
NSW SHIP EMISSIONS STUDY

Emissions from ships operating in the Greater Metropolitan Area

NSW Environment Protection Authority



Project name: NSW EPA Ship Emissions Study

Project No.: PP117488

Document title: Emissions from ships operating in the Greater Metropolitan Area

Document No.: 1K2V16P-6

Date of issue: 6 June 2015

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Objective: DNV GL has been engaged by the NSW Environment Protection Authority (EPA) to estimate ship emissions in the Greater Metropolitan Area and key GMA ports by using Automatic Identification System (AIS) and databases of ship fuel consumption and emission factors. Furthermore, measures used nationally and internationally to reduce ship emissions including broad policy instruments, economic instruments, management practices, technological options and voluntary measures are assessed and evaluated.

Keywords:
Ship emissions
Passenger ships
Greater Metropolitan Area
New South Wales
AIS – Automatic Identification System
Australia

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1 GLOSSARY OF TERMS

AAPMA	Association of Australian Port & Marine Authorities
AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
BITRE	Bureau of Infrastructure, Transport and Regional Economics
CallSign	A unique designation for a radio transmission station
CAPEX	Capital Expenditure
CBD	Central Business District
CO2	Carbon Dioxide
CSI	Clean Shipping Index
cSt	Centistokes (viscosity)
DME	Dimethyl Ether
DNV GL	Det Norske Veritas Germanischer Lloyd
ECA	Emissions Control Area
EEDI	Energy Efficiency Design Index
EGR	Exhaust Gas Recirculation
EU	European Union
GHG	Greenhouse Gas
GMA	Greater Metropolitan Area
GT	Gross Tonnes (Here: "the moulded volume of all enclosed spaces of the ship")
HC	Hydrocarbon
HFO	Heavy Fuel Oil
Hz	Hertz
IFO	Intermediate Fuel Oil
IMO	International Maritime Organisation
ISO	International Standards Organisation
ISPS	International Ship and Port Facility Security
kV	Kilovolt
kW	Kilowatt
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
LSF	Low Sulphur Fuel (0.1% unless otherwise stated)
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MEPC	IMO Marine Environment Protection Committee
Metric Tonne	A unit of mass equal to 1,000 kilograms (2205 pounds)
MGO	Marine Gas Oil
MMSI	Maritime Mobile Service Identity
MRV	Monitoring, Reporting and Verification
N connector	Threaded, weatherproof, medium-size connector used to join coaxial cables
NCA	Norwegian Coastal Administration
NPV	Net Present Value
NOX	Nitrogen Oxides

NSW EPA	New South Wales Environment Protection Authority
OPA	Oil Pollution Act
PM2.5	Particulate matter with aerodynamic equivalent diameter of less than 2.5 micrometres
PM10	Particulate matter with aerodynamic equivalent diameter of less than 10 micrometres
Prod Tanker	Product Tanker
RoRo	Roll on Roll Off
RPM	Revolutions Per Minute
SCR	Selective Catalytic Reduction
SE ASIA	South East Asia
SEEMP	Ship Energy Efficiency Management Plan
SNCR	Selective Non-Catalytic Reduction
SO2	Sulphur Dioxide
SOG	Speed Over Ground
SOLAS	Safety of Life at Sea
SOX	Sulphur Oxides
STCW	Standards for Training, Certification and Watchkeeping for Seafarers
TEU	Twenty Foot Equivalent Unit
UNCLOS	UN Convention on the Law of the Sea
V	Volt
WPCI	World Port Climate Initiative

2 EXECUTIVE SUMMARY

This report presents characteristic emission components from ships, their legal regulation and selected abatement methods to reduce emissions. All main classes of ship traffic in the NSW Greater Metropolitan Area (GMA) are analysed by AIS (Automatic Identification System) covering fuel consumption, emissions, speed, route, size, number of ships and time in GMA waters for the calendar year 2013. Forecasts for ship emissions in the GMA and selected NSW ports towards 2040, along with various abatement initiatives and costs, have also been included.

Scope of Work

The work assesses the technical feasibility, costs and emission impacts of adopting emission reduction measures for ships at major ports in the NSW GMA. The report undertakes a detailed:

- Stocktake and evaluation of all measures used nationally and internationally to reduce ship emissions. These include broad policy instruments, economic instruments, management practices, technological options and voluntary measures; and
- Assessment of the logistical and technical feasibility of adopting lower sulphur fuel (including fuel switching), seawater scrubbers, vessel speed reduction and shore side power for ships.

The study covers details such as:

- 'Hot spots' in the GMA
- Current and projected ship movements
- Current and projected fuel availability and supply logistics
- Ship capabilities for using emission reduction measures
- Wherever reliable data is publically available, an estimate of costs and emission benefits of feasible options
- Wherever reliable data is available from public sources or through DNVGL's industry network, an estimate of Net Present Values (NPV) of certain measures for standard ship types are provided
- Stakeholders in the maritime supply chain including ship owners, operators, suppliers, regulators, ports and other interested parties

For this study, the GMA is defined as encompassing the area bounded by Newcastle to Port Kembla, to a distance of 120km from the coastline (ref: Figure A). What follows is a summary of the analysis completed.

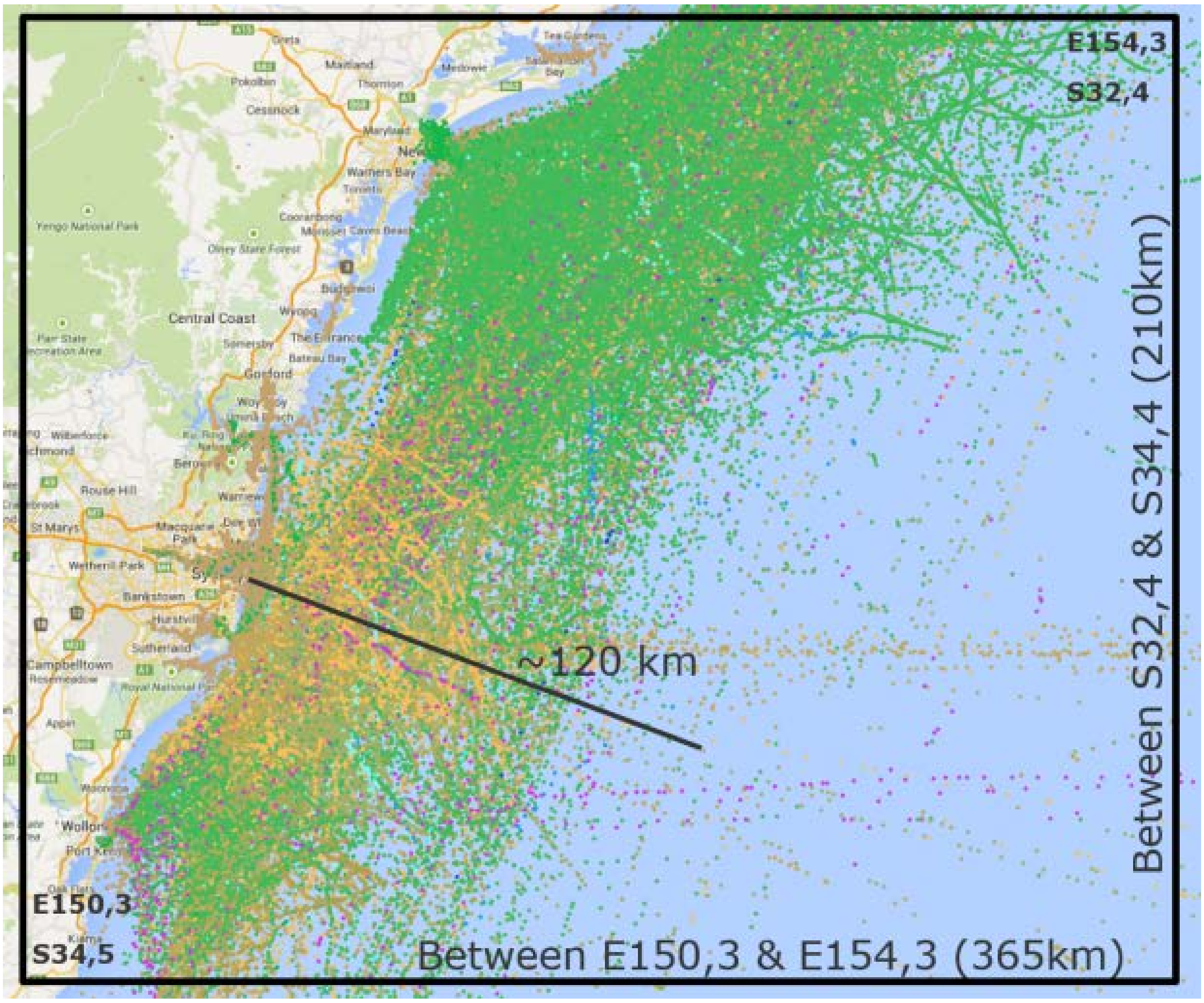

Figure A: Boundaries of NSW GMA

Fuel consumption and emissions in the GMA

Total maritime fuel consumption for the GMA in 2013 was approximately 273 000 tonnes. This was consumed by 2 452 unique vessels over 1 000 gross tonnes (GT) and dominated by:

- Unique vessels - bulk carriers (56%), container vessels (11%), RoRo vessels (8%), general cargo vessels (7%) and oil tankers (7%), while passenger vessels accounted for 2% of the total
- Fuel consumption - bulk carriers (33%), container vessels (23%), oil tankers (14%), chemical/prod tankers (6%), while passenger vessels accounted for 11% of the total

These figures do not include smaller vessels such as passenger ferries operating in Sydney Harbour (Port Jackson).

Over the study period, the total monthly fuel consumption (includes all on-board engines, boilers) remains relatively flat, as depicted in Figure B.

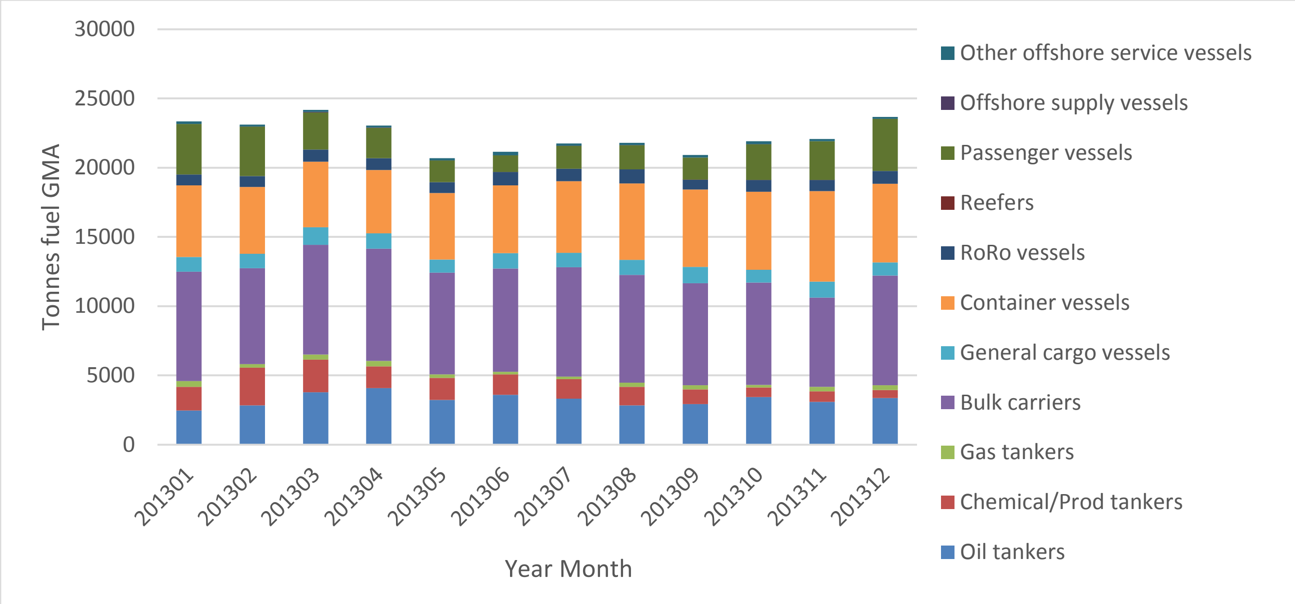

Figure B: Fuel consumption by main ship types for all identified ships in the GMA, monthly, 2013

In terms of emissions (CO_2, NOx, SOx[1] and PM2.5), the large majority occurs outside the Port areas studied. As depicted in Table A below, Port Jackson and the Port of Newcastle have approximately the same share of emissions (of total GMA) even with contrasting dominant ship types – passenger vessels in the case of the former and bulk carriers in the case of the latter. Port Botany has approximately double the emissions as these two, dominated by container vessels. Port Kembla, has approximately half of Port Jackson/Port of Newcastle, dominated by bulk carriers as well.

Table A: Ship emissions GMA in 2013, sum of all on-board engines and boilers, all ship types

	CO_2	NOx	SOx	PM2.5
TOTAL in the GMA (tonnes)	869,649	14,443	14,162	1,553
Port Jackson, share	3.9%	2.0%	3.5%	3.0%
Port Botany, share	10.3%	5.3%	10.5%	9.0%
Port of New-castle, share	4.5%	2.8%	4.3%	3.9%
Port Kembla, share	2.0%	1.3%	2.0%	1.8%
Balance (non-port GMA emissions)	*79.3%*	*88.6%*	*79.7%*	*82.3%*

[1] According to USEPA (5), it is assumed that 97.753% and 2.247% of the sulphur in fuel is converted to SO2 and PM10 sulphate, respectively during combustion. DNV GL methodology calculates SO2, but in this report SO2 refers to the equivalent SOx on a 1 to 1 basis. The SO2 is calculated as 2 times the molecular weight of elemental sulphur.

Emission abatement measures

There are several options for ship owners/operators to reduce emissions whilst in the GMA, but there is no simple, single solution that significantly reduces all emission components from large ship engines. However, there are individual on-board systems available to reduce individual components (SOx, NOx, particulate matter or CO_2 by reducing fuel consumption). Such systems typically reduce emissions of one or two components, but may even increase others. For instance, scrubbers reduce SOx and PM emissions significantly, but increase CO_2 emissions; and it is still uncommon to combine scrubbers with NOx-reducing systems. Another example is switching to low-sulphur distillates (with 0.5% or 0.1% sulphur) to nearly eliminate SOx emissions but these will not remove NOx.

Recently, novel 'hybrid' fuels have been introduced to the marine market; these are blended products with higher viscosity than distillates and a maximum content of 0.1% sulphur. However, the long-term experience from using 'hybrid' fuels is limited and thus this report focuses on low sulphur distillates.

LNG as fuel is another interesting example which removes SOx and NOx substantially and even lowers CO_2 emissions slightly, but require large investments both on-board and onshore for fuelling stations. Another novel and capital intensive solution both on land and on-board is shore-side powering of ships; this practically eliminates ship emissions at berth but may increase emissions from the land-side power utility. Table B below summarizes the emission reduction potential for each of the main measures; some NOx reducing alternatives are also included.

Table B: Estimated emission reduction potential of key technical abatement options[2]

Abatement option:	NOx reduction	SOx reduction[3]	CO2 reduction	PM reduction
Slow steaming	Limited saving potential inside GMA because ships already sail slowly. Outside GMA: Up to 10-30% emission reduction, depending on starting point.			
Low Sulphur Distillates	-	~80% (0.5% S fuel) ~96% (0.1% S fuel)	-	Approx. 90%[4]
Scrubber (wet)[5]	-	90-95%	1.5-2% increase	80-90%
Shore-side power, not including any increase at shore side power plant	~96% reduction achievable for all emission components. Approx. 80% of the current GMA emissions are non-port emissions, ref Table A.			
SCR	4-stroke: 90% typically	-	Slight increase	20-40%
LNG as fuel	Low pressure engine: 90% High pressure engine: 40%	90-100%	Approx. 15%	More than 90%
EGR	35-40%	-	Slight increase	Slight increase
Direct water injection	20-40% typical	-	Increased	-
HAM / Humid Air Motor	20-40% typical	-	-	-
Engine Modification	20-40%	-	Slight increase	Marginal reduction

2 This table refers to maritime industry's understanding and DNVGL's best knowledge through work for the NOx Fund, assessment of scrubbers etc. Different engine configurations, operational profile, external operating conditions and varying fuel qualities complicate such studies.

3 Reduction from current average sulphur content (2.7%) in GMA

4 Extensive PM data series from large series of ships and engines have not been reported; we use same reduction rates for PM2.5 and SOx: 80% and 96% reduction when switching from HFO to distillates with 0.5% and 0.1% sulphur, respectively.

5 Since the operational experience from dry scrubbers is minimal and wet scrubbers by far are the dominant scrubber solution, in this work wet scrubbers are referred to when addressing scrubbers unless dry scrubbers are specifically mentioned.

The following summary provides the main options suitable for reducing emissions in the GMA:

- Extended slow steaming (speed reductions) on approach to the Ports in the GMA will reduce all emissions, albeit in areas some distance from land and human populations. However, within the ports of GMA, all ships already are required to observe very low speed limits thus the emission (reduction) gains by slowing down further is minimal.
- Switching from typical heavy fuel oil (2.7% sulphur content) to low sulphur distillates (with 0.5% or 0.1% sulphur) whilst in the GMA will reduce SOx emissions by approximately 80% or 96% respectively and remove approximately 90% of PM, but will not significantly lower CO_2 or NOx emissions. Low sulphur distillates[6] are 40-80%[7] more expensive than heavy fuel oil and may require modifications of fuel systems and tanks on-board, but still represent the least burdensome abatement option and is currently the most common way to meet the ECA requirements in Europe and North America.
- Establishing a shore-side power system on land and a matching infrastructure on the largest polluting ships will inevitably be costly both for the ship owner and certainly also for the involved parties on land. Although this effectively removes emissions directly from the ship and the solution gets more technically harmonized around the world, it is not a mainstream solution and will take years to phase in unless extraordinary measures are initiated in the GMA ports.
- Other emission abatement solutions are increasingly available such as on-board exhaust scrubbers or exhaust capture and treatment systems. However, IMO's 2020 (possibly delayed until 2025 at latest) global 0.5% sulphur limit in fuel (1) will trigger significant SOx emission abatement outcomes across all GMA waters.

Emission forecasts

In this work it was found that ship emissions in the 4 ports combined only account for 10-20% of the overall ship emissions in the GMA. This may be explained by a large number of ships moving around, in and through the GMA, and many vessels keep waiting at anchorage for cargo operations.

It was also seen that total emissions from the merchant fleet are approximately 10 times higher than the emission levels from passenger ships. However, passenger ship emissions are typically emitted closer to large urban residential areas, increasing the risk of causing human pollutant exposure.

Traffic is projected to grow considerably over the next 15-years in all segments. Whilst advances in design of future new-builds may change the profile and/or spread of ship sizes visiting the GMA, the cargo volumes will display significant growth. Container vessel traffic is forecast to grow by approximately 100% whilst the number of bulk carriers ('non-containerized') will grow by almost the same, at 80% (2). Passenger vessel traffic over the next 10-years will also increase by approximately 85% (3). These particular segments will see the biggest effects in terms of fuel consumed and emissions in Port Botany (container vessels), Port of Newcastle (bulk carriers) and Port Jackson (passenger vessels).

[6] LSF is not widespread in the industry, and the usual solution for using low sulphur fuels is to use low sulphur distillates such as MGO (marine gas oil) or MDO (marine diesel oil). Distillates cost ca. 80% more than HFO. This is the basis for all calculations done in the report. Further, experience with industry through projects indicates that it is DISTILLATES most owners use when they enter ECAs today (not low sulphur HFO fuels.)

[7] Source: Bunkerworld http://www.bunkerworld.com/prices/ For example, 15 May IFO380 ($376 USD/t) versus MGO ($597 USD/t) = 59% premium

The 2013 ship emissions in GMA are 869,650 tonnes of CO2, 14,440 tonnes of NOx, 14,160 tonnes of SOx and 1,550 tonnes of PM2.5. In this study ship emissions are predicted up to 2040 based on IMO's 2nd GHG study (4) with the predominant emission reducing regulation currently applicable for the GMA being IMO's global limit of sulphur in fuel of 0.5% coming in 2020-25. This represents the Business As Usual (BAU) case, without potential new local or regional limitations of ship emissions.

The BAU forecast for 2016 is approximately 12,000 tonnes of SOx and 1,350 tonnes of PM2.5 in the GMA from all ships identifiable by AIS.

Under the BAU case, merchant ships in the GMA will emit more than a million tonnes of CO_2 per year by 2040. SOx emissions will drop from current level of 11,000 annual tonnes to about 2,400 tonnes by 2020 (or by 2025 in delay of IMO's limit), thereafter rise to above 4,300 tonnes by 2040. The NOx emissions will remain relatively steady at 12,000 tonnes/year and PM2.5 is also expected to drop from 1,200 to approximately 300 tonnes/year in 2020/25.

Still under the BAU case CO_2 emissions for passenger vessels in the GMA will climb towards 124,000 tonnes annually by 2040. SOx emissions will drop from 1,200 to 260 tonnes/year by 2020 (2025), while NOx emissions remain relatively steady towards 2040 at about 1,600 tonnes/year. PM2.5 is also expected to drop from 140 to 30 tonnes/year under the BAU case.

In the BAU forecast SO2 emissions from passenger ships in Port Jackson will drop from 140 tonnes/year to 30 tonnes/year in 2020, along with a reduction of PM2.5 from 14 tonnes/year to 3 tonnes/year.

If NSW authorities go beyond MARPOL's 0.5% sulphur cap on fuel with low sulphur regulations starting July 2016, forecasted emission reductions have been calculated for the following scenarios:

a) 0.5% low sulphur limit (or equivalent treatment) in the entire GMA / in Port Jackson only
b) 0.1% low sulphur limit (or equivalent treatment) in the entire GMA / in Port Jackson only

The following table summarizes annual reductions of SOx and PM2.5 emissions for year 2017 for the case with local implementation of low-sulphur regimes in 2016, well before IMO's global sulphur cap.

Table C: Relative emission saving if implementing low sulphur regime in 2016 instead of waiting for the global regulations. All values refer to 2017 emissions in BAU scenario.

Emission type Tonnes/year	Annual emissions reduction in 2017 (metric tonnes/year)			
	GMA, passenger traffic	GMA, merchant shipping	Pt Jackson, passenger traffic	Pt Jackson, merchant shipping
SO2 reduction, 0.5% regime	970	9086	114	243
PM2.5 reduction, 0.5% regime, with distillates, not 'hybrid fuels'	112	990	11.3	22
SO2 reduction, 0.1% regime	1177	11031	138	295
PM2.5 reduction, 0.1% regime with distillates, not 'hybrid fuels'	136	1202	14	27

The table shows that the significant emission savings can be achieved with low sulphur distillates or comparable SOx abatement technologies. However, for establishing such a regime the industry must have time enough to react and set aside funds for investments.

The timing effect of advancing the low-sulphur initiatives from 2020 (2025) to 2016 is significant, provided all ships comply with the regulation and do not reduce the services in the GMA. With an early implementation of a low-sulphur fuel regime in the GMA based on local regulations the emission savings add up over several years until IMO's global sulphur cap is initiated.

With a local 0.5% fuel sulphur limit SO_2 and $PM_{2.5}$ emissions from all ships in GMA will be reduced by more than 10,000 and 1,100 tonnes/year in 2017 respectively, compared to the Business As Usual scenario with IMO's 0.5% limit coming in by 2020 (2025).

A potential 0.5% or 0.1% sulphur limit for passenger ships calling Port Jackson without any other GMA emission regulations will remove 114 and 138 tonnes/year of SO_2 respectively in 2017; and 11 and 14 tonnes/ year of $PM_{2.5}$, respectively, compared to the BAU regime based on IMO's 0.5% sulphur limit.

Much of the emissions from passenger ships originate from cruise ships visiting Port Jackson. Recent unconfirmed developments include that major operators will phase in some of the newest and technologically most advanced ships from the 2016/17 season. These will probably have lower emissions per passenger than many of the current ships.

Given the number of ships and high investment costs for most of the emission reducing options, we find implementation of low-sulphur distillates requirements being the most feasible alternative in such a short implementation time. This will reduce SO_x and PM emissions significantly but increase the fuel costs by 40-80% during GMA operations. Given the poor current profitability in many sectors of the maritime industry, this may restrict some owners from operating in the GMA unless the additional costs are fully absorbed by the end user of the ship services.

In 2013, 273,000 tonnes of fuel, mainly HFO, was consumed in the GMA. If all this fuel is substituted by low sulphur distillates (marine gas oil, MGO), the fuel bill would increase by about 65%[8] with current prices[9]. The additional cost for substituting 273,000 tonnes of HFO with MGO is estimated to be $75 m AUD. This is based on Singapore distillate prices, representing a typical bunker hub for ships visiting Asia. Low sulphur novel 'hybrid' fuels may be cheaper than distillates, but are not covered in detail in this report since these are not widely distributed across the world and are not much used by ships.

The investment analysis demonstrates that the added NPV for a large cruise ship that starts using a scrubber in the GMA in 2016 instead of in 2020, adds up to $2 mAUD. It also means that the added costs for using LSF instead of HFO+scrubber is very significant over time. However, the added costs for using LSF only in the GMA during the period 2016 to 2020 is limited, with added NPV around $100 kAUD.

Currently, abatement measures in use by ships owners/operators in the GMA mirror those typically found all over the world with 'operational' optimization top of the list (see Figure C below), primarily to save fuel. These include slow steaming (lower speed), voyage / cargo planning (including speed, weather, just in time arrival) and improved maintenance (including hull fouling management, propellers, engines, use of LED lights). This supports the notion that emission reduction measures that are both cost effective and easy/quick to implement stand the greatest chance of acceptance, however it is still worth mentioning that newer ships typically are better equipped with fuel-saving systems and have more fuel efficient underwater hull designs than older vessels.

[8] See footnotes 6 and 7 above

[9] See footnote 6 and 7 above

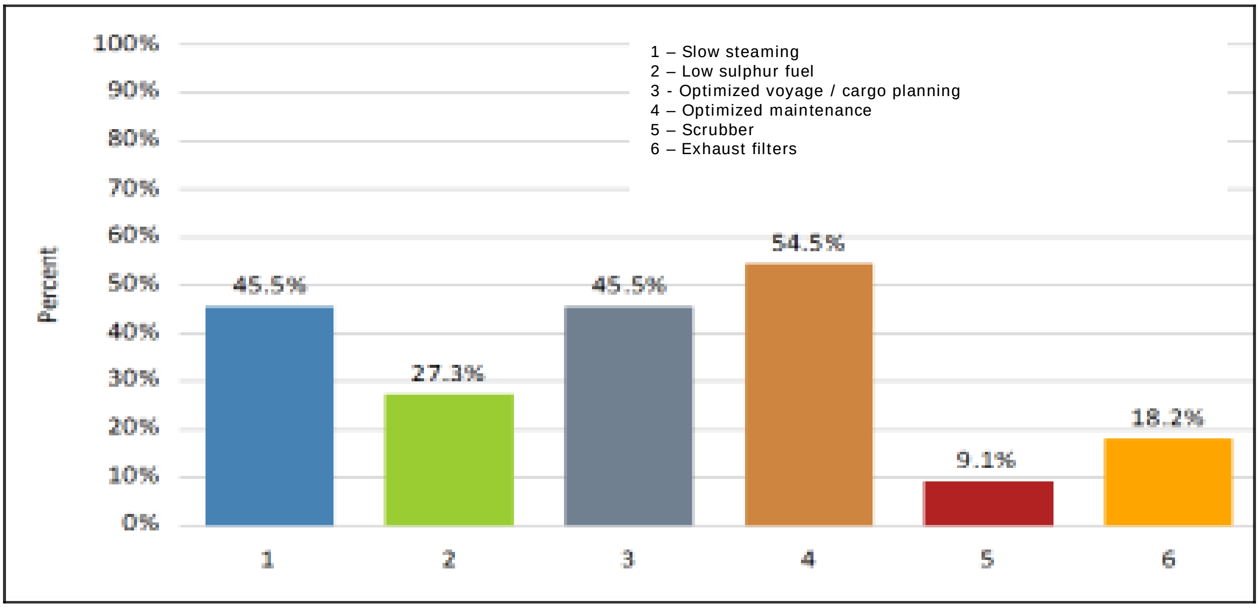

Figure C – Current emission abatement measures of all ship types operating in the GMA – Report Stakeholder Questionnaire. Most popular measures include optimized maintenance, optimized voyage and slow steaming

Stakeholder consultation

Feedback and input was sought from a wide section of interested parties covering current and future emission abatement strategies, regulatory requirements and the maritime industry in general. Key observations included:

- ‘Regulations and compliance’ are an accepted part of business and that although some incur compliance costs the main concern was that the oversight and penalties for failure to comply were not always an adequate deterrent. This last point was based on overseas experience and not activities within the GMA.
- With new regulations and requirements, come increased costs both upfront and ongoing. The challenging maritime market at present makes it difficult to simply pass these costs onto customers. This results in lower margins for operators adding downward pressure on the industry to ensure that any new investment based on stricter emissions regulations is not only proven but also will not adversely affect the viability of trading. Further, consensus was that as far as possible, all Maritime jurisdictions should align with global standards, particularly for vessels that visit the GMA from foreign ports. Introducing stricter sulphur limits in the GMA than in the world oceans would add to the complexity of compliance for vessels on international trade routes (that is, almost all bulker carriers, container vessels and passenger vessels).
- For Current Emission Abatement Measures, stakeholders contacted through this project showed a high degree of preparedness to go beyond the bare minimum.
- In terms of the planned (future) state of stakeholders to address stricter emission limits, many ship owners/operators have already embarked on 5+ year plans to ensure compliance with the International Maritime Organisation’s (IMO) global sulphur limit in 2020 or 2025 (requiring all ships over 500 Gross Tonnes to limit the sulphur content in the marine fuel they consume to 0.5% from the current world-wide limit of 3.5%).

3 INTRODUCTION

Ship emissions are a significant environmental and human health concern, both on a global and a regional basis. IMO's global ship emission regulations will also reduce SOx and PM2.5 emissions from ships in the GMA from 2020-25. In certain geographic areas ship emissions are further scrutinized by local or regional regulations, and stricter emission regulations have also come on the agenda in NSW.

The report covers all types of shipping in the Greater Metropolitan Area (GMA) categorized into 12 main ship classes, a methodology DNVGL has derived from IHS Fairplay[10] and used for several years.

For this study, the GMA is defined as encompassing the area bounded by Newcastle to Port Kembla, to a distance of 120km from the coastline.

The analysis resembles previous assessments DNV GL has done for Norwegian authorities and the International Maritime Organisation (IMO) related to the establishment of the North Sea Emission Control Area (ECA) and similar initiatives. The work combines Automatic Identification System (AIS) tracking with databases of IMO ship identification numbers and specific ship fuel consumption for ships identified in the GMA, number of voyages, ship type and size, fuel consumption and corresponding emissions. This approach allows the effect of implementing various emission abatement measures to be assessed.

This is well-reputed approach that has been recognized by several national and international players in the maritime industry. The AIS-based methodology, which is derived from US EPA's methodology for ship emission inventories (5) is further elaborated in Sections 6 and 7.

The work was undertaken by DNV GL experts in Australia and in Norway.

The core analysis follows these steps:

a. Establish an overview and description of all measures used nationally and internationally to reduce ship emissions (in particular, but not limited to, PM2.5 and NOx).

b. Establish the 2013 base year emission inventory for the Greater Metropolitan Area (GMA), and detailed for the ports of Port Jackson, Port Botany, Newcastle and Port Kembla. The ship movement data, supplied by NSW EPA, will be used as a quality assurance in the project to ensure that all vessels are included in the analysis.

c. Evaluation of:
   i. Available reduction measures for passenger ship segment.
   ii. Logistical and technical feasibility of adopting lower sulphur fuel (including fuel switching), seawater scrubbers, vessel speed reduction and shore side power for ships.

d. Discuss policy instruments, economic instruments, management practices, technological options and voluntary measures.

e. Forecasting for the coming 15 to 20 years.

f. Financial analyses

This report is composed in the following sequence:

- Background for the work
- Review of technology, emission components, regulations
- Current ship traffic and traffic growth
- Current ship emissions and emissions forecasting
- Stakeholder consultation, discussion and conclusions

[10] See https://www.ihs.com/products/maritime-world-ship-register.html

4 MARINE ENGINES, FUELS, EMISSION COMPONENTS AND REDUCTION TECHNOLOGIES

Ship engines, their fuel quality and consumption frame the possibilities of emission reduction.

4.1 An introduction to marine fuels

4.1.1 International marine fuel types

During past generations, shipping has sought inexpensive and safe fuels, which are easy to store and replenish worldwide. The vast majority of large ships' main engines (ME), most auxiliary engines (AE) and ship boilers use so-called residual fuels. This also applies to ships visiting GMA waters. Newer ships may use distillates for their AEs, and smaller ships typically used distillates also for their main engines. Residual fuels have high sulphur content, which increasingly is under scrutiny.

There is a different situation in sulphur regulated areas (Europe, North America already implemented), where low sulphur distillates, scrubbers or LNG fuel are used to meet specific regulations. But the vast majority of the world's 80,000 large ships use heavy fuels today.

Marine fuel oils are defined by ISO standard 8217, and are split into numerous categories primarily based on their origin and viscosity. There are three types of marine fuel: distillate fuel, residual fuel and a combination of these to create a so-called "intermediate" fuel oil (IFO). While ISO 8217 defines the fuel specifically and provides technical codes for the different qualities, the marine industry usually uses colloquial names for the different fuel types. The table below lists examples of major marine fuel grades and their colloquial specification. In terms of costs, distillate fuels are more expensive than intermediate products, while residual fuels are the least expensive.

Heavy fuel oil (HFO) defines a fuel made up from the residue oils, and must have a kinematic viscosity above 10 cSt at 80 degrees C, flashpoint above 50 degrees C and density higher than 0.90 kg/l. Typical distillates are Marine Gas Oil (MGO) and Marine Diesel Oil (MDO). Distillate fuel oils must have a flash point above 60 degrees C and kinematic viscosity between 0 and 9.9 cSt.

Table 4-1 Marine fuel types[11]

Fuel type	Fuel grade	Colloquial industry name
Distillate	DMX, DMA, DMB, DMC	MGO/Marine Gas Oil, MDO/Marine Diesel Oil
Intermediate	RME/F-25, RMG/H-35	Intermediate fuel oil (IFO 180, IFO 380)
Residual	RMA-RMH, RMK, RML	Fuel oil or residual fuel oil

All fuels are termed with a three-letter combination; distillates are characterized by the initial letter D while residual fuel qualities start with R. Residual fuels have to be heated up on-board in order to get the right viscosity and ability to flow into the fuel system and engine. The novel low sulphur 'hybrid fuels' falls outside the specifications of ISO 8217, are not widely used and hence not discussed here in detail.

IMO MARPOL Annex VI requires that a Bunker Delivery Note (BDN) must follow each bunker purchase and delivery aboard to ships above 400 GT. The BDN contains information about the sulphur content,

11 Adapted from US EPA: "In-use marine Diesel Fuel". EPA 420-R99-027 (1999)

density, viscosity, fuel grade, amount purchased etc. DNVGL's experience tells that the majority of ships larger than 5000 GT mainly use high sulphur intermediate or residual fuels with viscosity above 80 cSt.

4.1.2 Fuel suppliers to the GMA

Two suppliers currently supply the majority of conventional marine fuels in the GMA – Caltex Australia and Viva Energy (formerly Shell Australia). Information was received from both organisations in the course of this study. Separately, NSW EPA has ongoing channels of communication with both entities on a range of subject areas. Contact was made with all other suppliers listed by AMSA as serving the ports of the GMA. However, responses from this group were insufficient to aggregate data.

For ships on international routes that have a port call in the GMA, numerous other suppliers exist, predominantly in SE Asia but also including BP in Brisbane. No direct contact was made with these organisations due to lack of time and scope of study.

Based on the current sulphur limit within NSW ports of 3.5% (6), the supply and storage of marine fuels in the GMA is predominantly for Intermediate Fuel Oil (IFO) as used by most ship types when at sea. Marine Diesel Oil (MDO) and Marine Gas Oil (MGO) are supplied in lower quantities to vessels for use whilst at berth. Further, ultra-Low Sulphur Fuel (LSF) is supplied by both Caltex and Viva.

In 2014, the following points summarise the supply of IFO/LSF in the GMA:

- 257 000 MT of marine fuel oils (maximum 3.5% sulphur)
- 38 000 MT of ultra LSF (0.001% sulphur)

Figures available through the Federal Department of Industry and Science via its published reports on 'Australian Petroleum Statistics' carry statistics on sales and deliveries of petroleum products by state marketing area. In this context, the GMA is a part of NSW and the ACT. However, the figures do not sufficiently define the type of fuel to determine supplied quantities by weight/density. For the purposes of comparison with collated figures from marine fuel suppliers contacted as a part of this study, it is assumed that 'marine fuel oils' are equivalent to RMG 380 and 'ultra LSF' is the equivalent of MGO. Thus it can be stated that over 68% of all marine fuel sold[12] in NSW (incl. ACT) is from the combined volumes of Caltex and Viva.[13]

It is worth pointing out that there have been no historical supplies of LSF with a sulphur content of 0.1% neither in the GMA nor in South East Asia in general due to an absence of Emission Control Areas outside of the major ones in Europe and North America where this is required.

If there was a sudden increase in the demand for LSF / MGO / MDO, within a relatively short timeframe (ca. 3 months) greater quantities can be delivered and stored in temporary arrangements. This is based on the fact that the existing permanent tanks (on shore at Kurnell and Gore Bay) are currently being used for IFO. Kurnell has storage capacity for 14 000 MT, while Gore Bay has storage capacity for 12 000 MT. Both suppliers indicated there would be no problems sourcing and supplying increased quantities of LSF / MGO / MDO to NSW GMA if the market demanded this. However, transporting the fuel from the refinery locations abroad may prove more of a short to medium term challenge.

Once the product arrives in NSW, storage prior to distribution would be of a temporary nature in the short term (as above). This could present some logistical challenges with mooring at Kurnell / Gore Bay

[12] Australian Petroleum Statistics, http://www.industry.gov.au/industry/Office-of-the-Chief-Economist/Publications/Pages/Australian-petroleum-statistics.aspx

[13] All suppliers to the GMA listed with AMSA, were contacted as a part of this study. At the time of writing not all had replied with data on fuel type/supplied. See this link for list: https://www.amsa.gov.au/environment/legislation-and-prevention/local-fuel-suppliers/

plus an increase is safety risks if barges (moored at Kurnell) were required to move through the heads to access Port Jackson. This solution is not likely to be viewed as sustainable in the long-term.

For a more permanent long-term storage solution, extensive lead time and investment would be required. Both mentioned suppliers have previously/ongoing investigations of alternative or additional storage sites including Port Kembla, Kurnell and Newcastle. None of these have yielded any clear candidates for selection. Approximate lead times required until operation of a potential new land-based site include two years for land clearance and site remediation (if necessary), and additionally two years for planning, construction and commissioning. Capital costs to construct a new storage tank facility will likely run to roughly $20-50m AUD (3).

4.2 An introduction to marine diesel engines and configurations

4.2.1 Engine types

Machinery Systems on ships have two main purposes:

a) Ensure the ship's propulsion
b) Provide power to the navigation / management / control, and heating / cooling for all purposes on board as light, loaders, pumps etc.

Traditionally, this has been solved by having a main engine dedicated for propulsion and a set of auxiliary machinery to supply additional power and heat as necessary. Marine diesel engines are found in versions of below 100 kW to more than 100,000 kW. Diesel engines are either 2- or 4-stroke engines with a speed of around 70 up to several thousand revolutions per minute (RPM). Recent efficiency requirements in the shipping industry have led to changes in machinery configurations. Primarily these changes are driven by economic requirements, but also regulatory requirements from various authorities. A common approach is to divide the machines in three categories by revolution rate:

- Low-speed engines: up to 150 RPM - these are mostly large machines used aboard large ships in international / continental shipping - usually tank, bulk, gas and container trade where there is higher acceptance for higher vibration levels and noise.
- Medium-speed engines: from 150 to 1,000 RPM - Used mostly in small to midsize cargo, larger ferries and cruise ships.
- High-speed engines from 1,000 RPM and above - used consistently in smaller vessels.

Low-speed engines are large 2-stroke engines used for their high thermal efficiency. The flipside of such high energy efficiency is substantially higher NOx emissions and more noise and vibrations from the engines. Medium- and high-speed engines are, with some exceptions, 4-stroke engines with lower energy efficiency, lower NOx emissions and less induced vibrations.

4.2.2 Engine configurations

For larger cargo, fuel costs are the biggest single cost associated with running the vessel. Even small changes in efficiency will lead to major changes in operating costs over time. Machine configuration and efficiency is given considerable attention. Generally, you get the best results (and lowest operating cost) by having as large a propeller as possible, which operates at as low a speed as possible. Rotation speed is determined by the machinery design while the propeller diameter is a function of ship draft and aft ship design. This configuration is extensively used for large merchant ships.

The economic drivers will usually be to maximize cargo space for cargo, maximizing passenger space for ferries and passenger vessels, and maximize the working deck for fishing and offshore vessels. The two most common mechanical configurations are:

1. One or more main engines, two or more auxiliary engines.
2. One or more main engines with a connected generator, two or more auxiliary engines.

New propulsion configurations are now entering segments of the maritime industry:

3. Diesel-electrical systems (Propulsion by electric engines, all diesel engines generating electricity). This is common among offshore service vessels, and also gains ground in other ship segments.
4. Various battery hybrid solutions for mechanically powered ships, and for diesel-electric ships.
5. 100% battery-powered ships are now in operation for passenger traffic.

The typical large merchant ship and older cruise ships entering the GMA have mechanical engine configuration (# 1 and 2), while many of the newer cruise ships are diesel-electric (# 3).

One or more main engines, two or more auxiliary engines

This is the classic engine configuration typically found on older vessels and larger cargo ships, tankers and bulk carriers. To maximize energy efficiency engines with as low rotation speed as possible, direct coupling (gear) to the propeller is preferred. Other energy requirements on board are covered by auxiliary engines (for electric power) and boiler for heating.

This configuration requires a relatively large main engine, which limits the type of ships that can use this solution. Smaller vessels can typically not accommodate a large slow-moving engine, and will use smaller medium speed engines which require less space, but in turn require a gear between engine and propeller to reduce the propeller velocity.

One or more main engines with a connected generator, two or more auxiliary engines

By connecting a generator directly to the main engine the engine operates closer to its optimum efficiency point, and the load on the auxiliary engines is reduced. This improves the overall energy efficiency. This solution was initially used by vessels with gear before the propeller, but is now also available in designs without gear. This is a slightly more expensive set-up, but is beneficial for cargo vessels, large fishing vessels and offshore ships.

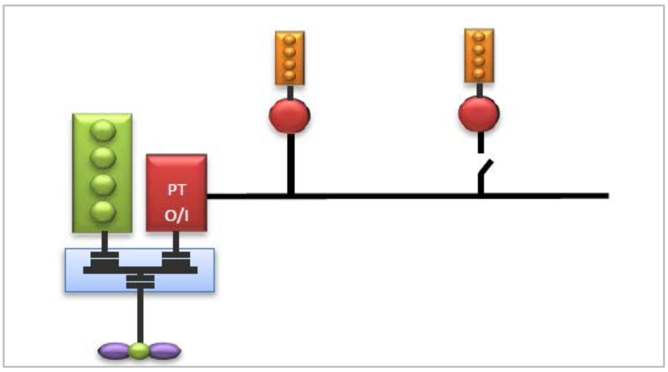

Figure 4-1: Main engine with connected generator and two auxiliary engines

Diesel electrical systems, propulsion with electric engines

For vessels with limited space and / or highly variable operation and power requirements, a design with only one or two engines is limiting. This is typically solved by having an engine set-up which only generates current for electric engines which in turn drive the propeller(s). This is particularly suitable for vessels with high requirements for redundancy. This solution is preferred for offshore ships and large passenger ships and is highly flexible both with regard to engine room layout and operations. The system has a high degree of redundancy, develops little vibration and can be expanded to include battery hybridization. This is the only solution for offshore vessels with advanced Dynamic Positioning (DP) systems. However, the solution is intensive on capital and maintenance.

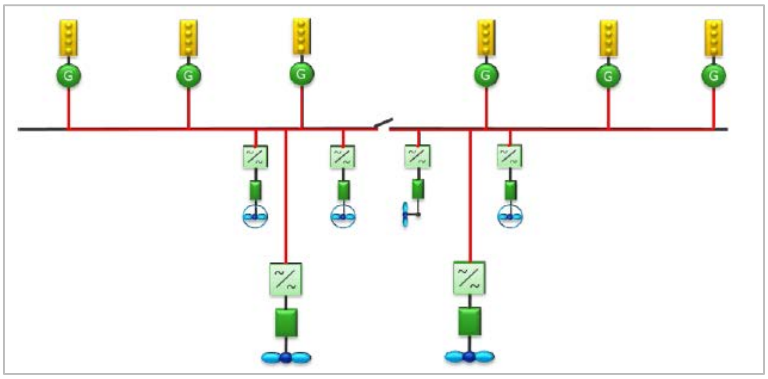

Figure 4-2: Typical diesel-electric engine configuration

Newer configurations

Several of the above machinery configurations can be combined in different hybrid solutions with batteries. An attached generator can be reversed, turning it to an electric engine able to assist in vessel propulsion. This is particularly interesting for ships with large variations in power output where the main engines are operating outside their optimum efficiency point. Operations with large variations in power needs will benefit most from full or partial electrification. Typical examples are offshore, fishing and shorter national ferry crossings.

Ship boilers

Although most ships today are not steam driven, boilers and steam systems are still crucial for running ships' helping systems and heaters. Crude oil carriers typically have large boiler systems for warming their cargo, and all HFO-fuelled ships have some boiler capacity for heating their fuel to obtain desired viscosity. Steam can be produced by recovering heat from the main engines by exhaust gas boilers when the ship is steaming, however steam is produced by separate boilers fuelled by ship engine's fuel while in port. In a study like this it is difficult to estimate exactly to what extent boilers are operated for various ship types while in port, but we have made qualified estimates as a basis for our emission inventories.

The main job of a boiler is to make high pressure steam. The feed water supplied to the boiler drum utilizes the heat of the energy released by burning the fuel. The process of steam generation starts when the feed water enters the steam drum through both internal tubes and the tubes surrounding the furnace. The steam produced in the steam drum is termed wet or saturated steam. This steam must then be dried and heated with the help of a superheater. Once all the moisture is removed from the steam, the superheated steam can be supplied to other systems. The superheated steam is thereafter cooled down to the right temperature, and used for heating of bunker fuels, fuel sludge tanks, accommodation, sea chest, and to warm water for cargo tank cleaning and washing. Steam is also used for running steam driven cargo pumps, etc.

4.3 Characteristics of key ship emissions

Approximately 70% of global ship emissions occur within 400 km (216 nm) of coastlines (7), and emissions from ships at sea can be transported several hundred kilometres inland. Ship emissions thus contribute to pollution in both coastal and inland areas. Major populated cities in the GMA are adjacent to major NSW shipping ports of Port Jackson, Port Botany, Newcastle and Port Kembla. There is also a high level of community concern regarding potential localised health impacts of air emissions from ships berthed near urban locations.

Ship emissions consist of global pollutants like CO_2 which is a climate gas, as well as sulphur oxides (SOx) and nitrogen oxides (NOx) which generate local and regional pollution like acid rain. In addition, there are components such as non-combusted hydrocarbons, soot and fine particulate matter. These days, the main focus in shipping is on reducing SOx and to some extent NOx emissions. Reducing SOx is a key means also to reduce PM emissions which dominate health impact of air pollution. Large ships typically run on residual fuels with around 2.7% sulphur in the fuel, and these emit considerably more SOx than comparable ships fuelled with distillates.

4.3.1 SO_X – Sulphur oxides

The formation of sulphur oxides (SO_X) in exhaust gases is caused by the oxidation of sulphur in fuel into SO_2 and SO_3 during the combustion process[14]. The amount of SO_X formed is proportional to the sulphur content of the fuel. Both SO_2 in its untransformed state, and the acid and sulphate transformation products of SO_2, can have adverse effects on human health or the environment. SO_2 itself can cause adverse effects on respiratory systems of humans and animals, and damage to vegetation. When dissolved by water vapour to form acids and acid rain, it can again have adverse effects on the respiratory systems of humans and animals, and it can cause damage to crops, buildings and materials, and contribute to acidification of aquatic and terrestrial ecosystems. Sulphate ions may also be adsorbed onto particulate matter (PM).

4.3.2 NOx – Nitrogen oxides

High temperature combustion processes (e.g. those occurring in car engines and power plants) are the major sources of nitrogen oxides, NOx, the term used to describe the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). NO makes up the majority of NOx emissions. The most important reactive nitrogen components for tropospheric chemistry are the two nitrogen oxides NO and NO_2. They play essential roles as catalysts for tropospheric ozone formation and control the concentration of the hydroxyl radical. NO and NO_2 are reactive and very rapidly inter-converted. Therefore they are often treated as NOx ($NOx=NO+NO_2$). NO_2 is a reactive gas that is mainly formed by oxidation of NO. Inhaled NO_2 is relatively insoluble and therefore likely to deposit in the lower airways. Health impacts to people exposed to high NO_2 concentration include respiratory irritation, and increasing susceptibility to viral infections, bronchitis and pneumonia (8).

NO and NO_2 also form secondary particles that are included in particulate matter. NOx emissions contribute to the acidification of aquatic and terrestrial environments and occur through deposition of nitrogen compounds from the air and causes damage to forests, fish and other plant and animal life. The relative importance of nitrogen as a trigger of acidification will increase with the general decrease in sulphur emissions. Nitrogen compounds function as a fertilizer for plants and algae. The majority comes from the atmosphere (wet and dry deposition) and by biological nitrogen fixation. Increased access to nitrogen from air pollution (NOx) can lead to fertilizer effects on vegetation and consequential damages.

It is estimated that shipping accounts for 15% to 30% of global NOx emissions. Monitoring of NO_2 signal over major shipping routes increased steadily between 2003 and 2008, and then dropped sharply due to the global recession and reduction in ship traffic[15].

[14] According to USEPA (5), it is assumed that 97.753% of the sulphur in fuel is converted to SO2 during combustion. Our methodology calculates SO2, but in this report we refer SO2 equivalent SOx. The SO2 is calculated as 2 times the molecular weight of elemental sulphur.

[15] NASA. NASA Global Climite Change. [Online] NASA, 11 February 2013. [Cited: 31 03 2013.] http://climate.nasa.gov/news/860.

4.3.3 PM – Particulate matter

Particulate matter (PM) is the general term used for a mixture of aerosol particles (solid and liquid) with a wide range in size and chemical composition. PM2.5 refers to 'fine particles' that have a diameter of 2.5 micrometres or less. PM10 refers to the particles with a diameter of 10 micrometres or less. PM10 includes the 'coarse particles' fraction in addition to the PM2.5 fraction.

Fuel quality, engine type (combustion conditions) and vessel activity play major roles in the properties and variability of emissions. An improved understanding of emissions and processing of particles from a cross section of marine fuel types, diesel engine types and ship activity is essential to improve understanding of ship PM characteristics in the atmosphere, and the impact of shipping emissions on health, visibility and climate. The primary reason for the impact of shipping emissions to health is because 70% of shipping occurs within 400 km of land and major shipping ports are located in areas surrounded by large populations. PM is the least understood emission component from shipping and further work for obtaining improved emission factors is seen essential. An increased use of distillates and LNG as fuel will reduce the problem, but the relation to fuel quality is far from linear, nor fully described.

4.3.4 CO_2 – Carbon dioxide and greenhouse gases

A greenhouse gas (GHG) is a gas in the atmosphere that absorbs and emits radiation as heat. Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. Human activities seem to alter the carbon cycle—both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere. CO_2 emissions from shipping are directly correlated to fuel use, and consequently energy efficiency is a key to reducing GHG from shipping.

4.4 Emission abatement initiatives

4.4.1 Introduction to ship emission abatement technologies

There is a growing market for ship emission reduction measures. Most offer a 'ticket to trade' by enabling a ship to meet SOx or NOx standards at a given cost, but some may also save operational costs over time (e.g. LNG fuel or scrubbers). Emission abatement typically combines measures taken on the fuel choice, on the engine itself or on exhaust gas management. Typically, multiple measures are needed on-board to reduce multiple emission components, and many of these initiatives are costly and based on rather novel technology.

But abatement solutions emerge continuously and we now see some interesting new hybrid fuels entering the market and various promising new abatement technologies, especially for 2-stroke engines. Another novel solution we see on smaller ships includes battery hybridization, allowing the diesel engines to operate at their optimum load, or remain shut-off during full battery-driven propulsion. Not all possible abatement technologies were evaluated in this study; instead a short list was created that included those that were considered the most practical and feasible for shipping in the GMA.

Most abatement measures increase ship operation costs, and these are typically not compensated by higher charter rates to the ship owner. However, with increasing scrutiny on emissions, abatement initiatives have become a prerequisite to operate now in North America, Europe and in the future on a global basis[16].

[16] The EU has proposed that the Monitoring Reporting Verification system apply to shipping activities carried out from 1 January 2018. See http://ec.europa.eu/clima/policies/transport/shipping/index_en.htm

4.4.2 SOx abatement technologies

SOx emissions are generated from the sulphur present in fuel and the emissions depend on the sulphur content of the fuel used. However, IMO MARPOL Annex VI (1) provides alternatives to low sulphur fuel if similar performance may be documented.

Switching to low sulphur distillates or low sulphur 'hybrid' heavy fuel when in ECAs

Sulphur is not a necessary component of the combustion but an impurity in the fuel. However, sulphur is a great lubricant for moving mechanical parts in contact with the fuel. Residual oil has to be treated on-board the ship before use. This includes heating to decrease viscosity, and removal of sludge, particles and water, which can be harmful to the engine. The sludge represents a loss of fuel and has to be disposed of either on-board the ship, where it is usually burned in incinerators, or on land.

Switching to fuels containing less sulphur will reduce the emissions of SOx and PM2.5. For ships operating primarily inside strictly regulated areas, switching to a low sulphur fuel type altogether is an option. Ships not frequently visiting ports or areas where emissions are regulated may prefer to switch to a low sulphur fuel only when entering these areas. This option requires a sufficient number of tanks for segregation of fuels of different qualities and no heat ingress into the distillate tanks.

Switching to low sulphur distillates (defined here as MGO with 0.1% or less sulphur) is currently the most common option for following the new sulphur threshold limits in the Europe and North America Emission Control Areas (ECAs) due to minimal need for investment and the recent significant drop in MGO prices. Under current regulations (MARPOL Annex 6), HFO can be used in the GMA until the global sulphur limit enters into force in 2020 or 2025; at this stage the sulphur limit will become 0.5% in the GMA. From a technical point of view, switching from HFO to 0.1% or to 0.5% distillates is considered equal in complexity. However, the maritime industry has very limited experience with ultra-low sulphur fuels with far less than 0.1% sulphur and hence these qualities are not further discussed in this work.

Switching between HFO and low sulphur distillates may appear to be a simple task at first glance, but the change-over procedure actually requires significant attention from crews in terms of operating, as well technical on-board preparations and possibly also tank modifications. Dealing with the differences between HFO and LSF / MGO, specifically lubricity, density, temperature, viscosity, calorific value and acidity presents challenges for crew. A summary of the main issues follows (9):

- Temperature: The operating temperature gradient between HFO and MGO is typically around 100°C and can be up to 120°C. During the change over from hot HFO to cold MGO the temperature of the injection equipment changes accordingly, creating potential hazards such as thermal expansion or contraction. This can cause the pump plungers and fuel valves to scuff, stick or seize.
- Viscosity: The difference in chemical composition means that LSF has a much lower viscosity than HFO (2-11 cSt for MGO versus 10-20 cSt for HFO at operation). As most engine manufacturers require a minimum viscosity to ensure a uniform lubricating film between the moving parts. If this is too low equipment such as fuel pumps can seize and/or result in increased leakage.
- Fuel incompatibilities: During the fuel change over process, mixing of two different fuels is inevitable. This can cause the asphaltenes contained in the residual fuel to precipitate as sludge and clog up filters and in some cases even cut off fuel supply to the engine altogether causing an engine shut down.

- Flashpoint: Under IMO regulations, fuels with a flashpoint (the temperature at which a substance combusts) lower than 60°C are banned. There have been studies carried out that indicate that LSF often have a flashpoint lower than this 60°C limit.
- Storage tanks: One of the greatest challenges is to avoid contamination between HFO and LSF. A tank that was formerly used for HFO needs to be professionally cleaned and/or if the tank is to hold (via a divider) both HFO and LSF, sufficient insulation is needed to ensure that the MGO does not heat up. This in turn requires special attention to the bunker/transfer pipes, air/overflow systems, sounding devices, tank heating and updating of trim and stability booklets due to different fuel properties.
- Service tanks: According to SOLAS Chapter II-1/26.11, the service tank should have sufficient capacity for 8 hours of normal operation. To avoid possible contamination (from fuel oil transfer piping) and/or fire hazards (heating from HFO service tank) and/or too low viscosity, special attention needs to be paid to the actual separation of the tanks and transfer piping from these service tanks.
- Low sulphur distillate fuels require different cylinder oil than HFO, so switching between these fuels will also require introduction of a second cylinder oil system.

Most large ships shut down their main engines when in port, only relying on their auxiliary engines for necessary on-board power production. Auxiliary engines consume less fuel, have another configuration and have lower emissions than main engines. We have heard that of the passenger vessels due to be sailing in the GMA after July 1, 2016, the very large majority are capable of switching to LSF for use in auxiliary and/or main engines - for more or less all of their power needs - whilst at berth without the need for (substantial) modifications.

However, for some vessels this is contingent on a port stay (at berth) of approximately 8-hours (that is, the typical length of time currently experienced in Port Jackson excluding the time required for berthing and departing). Should the time at berth exceed this current typical duration, problems with the tank capacity and effects of more prolonged exposure of pipes, injectors, etc. to HFO residue deposits freed by the LSF, are intensified thereby increasing the risks of technical failures.[17]

Please note that as the technical profile and requirements can vary greatly from one vessel to another it is recommended that ship-specific responses from operators of passenger vessels in the GMA should be sought in order to determine the actual capacity/capability of each.

During the second half of 2014 several fuel oil producers started to introduce a completely new blend of fuels into the market termed 'hybrid fuels' with maximum 0.1% sulphur. These low-sulphur heavy fuels appear promising for the industry and may have fewer operational obstacles than distillates, but long-term storage stability and mixing properties with conventional fuels are not fully understood. Most of the new hybrid fuels are blended products and have some characteristics of distillate products. This means they may exert a 'cleaning' action, mobilising previously deposited material in old fuel tanks, potentially leading to increased filter loading and other operational issues.

On-board and onshore / barge mounted scrubbers

The alternative to fuel switching is to use an exhaust gas cleaning system, also called on-board scrubbers. IMO accepts scrubbers in combination with HFO as a full alternative to low sulphur distillates.

[17] Stakeholder information received

Scrubbers remove SOx from the exhaust gases of vessel engines and boilers. It cleans the exhaust gas by using a scrubbing agent which can be sea water, chemically treated fresh water or dry substances such as limestone. By using a scrubber the ship can continue using heavy fuel oil which is plentifully available, well-known to crew and to fuel purchasers, and has an attractive price.

There are two main types of scrubbers, wet and dry. Wet scrubbers are then divided between open loop, close loop and hybrid. A wet scrubber works by intimately mixing the exhaust gas with water, which leads to several chemical processes between the sulphurous components in the exhaust and water. Sulphuric acid is formed when sulphur oxides are captured and dissolved in the water. Before discharge the effluent pH must be raised and the sulphur converted to less reactive species such as sulphite. The water phase can either be continuously fed seawater with a natural pH buffering capacity or fresh water circulating in a loop with buffering chemicals. Common chemicals used are caustic soda or magnesium oxide. The chemical reactions generate sludge which is separated from the water phase and gets stored aboard until delivery to an approved port reception facility. The purified water may need further pH adjustment before being discharged into sea in an open loop system or recirculated in a closed loop system. A hybrid system can switch between open and closed loop operation and are quite popular now.

Some wet scrubbers clean multiple exhaust sources simultaneously while others called “inline scrubbers” can only treat the exhaust from one engine. In the latter case, one tower is then needed per engine but each tower is much smaller than the multi-inlet scrubbers. Some scrubber suppliers are specializing in either inline or multi-inlet types, while others supply both technologies. There are currently more than 10 scrubber suppliers world-wide.

Exhaust gas cleaning system technologies have a good track record for use in onshore power plants. Turning scrubbers into a marine technology has caused integration and reliability issues but the solutions are now maturing. The cruise ship industry’s large ongoing installation programmes will strengthen the technology further. Based on DNVGL’s experience there are now more than 200 ships that have, or have ordered, scrubbers. While closed loop systems are favoured in lakes or closed areas, the trend for open seas leans towards hybrid scrubbers.

Using scrubbers comes with a typical fuel penalty of up to 2%, and also add costs for chemicals, sludge handling, discharge water control, and general operation and maintenance. However scrubbers allow the ship-owner to keep running on HFO which they are familiar with, and therefore sharply reduce the fuel costs when compared to using MGO. In sulphur regulated areas, scrubbers can be an attractive solution especially for ship owners who pay their own fuel costs, avoiding costly distillates.

Installation costs: Reliable turn-key installation costs for wet scrubbers are hard to come by, but a typical installation will be $4-12m AUD per ship depending on scrubber and engine size. Of this, installation costs are approximately $1.5-4m AUD for a retrofit installation; installation in a new ship is less expensive. We have seen system costs, exclusive installation costs; in the range of $200 to $420 AUD per kW installed engine power. In general, these costs are hard to isolate since the market is immature, and costs vary significantly from ship to ship due to different engine size, ship configuration and technology details.

In a dry scrubber, the exhaust gas is fed through a packed bed of calcium hydroxide granulates, forming gypsum (calcium sulphate). The produced gypsum (in granulate form) is stored in on-board containers, to be replaced during ship’s port calls. A dry scrubber does not produce a wet sludge nor discharge water. However, there are few, if any, dry scrubber manufacturers left in the market due to limited sales.

A new variant of scrubbers, capturing emissions from the funnel while the ship is at berth, is being developed in the USA. Herein, emissions are treated in a barge-mounted or land-based unit, removing the bulk part of the SOx, NOx and PM by scrubbers and SCR technology. The system is termed "Advanced Maritime Emissions Control System" (AMECS) and appears promising, albeit not widely used.

LNG as fuel

Using LNG as marine fuel significantly reduces SO_X and PM emissions, nets an approximately 15% reduction in greenhouse gas (GHG) emissions and diminishes emissions of NO_X by 85-90% in the case of low-pressure engines. With reduction of multiple emission components, LNG fuel addresses both local and global/GHG pollution issues. The recent introduction of large LNG fuelled (dual fuel) 2-stroke engines allows also use of LNG for propelling large oceangoing merchant ships.

At the time of writing, there are currently 63 LNG-fuelled ships (that is, non-LNG carriers) in operation worldwide, and about 81 ships are in the order books. Through previous market studies, DNV GL has estimated that by 2022-2025 around 1,000 vessels will be fuelled by LNG, with a corresponding LNG bunkering demand of 5-7 million tonnes of LNG per annum. Other analysts have even higher projections. The majority of these are predicted to be small to medium sized vessels sailing fixed routes within specified regions triggered by the ECA implementation, but the global sulphur cap has initiated an additional interest for LNG as fuel also for ocean going vessels. Further, LNG fuel responds to both the SO_X and NO_X challenges, and is quite attractively priced at least in the USA and Europe. We presume that ships spending significant time in ECAs will benefit from LNG as fuel. Australia has an ambitious, growing LNG industry and although LNG bunkering is not yet properly developed, there are companies around today that distribute LNG by tank trucks. Such capacities are too small for large vessels, but indeed suitable for local ferries and tugs etc. DNV GL has in several studies assessed the possible development of LNG fuel in Australia among these a Joint Industry Project (10) and with growing public focus on emissions along with lower LNG prices and more stringent international regulations there should be good cases for gas fuel.

LNG bunkering for selected ferries and offshore service vessels has been in operation in several ports along the Norwegian coast for 14 years. Small-scaled LNG distribution is necessary in order to make the LNG bunker supply system work. This is particularly true for bunkering ports that are located far from LNG terminals. There are currently 13 bunkering facilities for ships in the world, most of them being in Europe, multiple other are planned for the EU, US, Far East; Australian facilities are also being considered (11).

<u>Installation costs</u>: Reliable turn-key installation costs for LNG fuel installations are hard to come by, but a typical installation will add 10-20% to the new build price depending on ship type, engine size and yard. Retrofitting of existing ships is even costlier, if at all practically feasible. We have observed system and installation costs in the range of $800 to $3,000 AUD per installed kW of engine power. Added costs including the LNG tank, gas system, engine upgrade and installation for a ship with 5,000 kW and 10,000 kW installed is typically $1,500 AUD/kW and $1,000 AUD/kW, installed respectively. This is indeed higher than a scrubber installation, but with favourable LNG fuel prices the higher CAPEX can be recovered through lower operation costs as compared to scrubber or distillates. LNG is generally cheaper than low sulphur distillates, and in parts of the world (particularly in the US) it may also be less costly than HFO (11).

Additional CAPEX for LNG fuel installations are hard to standardise; real overall system and installation costs are difficult to retrieve since the market is immature, many markets are subsidized and hence true costs are somewhat hidden, and costs for one ship are not directly comparable to another ship. Although NSW ship traffic is dominated by large ships with 2-stroke engines which are less expensive to convert to LNG per kW than 4-strokes for smaller ships, the owners of large ships are typically more difficult to convince to use LNG than local ships under a regional or national legal administration.

The costs for developing an LNG bunkering infrastructure are not included in the figures above, and the practicalities associated with bunkering logistics must be carefully considered.

Table 4-2 Summary of SOx reduction measures for large ships[18]

Technology	Means	SO_X reduction from typical setup
Low sulphur distillates or new 'hybrid fuel'	Low sulphur fuels with reduced sulphur content (maximum 0.5% sulphur in fuel after IMO's sulphur cap is enforced; possibly earlier or even 0.1% if local NSW regulation)	Reduced SOx with 80-96% as compared to current HFO (2.7%)
Scrubber	Use a scrubbing agent to wash unwanted pollutants from the exhaust gas stream. Current scrubbers will make it possible to operate on traditional HFO and still meet ECA sulphur requirements and upcoming global 0.5% sulphur limit which also will affect shipping in the GMA.	≈95-98% when in use. This is true both for scrubbers on-board and based on land/on a barge
LNG	Replace traditional fuel with natural gas, either with specialized gas engines or dual-fuel engines.	95-100% when using only LNG on all engines

While Table 4-2 shows that low sulphur fuel, scrubbers and LNG as fuel remove SOx very effectively; there are still major differences between these solutions. The low sulphur option requires minimum investment and is simple to implement but adds significant operational cost. The scrubber requires installations and quite significant investments, but allows for use of relatively inexpensive HFO. The LNG fuel solution reduces all emission components relative to HFO, requires the highest initial investment in addition to a new bunkering infrastructure. However, over time this may still be the financially and technically preferred alternative.

4.4.3 NOx abatement technologies

The amount of NOx formed depends on the combustion temperature, premixing of fuel and air, and duration of the fuel in the cylinder. NOx can be abated by measures which reduce the formation of NOx during the combustion process, or by neutralizing NOx in the exhaust gases. There are many commercial available NOx emission reduction technologies in the market.

When operating in a NOx ECA area (i.e. presently in North America and US Caribbean), engines built after 2016 will have to comply with the Tier III (12) requirements as described in section 5.2.3. This puts a lot of strain on the machinery manufacturers, and currently only three technologies are capable of achieving the required Tier III NOx reduction requirements:

- Selective Catalytic Reduction (SCR).
- Exhaust Gas Recirculation (EGR) – possibly in conjunction with other NOx reduction measures.
- LNG (single fuel or duel fuel, 4 stroke or 2 stroke) engines.

The most common NOx reducing technologies are discussed below. The world's largest knowledge base for NOx reduction initiatives is in Norway due to stringent national NOx legislation and an associated

[18] This table refers to current maritime industry understanding and DNVGL's best knowledge through work for the NOx Fund, assessment of scrubbers and other initiatives, supported by industry documents such as Second IMO GHG Study, 2009. Complicating the picture is variations caused by different engine configurations, ship's operational profile, external operating conditions and varying fuel qualities.

private environmental technology subsidizing fund called The NOx Fund[19]. This fund is further described in the end of section 5.4.2.

Selective catalytic reduction

The selective catalytic reduction (SCR) reactor is a housing mounted onto the exhaust-funnel containing a *catalyst*. A *reductant* is injected into the housing, causing NOx in the exhaust gas to be chemically reduced to nitrogen gas (N2) and water vapour (H_2O). The catalyst is a metallic surface in contact with the reductant and the exhaust gas, accelerating the chemical reactions. Ammonia (NH_3) or urea ((NH_2)2CO) are typical reductants, whilst metal oxides (vanadium oxide or titanium oxide), act as catalysts. The catalyst itself is not consumed, but may be coated by other impurities and hence loses efficiency. Such problems are more likely to occur when fuelling with HFO than with cleaner distillates. In addition to the SCR reactor, the SCR system consists of a storage tank for the reductant and a pump and control system for the injection of the reductant. The SCR reactor also acts as a silencer and replaces the ship silencer. The reduction of NOx to N_2 and H_2O takes place at temperatures ranging from 270-500 °C, and the temperature inside the reactor is critical.

When urea is used as a reductant, ammonia is formed at an intermediate stage. If an excessive amount of reductant, urea or ammonia, is injected into the exhaust gas, ammonia will be emitted into the atmosphere. In addition to being a pollutant, ammonia can cause corrosion in the exhaust gas system.

Engine adjustments and engine modifications

By tuning the engine and modifying various aspects of the combustion process the emission of certain pollutants, most notably NOx, can be reduced. NOx is created mainly by a chemical reaction between oxygen and nitrogen gas in the intake air. Nitrogen present in the fuel, typically in the range 0.1 % up to 0.7 %, will also be transformed into NOx during the combustion phase. This contribution to the total NOx formation is relatively small compared to the contribution from nitrogen in the intake air.

In the combustion chamber oxygen and nitrogen react under high pressure to create NOx, and the amount of NOx created depends on the temperature and available reaction time. There are many available measures to reduce the temperature peaks in the combustion chamber which reduce NOx formation. However, reduced combustion temperatures typically also lead to lower fuel combustion efficiency and higher fuel consumption.

LNG as fuel

In the previous section about SOx, it was also mentioned that LNG as marine fuel removes 85-90% of the NOx in the case of low pressure engines (2- and 4-stroke), while for a high pressure 2-stroke dual fuel engine without further emission abatement systems, NOx removal is typically 40 to 50% when using LNG. With an integrated exhaust gas abatement unit, typically an EGR (exhaust gas recirculation unit), the high pressure 2 stroke engines can meet Tier III criteria, i.e. giving NOx emissions about 80% lower than an equivalent Tier II engine (12). Table 4-3 summarizes the most common, and some less known, NOx reducing initiatives.

[19] See https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/

Table 4-3 NOx reduction measures for large ships[20]

Technology	Means	NOx reduction from typical setup[21]
Selective Catalytic Reduction (SCR)	Converts, with the aid of a catalyst, NOx into N2 and Water.	50-95%
Engine modification/re-build	Adapt and optimize the engine with respect to NOx emission.	20-40%
LNG fuelled engines	LNG gives a much cleaner exhaust and is the only technology that results in an emission reduction for all major emission components.	~90% (low pressure engines)
Exhaust Gas Recirculation (EGR)	EGR's work by recirculating a portion of an engine's exhaust gas back to the engine cylinders. This reduces the combustion chamber temperature and thus the NOx generation is reduced.	35-40%
Water Emulsion	Fuel is mixed with an emulsifier and then the emulsion is mixed with water. This lowers the temperature in the combustion chamber and hence the NOx generation is reduced.	20-40%
Humid Air Motor (HAM)	HAM engines use water injection in the air intake to lower the combustion temperature and the NOx generation like for water emulsion.	20-40%

4.4.4 PM abatement technologies

For road engines a series of filter solutions have been developed, providing more than 90% reduction in PM emissions. These filters may also be tuned to reduce around 90% of CO and Hydrocarbon (HC) emission from diesel engines[22]. For maritime engines such filters have not proven to be practicable due to the large amount of ash emission from the fuel and lubrication oil, and the consequent clogging of the filters. However, the development is on-going and tests have indicated reduction potentials in the 60-80% region. This is counterbalanced by a small penalty on energy consumption due to increased back-pressure from the filters. Measures initiated primarily to reduce SOx typically also reduce PM emissions.

Table 4-4 - PM emission reduction measures[23]

Technology	Means	PM reduction from typical setup
PM filters	Physical filtration of the exhaust gas with the added penalty of increased back pressure and fuel consumption.	Potentially up to 85%
Scrubber	Washes out the exhaust gas with water and reduces the emission of both SOx and PM.	80-90%
LNG	Conventional fuel being replaced by a gaseous fuel without heavy pollutants.	More than 90%
Low sulphur distillates	Low sulphur distillates reduce PM emissions	approximately 90%
Low sulphur 'hybrid' fuels	Low sulphur high viscosity 'hybrid' fuels	approximately 20%

[20] This table refers to maritime industry's understanding and DNVGL's best knowledge through work for the NOx Fund, assessment of scrubbers etc. Different engine configurations, operational profile, external operating conditions and varying fuel qualities complicate such studies.

[21] Based on measured in-operation figures collected by the Norwegian NOx Found

[22] US Environmental Protection Agency http://www.epa.gov/cleandiesel/technologies/retrofits.htm

[23] Based on maritime industry's understanding and DNV GL 's client project work.

4.4.5 CO2 reduction initiatives technologies

There is a long list of fuels or energy carriers that can be used in shipping. The ones most commonly considered today are liquefied natural gas (LNG), electricity, biodiesel, and methanol.

Other fuels that could play a role in the future are liquefied petroleum gas (LPG), ethanol, dimethyl ether (DME), biogas, synthetic fuels, hydrogen (particularly for use in fuel cells), and even nuclear fuel. All these fuels are virtually sulphur free, and can be used for compliance with strict sulphur regulations. They can be used either in combination with conventional, oil-based marine fuels, thus covering only part of a vessel's energy demand, or to completely replace conventional fuels. Common for all these fuels is that they lack a developed infrastructure for supply, and the commercial and technical conditions for use are not fully defined. Some of them may also have safety and stability issues to be solved.

4.5 General emission reduction and fuel efficiency measures

In addition to the measures above that are specially designed to reduce individual pollutants, there are numerous initiatives available which are primarily designed to reduce fuel consumption but also reduce emissions of CO_2. Several of these initiatives have a technical nature, but many are purely operational and a part of 'good seamanship'. These may be rather inexpensive to implement, in contrast to the technical measures which often require a significant investment.

Fuel reducing measures typically have a lower reduction rate than measures optimized to curb SOx or NOx. In several cases, the immediate fuel saving alone cannot justify a ship owner's investment, and falling fuel prices may decrease the short-term rationale to invest in fuel saving initiatives.
Section 4.5.1 gives an introduction to some of the technical fuel and emission saving initiatives, while section 4.5.2 describes non- technical, operational measures to reduce fuel consumption and emissions.

4.5.1 Technical fuel saving measures

Shore-side electricity

Shore-side electricity, also referred to as cold ironing and shore power, is the provision of electrical power to ships at berth, normally from terrestrial power grid sources. This allows for the ship's on-board generators to be shut down, reducing its corresponding emissions to atmosphere in port. Ship engines must still run during manoeuvring, berthing and un-berthing; and boilers usually have to run also in port, thus shore-side power does not eliminate emissions completely.

To facilitate the use of shore-side electricity, ports must provide the necessary infrastructure including connections to the power grid, transformers and provide cabling to the ships. In addition the ship will require on-board connections for the power cable and alteration to the electrical system. Some ships may also require a high-voltage certified electrician on-board.

<u>Practical Considerations</u>

From a practical perspective it is important that the cablings are arranged in such a manner as to not pose a safety hazard or interfere with the ports operability. Some ships constantly operate between the same ports and always dock in the same position, for instance ports for ferries, ro-ro ships and oil tankers. For these ships, creating a safe and easy to operate cabling system should be a viable solution. For other ships however, like container ships, dry bulk, and reefers, ships which are loaded and unloaded using cranes and do not dock at any one particular spot along the quay, creating a good cabling system poses a greater challenge. One possible solution is using a 'power barge'. The cabling is connected to an anchored barge utilizing a cable reel and a hydraulic boom allowing it to regulate its position. Such a barge can be moved such that it does not interfere with any cranes or activity on the quay. This option could prove more expensive as it would require people capable of operating and monitoring the barge.

The necessary ship modifications needed to use shore side electricity are typically estimated at AUD 420,000-2,350,000 (13). While a number of variables impact capital expenditure, maintenance and electrical power provision costs, it has been observed that substantial cost savings of up to $600,000 per year may be realised for vessel operators taking advantage of shore side power.

The general system flow for shore side power provision includes:

1. Viable, active connection to Electricity Distribution Network
2. Onsite transformer and switchgear to output cable
3. Switchgear units at berth to distribute to electrical connection stations
4. Cable reticulation to the right number of berth electrical connection stations
5. Cable management/storage with modular plug/socket connectors
6. On vessel distribution transformation and power synchronization

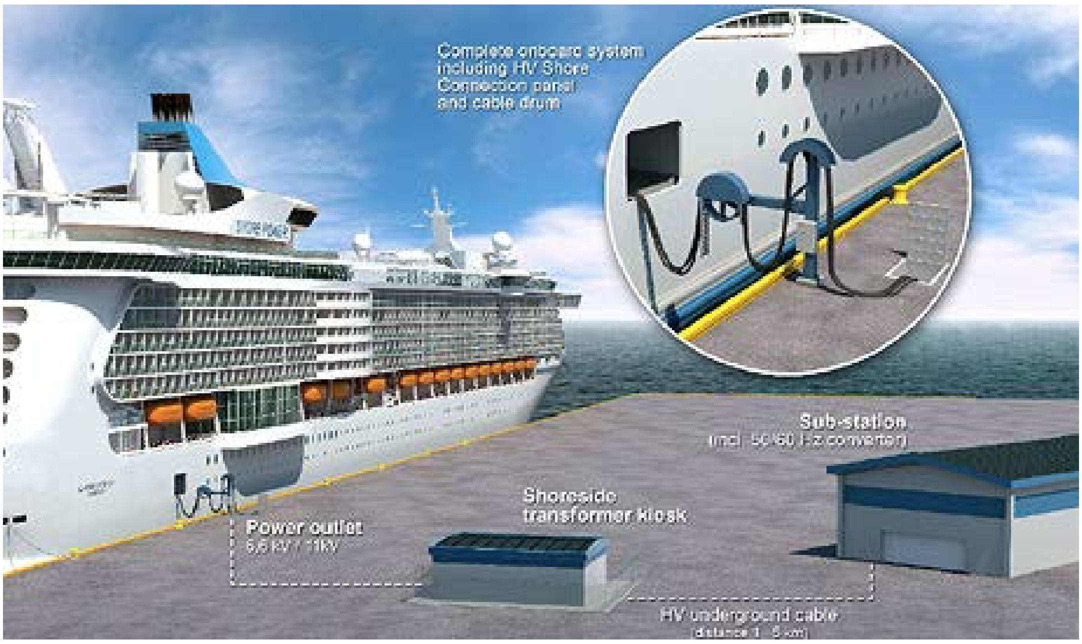

Figure 4-4: Typical shore side power system layout[24]

<u>Standardisation</u>

There are no broadly implemented international standards for the provision or acceptance of shore-side power currently in place. Efforts to pursue shore-side power standardization have been initiated by the International Organisation for Standardisation. The International Organisation for Standardisation (ISO) working group *ShorPwr – Electricla Shore-to-Ship Connections WG* has issued the standard IEEE *80005-1-2012 - IEC/ISO/IEEE Utility Connections in Port--Part 1: High Voltage Shore Connection (HVSC) Systems--General requirements* (14) which deals with the design, installation and testing of HVSC connections and equipment. Likewise, no broadly implemented universal connection equipment exists, however IEEE 80005-1 (14) compliant equipment specifications have been published within the standard.

[24] http://www.abbaustralia.com.au/cawp/seitp202/84051796b5d6f141c1257715004882a3.aspx

GMA Networks

The transmission and distribution of electricity to port locations within the GMA is provided by Ausgrid and Endeavour Energy.

Ausgrid services[25]:

- *Port of Newcastle*
- *White Bay Passenger Terminal*
- *Overseas Passenger Terminal*
- *Garden Island, and;*
- *Port Botany*

Endeavour Energy services[26]:

- *Port Kembla*

Ausgrid and Endeavour Energy transmit electricity at 33kV and distribute electricity at 415V and 11kV through overhead and underground reticulation networks at a frequency of 50Hz. Some areas of the distribution networks also have 33kV infrastructure in place. Electrical power demand for vessels can be upwards of 15MW for cruise ships, which can present technical challenges for 11kV feeder lines.

As power distribution within the GMA is generally 415V and 11kV at 50Hz, shore side power conversion may be required before foreign built ships can connect. Combinations of 50-60Hz and ~110-240V are common for use on ships globally thus necessitating the use of frequency and voltage conversion equipment.

Infrastructure, voltages and capacity available at each port location varies. DNV GL confirmed the following specifications and capacities at port locations within the GMA as follows[27]:

Port of Newcastle

11kV distribution is available in the area. There is capacity at the zone substation, however further detail regarding the 11kV network was unavailable as it is a triplex network, meaning that 11kV/415V distribution centres generally consist of three distribution transformers supplied radially via tee connections to three separate 11kV feeders. There is a 33kV line within approximately 1km. Depending on other network development in the area; this is likely to be a radial supply (N connection only).

White Bay Cruise Terminal

A number of connection options exist in relative proximity to the White Bay Terminal.

- Supply at 33kV is available at the Rozelle transmission substation, approximately 3km away. Capacity for supply at this point is not known. Other 33kV supply points include Pyrmont transmission substation (~3km) and Strathfield transmission substation (~11km), however these options are likely to prove more costly and challenging for connection purposes due to the built environment and water body features.
- There is capacity available at the zone level but limited 11kV network is available in the area with the nearest zone substation located at Balmain Road, Leichhardt approximately 4km away and hence augmentation is required if supply is required at 11kV. If supply is required at >11kV further investigation into augmentation and capacity would be required.

Overseas Passenger Terminal Sydney

There is only an 11kV service in the area and it is part of a triplex network in the Sydney CBD area. Condition issues of the existing zone substation in the area are set to be considered in

[25] https://www.ausgrid.com.au/~/media/Images/Network/About%20Our%20Area/Ausgrid_boundary_map_LRG.jpg
[26] http://www.endeavourenergy.com.au/wps/wcm/connect/EE/NSW/NSW+Homepage/ourNetworkNav/Our+network+area
[27] As advised by Ausgrid at January 2015

2018/2019. Hence, the timing of any further development is very important from the distribution networks staging point of view. Other supply options >11kV need to be investigated further and would require extensive augmentation.

Garden Island Wharf

Existing Garden Island load is supplied at 11kV. Any increase in load requires upgrade of 33kV feeders. The feeders are due for replacement in 2022 and any increase in load before 2022 would require advancement of this project.

Port Botany

Capacity at 11kV and 33kV is available in that area. Load can be supplied at 11kV from adjacent zone substations and at 33kV from the adjacent sub-transmission substation.

Port Kembla

Works to replace Port Kembla substation to provide 11kV and 33kV service and switchgear were scheduled for 2014 completion. The extent of augmentation required and capacity available from the Port Kembla substation are not currently defined.

Lead Time and Further Investigation

Ausgrid has notified that general supply options at 11kV or >11kV have a lead time of 2 years and 3 years respectively and that further detail will require a detailed feasibility study to more accurately identify costs and technical requirements.

Discussions with Ausgrid and Endeavour Energy representatives have indicated that large energy users may also be required to share loads where intermittent large user demand exists. In such cases the negotiated allocation of electrical load across large users is carried out in conjunction with the electricity distributor.

Grid Reliability Requirements

The reliability standards imposed on electricity network providers to ensure redundancy such that a single point of failure does not cut power. Whether these requirements apply to the provision of shore side power will likely impact the network capacity and associated development costs.

Estimated Industry Costing

DNV GL notes that no detailed costing has been undertaken however approximate indicative local and international costs have been seen in similar projects. DNV GL also notes that significant variables exist at almost every point in the delivery of shore power on the network, port and vessel sides that will materially impact actual costs. Based on DNV GL's global experience on Energy Advisory, Energy Infrastructure and market knowledge, the following costs are considered roughly indicative within urban environments.

Uncertainty associated with the costing of shore side power infrastructure is considered to be significant due to both the inherent variability of site specific locations and the magnitude of potential power delivery to vessels. As such, DNV GL notes that a further uncertainty range of 50% should be applied to all costs in this section. Likewise, an uncertainty of 50% is noted for all emissions reduction estimates due to the overlap of fuel use at berth before engine shut down and start-up, and shore side power down time. Moreover, typical HFO-fuelled ships must keep their fuel-fired boilers running in port to keep their fuel warm to avoid later viscosity problems; oil tankers will run boilers also to keep their cargo warm.

Table 4-5 Costing estimates for cruise ship capable shore side power per port within the GMA

Capital Expenditure Area	Indicative Cost (mAUD)	Indicative Lead Time (years)
Distribution Network Feasibility	0.025	0.25
~5km Extension of 11kV local distribution lines	10 - 20	2.0
~5km Extension of 33kV transmission lines	10 - 20	3.0
Grid connection facility	5	0.5 – 1.0
Port side switchgear, transformers, cabling and facilities	10 - 25	0.5 – 1.0
Total	35.025 – 70.025	3.0

Operational and Maintenance Costs:

Operational and maintenance costs are expected to be highly variable and dependent upon the scale, location, type and setup of shore side power assets for both port and ship owners and or operators. In the absence of analogous local examples, costs associated with Operation and Maintenance for shore side power have considered the analysis provided to the European Commission by Entec UK in 2005 (15).

Previous analysis has assumed all costs associated with electricity supply, operation and maintenance are passed on to the customer as a part of access/port fees and/or applied as a percentage of consumption. Excluding the variable cost of electricity supply DNV GL expects operational and maintenance costs to fall within 2.5–7.5% of port side Capex (includes on site grid connection facility, port side switchgear, transformers, cabling and other facilities). In broad terms this equates to opex costs (infrastructure) of $0.375-2m AUD.

Using shore-side power more or less eliminates emissions directly from the ship, as presented in table 4-6 below relative to 2.7% and 0.1% Sulphur Fuel. There will, however, be emissions during manoeuvring and before switchover has taken place.

Table 4-6 Shore Side Power Emissions Reductions

Measure	Emissions Reduction (only at berth) (15)		
	NOx	SOx	PM
Shore Side Power compared with 2.7% sulphur fuel	-97%	-96%	-96%
Shore Side Power compared with 0.1% sulphur fuel	-97%	~0%	-89%

Please note that of the passenger vessels scheduled to make GMA port calls after 1 July 2016, less than 30% are able to accept shore power for 100% of their power needs whilst at berth. The remaining 70% would require modifications to enable shore-side power. Specific vessels were not examined as a part of this study due to the anticipated changing in/out of vessels to the passenger fleets operating to/from the GMA from 2016 onwards.[28] Furthermore, since shore-side power does not serve moving vessels this

[28] Stakeholder information received

solution will not fully help ship owners to meet IMO's global sulphur cap, or any local regulations affecting moving ships in the GMA. These regulations will require additional on-board measures.

Improved on-board energy efficiency

Several technical measures, physical modifications or improved design of the ship itself can improve fuel efficiency. The technical measures fall into one of two broad categories; improving the shape, surface and propeller of the ship for reduced drag and increased thrust, and increasing the efficiency of the power generation and management. In general, but not always, newer ships have better fuel efficiency than older ones.

Ship fuel efficiency can be increased or decreased by upgrading and/or tuning the machinery. Replacing the entire engine is typically not an option, and the improvement potential depends on the engine in question. For new ships, more options exist, including choosing an alternative engine configuration. In a diesel-electric engine configuration, the propellers are driven by electric motors. These motors are powered via an electric generator driven by a diesel engine. This allows the diesel engine to run at a constant speed, giving better fuel efficiency, whilst the power to the propellers is regulated electrically. Some energy is lost in the transfer from mechanical to electrical energy, but for ships operating a significant amount of time on part load, this engine configuration gives better overall fuel efficiency.

The roughness of the hull influences the drag experienced by the ship. The application of self-polishing modern antifouling paints during docking and intermittent underwater hull cleaning go a long way to remedy the problem. However, it is found that the docking itself can increase the roughness of the hull. If the hull is not properly spot blasted before new paint is applied, the new paint can easily crack increasing hull roughness and accelerating corrosion. Performing the docking properly is therefore very important regarding hull roughness. A potential for improved fuel efficiency therefore lies in establishing good routines for *how* ships are docked and antifouling paint is applied.

A number of different propeller types exist, and as with the engine configuration, choosing the optimal propeller according to the ships operational pattern may give a fuel savings effect. There are also other technical measures to consider for an optimum hydraulic water flow into, and from, the propeller and rudder. Recently, also a large number of ships have been refitted with a new bulbous bow, better suited for current slow steaming (low speed) operations. Other measures include installing LED lamps in all fixtures, advanced control of the HVAC (heating and air conditioning) system and variable drives (frequency converters) on fans and pumps and even battery-hybrid systems. Furthermore, the routines for optimizing a ship's trim in the water are also improved. We observe that many ships have already carried out many of these modifications and measures due to high fuel prices during recent years.

Biofuels

Biofuels may reduce both SOx and GHG (greenhouse gas) emissions but their availability is still very limited for maritime use. In the last 10 years, an increase in ethanol production capacity in the USA and Brazil, and of biodiesel in Europe, has resulted in biofuels gaining a foothold in the global market for liquid fuels (16). The global biofuels industry seems promising. Ethanol and biodiesel seem closest to displace petroleum-based fuels in the road transportation sector. Further advances in biofuels derived from non-food feed-stocks may significantly alter the fuel industry, also opening such fuels to ship use. Despite the huge potential, however, biofuels are still challenged by issues such as feedstock access, limited supply chain infrastructure, and achieving price parity with conventional petroleum products.

DNV GL does not foresee biofuels to be a significant maritime fuel during the next five years or so, thus we have not considered biofuels to give any emission reducing effect in the GMA in this study.

Battery powered and battery assisted vessels

In Europe there are now all-electric ferries and some offshore support vessels are built with battery-diesel hybrid propulsion. All-electric ships and hybrid ships with energy storage in large batteries and optimized power control can give significant reductions in fuel costs, maintenance and emissions, in addition to improved ship responsiveness, regularity, operational performance and safety in critical situations. DNV GL estimates that hybridization of ships typically can provide fuel savings of up to 20 - 30% with a payback time of 2 to 4 years. It can improve performance of diesel fuelled systems as well as LNG fuelled systems, new-builds or retrofit, and it can work as a storage unit for energy from waste heat recovery, regenerative braking of cranes and renewable energy. Besides saving fuel, hybrid battery operation reduces emissions significantly; full electric operation gives zero emissions from the ship itself.

Batteries are increasingly also being considered to balance fluctuating needs for power consuming operations, such as to recover and temporarily store energy released during lowering of cranes etc. Strictly speaking batteries are not a power source but an intermediate storage unit, thus the method for producing electric power at the power plant, and disposal options for worn-out batteries, must be judged in a life cycle assessment of batteries. A full-battery solution will require investments in charging infrastructure on the quays, and new power cables to the city grid may be needed. Hybrid battery-diesel powered ships can manage without a proper battery charging station at the berth. Battery and hybrid-battery solutions are today most suitable for smaller vessels trafficking on fixed routes, i.e. they can be ideal for passenger traffic across Port Jackson and to Sydney's suburbs. New guidelines for including batteries in ships' power plants have been released, including one from DNV GL (17).

4.5.2 Non-technical fuel saving measures

Ship operation

Fuel efficiency can be improved by paying attention to *how* the ship operates. Employing operational measures saves fuel and emissions including CO_2, but will rarely be sufficient to meet strict SOx and NOx standards in Europe and North America. Speed is a crucial factor regarding fuel consumption as water resistance and - as a rule of thumb - the drag forces are proportional to the cube of the speed. For instance, the power needed to maintain a steady speed of 10 knots is only a third of that needed at 15 knots. This means, compensating for the extra time needed, fuel consumption and emissions are more than halved for any given journey by reducing speed from 15 to 10 knots. From an environmental perspective, reduced operating velocity is beneficial. Whether slow steaming is economically profitable depends on the price of fuel compared to the profit margins for each journey, and capacity of the transportation route. Taxation of emissions may give ship operators an economic incentive to slow down. Itinerary planning should also be done as an integrated part of the speed management discussions.

Fuel consumption can also be reduced through proper fleet management, i.e. improving the operational patterns of the ships. Many ships spend considerable time running in ballast conditions. Improved planning of cargo flows, by pooling and timing shipments can improve the efficiency of ships, thereby reducing the number of ships needed to perform a certain amount of transport work. Fuel consumption can also be reduced by utilizing so called "just in time arrivals". The ship's arrival at the port is timed so that the ship arrives when the port is ready for it. Fuel consumption is reduced by slowing the ship down making it arrive "just in time", rather than early. Also, given the location of departure and destination and generic information about the ship, modern weather routing systems choose optimal routes for ships. The use of weather routing can lead to fuel savings, particularly on longer journeys and for journeys in areas with unstable weather conditions. The price of such systems and subscribing to weather data is relatively low and accuracy is increasing.

In addition to the abovementioned generic operational measures, there are operational parameters which should be optimized for each journey. These include choosing an optimal trim, correct pitch of the propeller, reducing ballast and extra fuel to a minimum, and using a modern autopilot system to avoid unnecessary course alterations and keeping a constant engine load and consider running only one auxiliary engine in port. Efficient cargo handling, mooring, berthing and anchoring in port can save time, which in turn can be used to lower the speed at sea. Most of these measures can be assessed and followed up through implementation of ISO 14001 Environmental Management and or ISO 50001 Energy Management Systems (18) (19).

4.6 Summary of key abatement measures

Typical methods for curbing SO_X emissions include switching from high-sulphur to low-sulphur fuels, using scrubbers together with continued use of HFO, or have an LNG fuelled vessel. Shifting to LNG fuel will also give a significant positive effect on all emission components, and can almost remove SOx, NOx and PM. Although there is still significant progress and industry optimism, the lagging development of LNG bunkering infrastructure and high LNG prices in Asia hinder a rapid global growth of LNG as a marine fuel.

SOx reducing initiatives typically also reduce PM in addition to SOx emissions. Measures in the exhaust gas funnel such as special oxidation catalysts and particulate filters can also be efficient for PM removal.

For NOx abatement the most documented methods include Selective Catalytic Reduction (SCR) systems, internal engine modifications, and LNG as fuel. A new generation exhaust gas recirculation (EGR) is now emerging as a promising fourth alternative, although less documented.

Shore-side power will reduce SOx, NOx, CO_2 and PM while the ship is connected, but engines must run during manoeuvring and before completing shore-side connection. Furthermore, HFO-fuelled ships will keep their boilers running to maintain fuel (and cargo) temperature while in port, contributing to emissions. The development of shore-side power is typically hampered by significant needs for landside and on-board investments and missing global technical standards for such connections. Still, there are cruise ships in the US and EU outfitted for shore-side power supply, and several ports in these areas now offer the right power interface. It is worth noting that since shore-side power cannot serve ships in movement it is not a stand-alone ECA solution. Ships trading in ECAs will typically spend their abatement funds on solutions covering both sailing and berthed conditions, i.e. preferring scrubbers, LSF of LNG.

New solutions with exhaust collection and shore-side/barge mounted treatment are slowly also becoming available, these also aim at reducing SOx, NOx and PM. There is at least one supplier offering such a solution. Although the technology may work well, references are still few.

None of the abatement measure discussed herein will reduce GHG emissions significantly; biofuels may reduce both SOx and GHG emissions but their availability is still very limited for maritime use.

The emission reduction potential of the discussed abatement options is presented in Table 4-7 while the qualities of the measures are discussed in Table 4-8. Some of the measures can be combined, others not. Without any of these measures in place, fuel saving through improved vessel operation can reduce emissions typically between 2 and 15%.

Table 4-7 – Theoretical emission reduction potential of typical emission abatement options[29]

Option	NOx reduction	SOx reduction[30]	CO2 reduction	PM reduction
LNG as fuel	Low pressure engine: 90% High pressure engine: 40%	90-100%	Approx. 15%	More than 90%
Low Sulphur Distillates	-	~80% (0.5% S fuel) ~96% (0.1% S fuel)	-	Approx. 90%[31]
Scrubber[32]	-	90-95%	1.5-2% increase	80-85%
Shore-side power	Close to 100% emission reduction from the connected ships, but the overall emission reduction depends on how the electricity is generated and power plant emissions			
SCR	65- 90%	-	Slight increase	20-40%
EGR	35-40%	-	Slight increase	Slight increase
Direct water injection	20-40% typical	-	Slight increase	-
HAM / Humid Air Motor	20-40% typical	-	-	-
Engine Modification	20-40%	-	Slight increase	Marginal reduction

[29] This table refers to maritime industry's understanding and DNVGL's best knowledge through work for the NOx Fund, assessment of scrubbers etc. Different engine configurations, operational profile, external operating conditions and varying fuel qualities complicate such studies.

[30] Reduction potential from current average sulphur content (2.7%) of fuel used in GMA

[31] Extensive PM data series from large series of ships and engines have not been reported; we use same reduction rates for PM2.5 and SOx: 80% and 96% reduction when switching from HFO to distillates with 0.5% and 0.1% sulphur, respectively.

[32] Since the operational experience from dry scrubbers is minimal and wet scrubbers by far are the dominant scrubber solution, in this work wet scrubbers are referred to when addressing scrubbers unless dry scrubbers are specifically mentioned.

Table 4-8 - Abatement Options Advantages and Disadvantages

Option	Advantages	Disadvantages
LNG	Good projections for favourable LNG price over conventional marine fuels. Reduces SOx (Approximately 100%), NOx (up to 90% for 4-strokes) and reduces CO_2. Particulate matter reduced 90% No fuel oil purifier (gas only engine) Probably reduced fuel cost. Possibility of reduced maintenance cost compared to conventional fuelled vessels (seen from experience in Sweden and Norway)	Retrofitting is difficult. Requires larger fuel tanks, special engine and gas system, increasing costs. (However gas-only engines do not require traditional fuel heating system with coils, purifiers, treatment units, service- and settling tanks.) Possible loss of cargo space. Limitation on operational range and bunkering facilities. Fuel availability uncertain. Infrastructure currently limited. Special training required. Cryogenic, Flammable Slight methane slip/release (being improved) Increase of building costs.
Switch to Low Sulphur Distillates	Almost eliminates SOx emissions. PM emissions reduced approx. 90%. Little or no modifications and investment needed. Well known and tested. Does not require fuel heating.	Significantly higher fuel cost, and the gap between HFO and distillates may increase. Distillate demand may exceed supply. Distillate use requires different cylinder oil. Requires logging of fuel switching No CO_2 or NOx reduction. Fuel switching problems.
Scrubber+HFO	Continue to use cheaper, high sulphur HFO fuel. Fuel readily available. Effective SOx and particulate matter reductions.	Reduces the available space, loss of revenue for some ships. Increases operational demands. Increased fuel demand Significant investment cost. No significant reduction of NOx. Potential difficulties discharging water phase Sludge disposal - dry and wet. System reliability has been an issue.
Shore-side power	Significant drop in all emissions at berth	Requires high costs and time to implement. Potential supply/capacity issues. Relatively few current vessels capable of connecting, lack of uniform standards Emissions may increase at shore power plant Continued emissions at ship manoeuvring
SCR	Relatively mature technology. Only for NOx removal. Efficient.	Suitable for most four stroke engines, limited track record for two stroke engines. Possibly degraded efficiency over time.
EGR	Relatively mature technology. Only for NOx reduction. Quite effective.	May reduce engine efficiency. May give increased engine wear. Few operational references for shipping.
Water-based Technology	Well known means of reducing NOx emissions.	Not a mature technology for ships.
Low NOx Engine Modifications	Suitable for wide range of engines. No significant operational issues reported. Lasting effect.	Increased fuel consumption (?)

5 MAIN REGULATORY REGIMES

Modern shipping operates under a complex set of international and domestic regulations. Traditionally, the leaps in regulations have been event-driven, and in some cases even driven by events outside the sector. Well known examples are the Titanic disaster, which ultimately led to the International Convention for the Safety of Life at Sea (SOLAS) Convention[33], the Exxon Valdez oil spill, which resulted in the USA, the Oil Pollution Act (OPA 90)[34], and the '9/11 attack', which resulted in the International Ship and Port Facility Security (ISPS) Code[35]. However, the environmental regulations have generally lagged behind those of other industries. This situation is now changing. The increased focus on both global and local environmental issues in general, combined with the growing realisation of the actual pollution burden imposed by shipping, has led to an upsurge in both international and national regulations. Some are ready and will enter into force in the very near future, while others are still being developed and will have an impact only in the intermediate term.

The key issues that will have a significant regulatory impact this decade are, broadly speaking, sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter (PM), in addition to Green House Gases (GHG) such as CO_2.

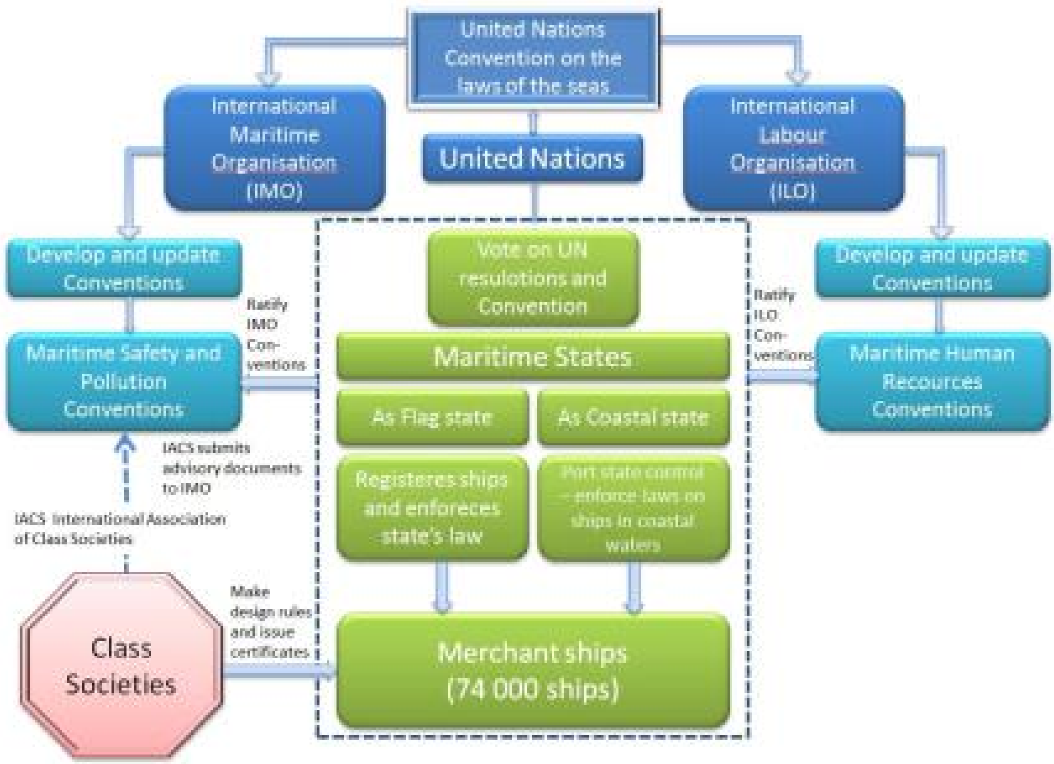

Figure 5-1:- The maritime regulatory system showing the role of the 166 maritime states (20)

33 See http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

34 See http://www.epa.gov/oem/content/lawsregs/opaover.htm

35 See http://www.imo.org/ourwork/security/instruments/pages/ispscode.aspx

5.1 UN Convention on the Law of the Sea

As shown in Figure 5-1 the UN Convention on the Law of the Sea (UNCLOS)[36] provides a universal legal framework for the control of marine related resources and activities. Any state's sovereignty over the territorial sea is subject to this Convention and to other rules of international law. Regulations on emissions to air have to be in line with UNCLOS.

A prerequisite to the Convention is that coastal states should not hamper the innocent passage of foreign ships through territorial seas except in accordance with the Convention. On the other hand, Article 21 permits states to "establish particular requirements for the prevention, reduction and control of pollution of the marine environment as a condition for the entry of foreign vessels into their ports". This is clearly defined in Article 21 "*Laws and regulations of the coastal State relating to innocent passage"* (21). This article states that coastal states may adopt laws and regulations for the preservation of the environment of the coastal State and the prevention, reduction and control of pollution. In short, coastal states may implement individual laws and regulations for the preservation of the environment. Note that this is not an option for straits. In general, for ships in innocent passage, national regulations will not apply. A vessel is only subject to such regulations when it is calling at one of the nation's ports. Hence, for the individual states there are no legal means of regulating international traffic only passing through.

5.2 The International Convention of the Prevention of Pollution from Ships (MARPOL)

The International Convention for the Prevention of Pollution from Ships (MARPOL)[37] is the main IMO Convention regulating emissions to air from shipping. MARPOL was designed to minimize pollution of the seas, including dumping, oil and exhaust pollution. Its stated object is to preserve the marine environment through the complete elimination of pollution by oil and other harmful substances and the minimization of accidental discharge of such substances. All ships flagged under countries that are signatories to MARPOL are subject to its requirements, regardless of where they sail and member nations are responsible for vessels registered under their respective nationalities.

The Convention is split into six annexes concerned with preventing different forms of marine pollution from ships. Annex VI of MARPOL regulates emissions to air from marine engines. In general, Annex VI applies to all ships 400 GT and above, and to all fixed and floating drilling rigs and other platforms.

The revised Annex VI will over the coming years introduce requirements for a considerable reduction of air pollution from ships, especially in relation to SOx and NOx, and in the so-called ECA areas.

5.2.1 Global SOx regulations

SOx emissions are regulated both on a global and regional basis and there is a growing pressure on oil producers and consumers to use fuels with lower sulphur content. However, low-sulphur distillate fuels are more expensive than residual fuels so shipping will typically use residual fuels when allowed.

We do not see limitations in the availability of either distillates or residual fuels in Australia, but ships in international trade will typically not purchase fuel in Australia due to pricing. Merchant ships trading between NSW and East Asia will typically bunker in Singapore or China.

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[36] See http://www.un.org/depts/los/convention_agreements/texts/unclos/closindx.htm

[37] See http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

The IMO MARPOL Annex VI regulates maritime emissions from on-board fuel combustion and therefore covers both main engines and auxiliary engines together with boilers and inert gas generators. Annex VI focuses much on SOx, but also regulates NOx as described further below.

IMO MARPOL Annex VI separates between emissions inside and outside the so-called Emission Control Areas (ECA). IMO regulations limit the sulphur content of maritime fuel to <0.10% in ECA regions from 1 January 2015, and in non-ECA regions (i.e. rest of the World) to 0.50% by a yet to be determined deadline between 2020 and 2025. IMO is set to decide in 2018 whether the 0.5% sulphur limit will be implemented in 2020 or 2025 after a thorough review of the low sulphur fuel availability. These ambitious targets represent significant reductions from the previous limits of <1.0% in ECA regions and <3.5% for non-ECA regions. These initiatives are expected to improve local air quality in coastal areas, ports and terminals significantly.

Emission controls are primarily achieved by limiting the maximum sulphur content of the fuel oils as it is loaded, bunkered, and subsequently used on board. Alternatively equally efficient abatement technology such as exhaust gas scrubbers, or a complete fuel shift to LNG, can fulfil the new regulations. These step-wise changes of fuel oil sulphur limits are presented in Figure 5-2.

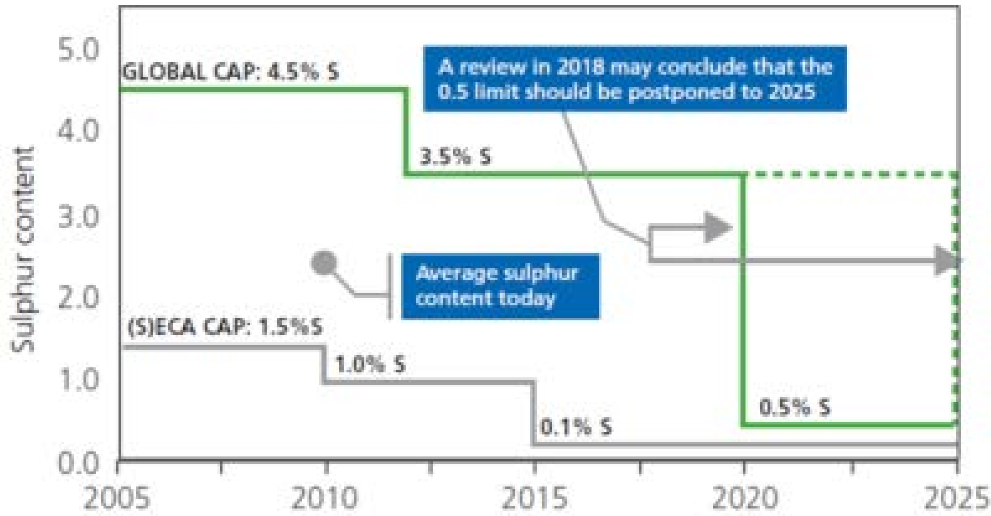

Figure 5-2: Timeline for restrictions on sulphur content (IMO 2011)[38]

5.2.2 Regional SOx regulations: ECAs, EU and California

The first two SOx ECAs, the Baltic Sea and the North Sea area, were established in Europe and took effect in 2006 and 2007 respectively. The third area established was the North America ECA, in effect from 1 August 2012. In July 2011 a fourth ECA was established, namely the United States Caribbean Sea ECA, covering the waters adjacent to the coasts of Puerto Rico (USA) and the United States Virgin Islands, in effect on 1 January 2014[39]. The ECAs are summarised in Table 5-1 and Figure 5-3.

[38] DNVGL 2014, Sulphur

[39] IMO MEPC. MEPC 62/24 Resolution MEPC.202(62), Annex 14. London : IMO.

Table 5-1- Confirmed ECAs & timeframe (1)

Name of ECA area	Adopted	Date of entry into force	In effect from
Baltic Sea (SOx only)	26 Sept 1997	19 May 2005	19 May 2006
North Sea (SOx only)	22 Jul 2005	22 Nov 2006	22 Nov 2007
North American (SOx, and NOx & PM)	26 Mar 2010	1 Aug 2011	1 Aug 2012
US Caribbean ECA (SOx, NOx & PM)	26 Jul 2011	1 Jan 2013	1 Jan 2014

In addition to the confirmed ECAs, we understand that there are a number of other countries and regions which may move towards the adoption of ECAs, some of which are introducing interim measures to curb emissions. These include Mexico, Hong Kong/The Pearl River Delta and the Turkish Straits and adjacent Marmara Sea. The timeline for implementation of these possible ECAs is quite uncertain; DNVGL's impression is that authorities now want to first learn how the current ECAs are implemented before establishing new ones.

Figure 5-3: Established IMO-ECAs (DNV GL 2013)

EU's Sulphur directive (Directive 1999/32/EC) was amended by 2012/33/EU of 21 November 2012 (22). The EU Sulphur Directive (2005/33/EC) sets limits on the maximum sulphur content of gas oils and heavy fuel oil in land-based applications as well as marine fuels. In doing so, the Directive incorporates the sulphur provisions of the MARPOL Annex VI.

The Sulphur Directive mandates that EU member states not only comply with the ECA requirements in relevant areas but also introduce a sulphur cap of 0.50% from 2020 for all non-ECA EU waters. This 0.50% sulphur limit for all fuel combusted in non-ECA EU waters will impact all ships plying the European part of the Mediterranean Sea significantly.

Article 4b of the Directive[40] has required that from 1 January 2010, Member States must take all necessary steps to ensure that all ships berthed or anchored in any European Community port are not permitted to consume marine fuels with a sulphur content exceeding 0.1% by mass. This regulation applies to all vessels irrespective of flag, ship type, age or tonnage. In practice this means that many ships must switch from residual fuel oil (HFO) to distillate fuel, such as marine gas oil, when in port. The Directive requires that this fuel change-over operation should be carried out as soon as possible after arrival and as late as possible prior to sailing.

A recent study reveals that levels of sulphur dioxide in EU ports have been reduced by 66% as a result of the EU Directive 1999/32/EC which required low-sulphur fuels for ships at berth or at anchor in ports[41].

It is worth mentioning that The California Clean Fuel Regulations[42], adopted in 2008, was one of many steps taken to reduce emissions from activities involving the movement of goods. In short, the Clean Fuel Regulations require operators of ocean going vessels to use less polluting marine distillate fuels instead of HFO in ship engines and boilers while operating within 24 nautical miles of the California coastline. From January 2014 there has been a 0.10% sulphur limit for marine fuels. We expect that these regional regulations are being lifted during 2015, leaving the ECA regulations alone in California.

In the revised MARPOL Annex VI, IMO introduces limits to how much sulphur vessels are allowed to emit. MARPOL Annex VI allows vessels to comply with the regulations in different ways. Either by using fuel oil with sulphur content below a prescribed limit or by utilising a “fitting, material, appliance or apparatus”. This may be exhaust gas cleaning technology, or by “other procedures such as on-board blending of fuel oil or the use of dual fuel (gas/liquid)”. When an alternative means of compliance is used it must be “at least as effective in terms of emission reductions as that required by this Annex”[43]. Any alternative means of compliance with the regulations must be approved by the vessel’s Flag Administration.

5.2.3 NOx regulation

The NOx control requirements of IMO MARPOL Annex VI apply to current marine diesel engines of over 130 kW output power other than those used solely for emergency purposes, irrespective of the tonnage of the ship onto which such engines are installed. IMO regulates NOx emissions by a three-tier system[44] and follows the year of vessel construction and engine’s rated speed. The Tier 1 and Tier 2 regimes apply globally. The Tier I regime applies for vessels built between 2000 and 2010; the Tier II from 2011 onwards.

Tier III is scheduled to be enforced from 01.01.2016, being limited to affecting operation inside NOx-ECAs (i.e. per date only the North American ECA and US Caribbean ECA) for new ships built after January first 2016 (i.e. keel laid after 01.01.2016). Outside the NOx-ECA areas the Tier II controls apply also after 2016.

The so-called Tier levels regulate NOx emissions and current limits are provided in Table 5-2 and Figure 5-4. The drop in allowable NOx emissions from Tier II to Tier III for NOx-ECA operations is significant, about a 70% reduction.

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40 See http://ec.europa.eu/environment/air/transport/pdf/ships/com_2011_190_en.pdf

41 See European Commissions Joint Research Centre, JRC: http://ccaqu.jrc.ec.europa.eu/ship-borne_measurements.php

42 See http://www.gard.no/ikbViewer/Content/20750079/CLAIMS-PI-FDD-%233895828-v2-Alert_Amendments_to_California_Clean_Fuel_Regulations.pdf

43 See MARPOL Annex VI

44 See http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

Table 5-2 - NOx limits for ship newbuilds

Tier	Applicable areas	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) (n=rpm, below)		
			n < 130	130 ≤ n < 2000	n ≥ 2000
I	Global	1 January 2000	17.0	$45 \times n^{-0.2}$	9.8
II	Global	1 January 2011	14.4	$44 \times n^{-0.23}$	7.7
III	ECA	1 January 2016	3.4	$9 \times n^{-0.2}$	2.0

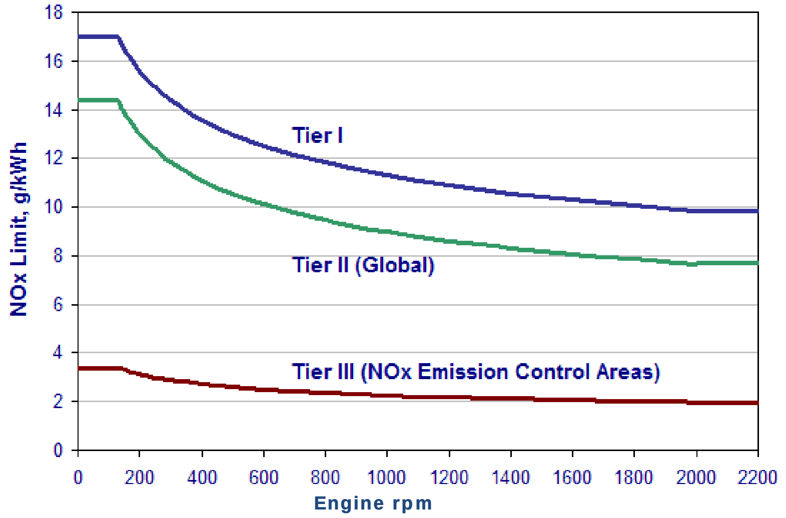

Figure 5-4: IMO NOx regulations, for all ships with engine of over 130 kW output power

5.2.4 Carbon dioxide (CO_2)

A key development under the auspices of IMO includes the finalisation and adoption of mandatory measures for GHG emissions control. A set of technical and operational measures to increase energy efficiency and reduce emissions of GHGs from international shipping were adopted by IMO MEPC[45] in 2011. MARPOL Annex VI was amended to include a new chapter 4 on regulations on energy efficiency for ships, making the Energy Efficiency Design Index (EEDI) mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. The regulations apply to all ships of 400 gross tonnes and entered into force on 1 January 2013. The EEDI requirements will become increasingly more stringent; EEDI requires that new ships in 2025 are 30% more fuel efficient than current ships.

Previously announced market based measures to curb CO2 emissions seem to have been given up by both IMO and the EU, instead a Monitoring, Reporting and Verification (MRV) regime is discussed. Further details are provided in section 5.4.1.

[45] See http://www.imo.org/MediaCentre/HotTopics/GHG/Documents/eedi%20amendments%20RESOLUTION%20MEPC203%2062.pdf

5.3 An introduction to Australian ship emission regulations

Each of the mainland states and territories of The Commonwealth of Australia has the capacity to make laws, as does the Commonwealth in its own right. The matters for which each jurisdiction may make laws are governed by the Constitution of the jurisdiction. In general, the Commonwealth makes laws that affect Australia as a whole (taxation, defence, customs and immigration, postal services, meeting international obligations and external affairs, for example). The states and territories make laws that relate to the good governance of the jurisdiction (for example, education, hospital services, transport, health and safety and local developments). As the requirements of each jurisdiction are peculiar to that location laws are not consistent between the states and territories.

The Australian Maritime Safety Authority (AMSA) is the Commonwealth authority that regulates maritime certification of commercial vessels. AMSA ensures maritime safety and ship sourced pollution prevention in Australian waters through instituting compliance with international guidelines (including SOLAS, MARPOL, STCW, etc.).

More specifically, AMSA was established under the Commonwealth Australian Maritime Safety Act 1990 with the power to promote maritime safety and protect the marine environment from pollution from ships. It has the power to do all things necessary or convenient in their discharge of these responsibilities and may arrange for a State to provide services or undertake a function on its behalf.

The jurisdiction of AMSA extends to all defined Australian waters up to 350 nM off shore. The current sulphur limit in NSW is 3.5% as set by AMSA (6) as there is no current reference to IMO MARPOL Annex VI - Regulations for the Prevention of Air Pollution from Ships in the NSW Regulations (23). The EPA has issued an introduction to emission components and their health effects (24).

NSW, on the other hand, is able to regulate activities within the Coastal Waters area (ca. 3 nM off shore[46], basically just outside the ports and coast) and includes adoption of Commonwealth Orders related to pollution from oil (MARPOL Annex I), noxious liquid substances (MARPOL Annex II), packaged harmful substances (MARPOL Annex III), sewage (MARPOL Annex IV) and garbage (MARPOL Annex V). Currently, NSW has not included reference or formal adoption of Commonwealth Orders related to Air Pollution from Ships (MARPOL Annex VI)[47].

Further, it worth pointing out that the Commonwealth does not have emission regulating legislation for internationally flagged vessels beyond what is ratified by the IMO.

5.4 Various incentive schemes

5.4.1 Clean port initiatives etc.

Several ports around the world offer reduced port fees and/or investment subsidies for visiting ships with emission abatement measures installed. There are also clean cargo initiatives, targeting owners with improved fuel efficiency.

One of the most recognized port initiatives in order to reduce port emissions is The Clean Shipping Index, CSI.[48] This index is an online tool which gives a rating to ships and shipping companies based on their environmental performance. This information is recorded in a database where cargo owners can

[46] NSW Marine Pollution Regulation 2014, See http://www.legislation.nsw.gov.au/sessionalview/sessional/sr/2014-529.pdf

[47] AMSA have ratified IMO MARPOL Convention Annex VI which regulates maximum sulphur content in fuels, See https://www.amsa.gov.au/environment/legislation-and-prevention/marpol/current-texts/index.asp

[48] See http://www.cleanshippingindex.com/

then compare the environmental performance of the shipping companies. CSI has now 31 affiliated cargo owners and 51 affiliated shipping companies.

World Port Climate Initiative (WPCI)[49] offers a different index to reduce GHG emissions from the maritime transport chain. The WPCI offers the Environmental Ship Index (ESI)[50]. The ESI identifies seagoing ships that perform better in reducing air emissions than required by the current emission standards of the International Maritime Organization. The ESI evaluates the amount of NOx and SOx that is released by a ship and includes a reporting scheme on the greenhouse gas emission of the ship.

The Maritime Singapore Green Initiative[51] seeks to reduce the environmental impact of shipping and related activities and to promote clean and green shipping in Singapore. This initiative includes a Green Ship Programme[52] which offers reduction of Initial Registration Fees and a rebate on Annual Tonnage Tax for Singapore-flagged ships that exceeds the EEDI (IMO's Energy Efficiency Design Index) requirements, or engages SOx reducing measures. This programme is valid for Singapore flagged ships worldwide.

In 2010, the Hong Kong Fair Winds Charter, a voluntary scheme aimed at reducing air emissions in port was established and ran until it officially expired at the end of the year (2014). It was an industry-led, voluntary, at-berth fuel switching programme for ocean-going vessels (OGVs) calling at Hong Kong. It was the first initiative of its kind in Asia, and the only shipping-industry led fuel switching initiative in the world. Participating vessels switch to low sulphur fuel (0.5% sulphur content or less) while at berth in Hong Kong. In 2012, the charter was partially supported by the government with a three-year incentive scheme that means owners can claim around 40% of the cost of switching fuel. This has since been replaced by The Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation[53] that requires the use of fuel with a sulphur content not exceeding 0.5% while at berth in Hong Kong (except during the first hour after arrival and the last hour before departure). Records of fuel switching must be kept for three years.

Worth mentioning is also the recent proposed EU regime for Monitoring, Reporting and Verification (MRV) ***(25)*** of ship CO_2 emissions, scheduled to be implemented in January 2018. Under this regime, operators of ships exceeding 5,000 GT will have to monitor and report their CO_2 emissions to, from and between EU ports. This is viewed as a precursor for a GHG regulation regime to be implemented at a later stage. An MRV regime is also being discussed at IMO level, although not implemented.
There may also be other local and regional port initiatives around the world not covered in this report.

5.4.2 Charterers / owners' options: Active public purchasing

Charterers and authorities can trigger the development of cleaner shipping by setting criteria for ships they intend to hire, or for fleets operating in their jurisdiction. Some examples from Europe are given below.

County of Hordaland, Norway. The National and regional public sector in the Nordic countries are major investors in public transport and hence they are also in the position where they may influence the technology choice and even the technology development. County of Hordaland in Norway, who charters ferries, altered their charter specification in 2012 to include alternative propulsion systems for ferries engaged in their 17 ferry routes. The average age of the fleet was 25 years and a renewal was called for.

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[49] See http://wpci.iaphworldports.org/
[50] See http://esi.wpci.nl/Public/Home
[51] See http://www.mpa.gov.sg/sites/maritime_singapore/msgi/maritime-singapore-green-initiative.page
[52] See http://www.mpa.gov.sg/sites/maritime_singapore/msgi/green-shipping-programme.page
[53] See http://www.info.gov.hk/gia/general/201503/11/P201503110549.htm

An open scope approach was selected both for the choice of energy carrier and propulsion technology, and some quite radical solutions including battery/electric propulsion came out favourably.

Fairway dues, Sweden. After a decision by the Swedish Government in February 2004, the Swedish Maritime Administration was assigned the task of developing a fairway dues system[54]. The main purpose of the change was to increase the financial incentives for improving the environmental performance of vessels. This approach has been further strengthened with the tightening of environmental differentiation in the system that was implemented on 1 April 2008.

Fairway dues are in two parts where one part is based on the vessel's gross tonnage and the second part on loaded and unloaded cargo. For domestic freight the tax is goods-based only.

Vessels operating solely on bunker fuel with a sulphur content not exceeding 0.5% by weight are given a discount of SEK 0.50 (~$0.08 AUD) per tonne on sulphur charges, which usually would amount to 0.70 SEK (~$0.11 AUD) per tonne. Vessels operating solely on bunker fuel with less than 0.2 weight-% of sulphur are exempted from tax.

Vessels that have installed equipment to reduce NOx emissions receive a discount on the gross tonnage based fairway dues. This is given as a linear scale that starts at an emission level of 10 g / kWh and goes down to below 0.4 g / kWh which vessels are exempt from gross tonnage-based fairway dues.

The Business Sector's NOx Fund[55] (Norway). The NOx Fund was initiated after the introduction of the Norwegian tax on NOx emissions in 2007. To date, the NOx Fund has granted more than 420 million AUD in investment support to verifiable NOx reduction abatement initiatives on ships operating in Norwegian waters. DNV GL acts as a technical advisor for this regime and has overseen more than 1,000 applications for investment support to NOx reduction measures and has validated nearly 700 investment cases to reduce ships' NOx emissions.

The NOx Fund relies on revenues from all ships sailing between Norwegian ports or offshore installations (approximately $0.65 AUD/kg NOx emitted on route between ports), and from the offshore installations (approximately$1.80 AUD/kg NOx emitted). Emitters who pay to the NOx fund are exempt from the national NOx tax of approximately$3.14 AUD/kg NOx, i.e. enrolment in the NOx Fund regime both lowers the emission fees and opens up grants covering substantial part of the investments. The size of the grants depend on the abatement efficiency; typically given as $32 AUD per kg lowered annual NOx emissions for LNG fuelled ships, and $16 AUD per kg lowered annual NOx emissions for other NOx abatement measures (SCR, engine modification etc.).

41% of the overall NOx reduction is done by Selective Catalyst Reduction (SCR), 19% and 17% of the reduction is obtained by using LNG as fuel or modification of conventional engines, respectively. Other supported measures include humidity or emulsion systems, exhaust gas recirculation and various fuel saving measures.

All ships paying NOx tax to the Fund are eligible for investment support. The degree of support for a specific measure depends on type of NOx reducing measure, amount of NOx reduction (kg per year) and investment costs.

Since there is no tax on NOx or SOx in NSW, we do not foresee that a fund of this kind can be easily established in the near term.

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[54] See http://www.sjofartsverket.se/en/About-us/Finances/Fairway-Dues/

[55] See https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/

5.5 Internationally trading ships' typical response to upcoming IMO emission regulations

Usual practice for the shipping industry is to have a reactive approach towards environmental regulations and only implement measures that saves fuel costs or is a prerequisite to operation in a certain trade. The practice is also influenced by which party pays for the running fuel costs, the ship owner or ship charterer.

Since most of the emissions in the GMA originate from ships operating under the international shipping regime, the influencing power of local or regional authorities to curb emissions is limited. Nevertheless, ship owners in general are well aware of the development towards stricter sulphur regulations, and possibly also PM and CO_2 in the future. And, as more ships are built to the stringent IMO Tier II NOx standard of 2011 and the very strict North American ECA Tier III standard of 2016, visiting ships will gradually emit less NOx in NSW waters (12). All new ships are also designed to use less fuel per cargo unit; this also reduces CO_2 emissions proportionally.

The first hurdle to overcome for ships operating in Australian waters is the global limit of 0.5% sulphur in fuel by 2020 (or 2025 at latest, pending 2018 fuel availability review) (6). However, ship owners do not benefit commercially by having SOx abatement measures in place before this regulation is enforced; the typical charterer does not pay extra for low-emitting ships. Ship owners now also monitor closely how the new sulphur regulations will be enforced. Since there is quite low chance to be checked for compliance and fines are modest (approximately $7,000 AUD in EU and approximately $30,000 AUD in the USA), many owners may be tempted to be non-compliant unless the scrutiny regime is tightened.

Since all emission reducing solutions, perhaps except LNG fuel, increase the investment needs and operational costs without giving a fiscal reward we foresee that reduced emissions can only be achieved by stricter regulations. The global IMO sulphur cap (2020-2025) will surely give lower emissions in the GMA; beyond this, additional local regulations are necessary if further reductions are desired.

The cruise ship industry is typically responding adequately to new environmental regulations, and we now see news that main operators will employ new, modern ships in Australia from the 2016/17 season.

6 AIS-BASED EMISSION ANALYSIS METHODOLOGY

6.1 AIS data

Through the introduction of the Automatic Identification System (AIS)[56] and by making its use mandatory for ships above 300 GT and for all passenger ships, a simple and efficient way of collecting detailed ship traffic information was created. The regulation applies to ships built on or after 1 July 2002 and to ships engaged on international voyages constructed before 1 July 2002. The system was initially introduced as an aid to navigation, offering simple means for one ship to determine the identity, position, course and speed of all ships in its vicinity. As of today, AIS works on VHF radio and this limits the range of coverage to about 40-60 nautical miles or ca. 74 to 110 km. Thus, AIS data was initially used for monitoring coastal shipping only, but with the introduction of dedicated AIS satellites, intercontinental open sea traffic could also be included in the data material.

The AIS data have several fields giving specific information on ship identification and ship particulars. However the ship particulars presented in the AIS source are limited and links with a comprehensive and consistently updated ship register is required for achieving a data quality sufficient for consistent emission and risk calculations. Linking the AIS data and quality ship registers enables in-depth analysis and calculations for environmental accounting, risk analysis, analysis of voyage performance, etc.

Connecting the AIS data and the ship register is made through the fields MMSI, IMO number and Callsign. The MMSI field is unique for each AIS transponder and is used as an additional source for identifying actual vessel.

DNV GL holds a unique register of all DNV GL classified ships and in addition a register of all ships above 100 gross tonnes (Lloyds Fairplay). Both registers are continuously monitored and updated so that any changes of ship particulars will be captured. The ship registers contain numerous data fields which contain information that potentially can be used in an accounting system or giving valid input for improving the emission and discharge calculations.

6.2 Ship movement and emission analysis

DNV GL has developed an AIS-based modelling tool covering ship emissions and potential discharges to sea (26) (13). The framework, outlined in Figure 6-1, combines AIS data and ship particulars from ship registers to form an activity basis for the observed fleet. The model have been integrated in an IBM Netezza database for storing of AIS data, linking of ship registers, calculating and reporting. The AIS-based modelling tool builds on individual tracking of ships and each AIS ship position record to calculate operational parameters such as sailed distance, ship speed and engine load to estimate fuel consumption and emissions.

By aggregating the results for a geographical area and period, an inventory of fuel consumption and emissions are established. The inventory follows US EPA's methodology for quantifying ship emissions (5) modified with a more fine-granular method for determining vessel speed by reading position each sixth minute to more accurately estimate ships' engine load and actual operation. The inventory is continuously updated by automatic downloading AIS data.

For reference, The Norwegian Coastal Administration (NCA) uses an AIS-based modelling tool in their environmental accounting system for estimating emissions and potential discharges to sea for Norwegian

[56] For more details, see http://www.amsa.gov.au/navigation/services/ais/

waters. Having created an inventory, the concentration and impacts of the pollutant in question can be assessed using relevant atmospheric models or risk models. Assessment of cost and effects of implementing mitigation measures are made through linking data on mitigation options with the inventory data in “what-if” analysis. Spatial distribution is inherent in the AIS data to aggregated and present results at any relevant resolution, e.g. 0.1 x 0.1 degree grids.

Besides modelling of ship air emissions, our AIS based approach can also model navigation risk and potential discharges to sea (ballast water species, grey water, black water, oils, etc.). The high resolution of the inventories, combined with the ease of adding effect of abatement initiatives (e.g. lowered emission factors caused by exhaust treatment systems or alternative fuels, etc.), makes our approach ideally suited to give a good decision basis for policymakers and regulators, ship-owners and other stakeholders.

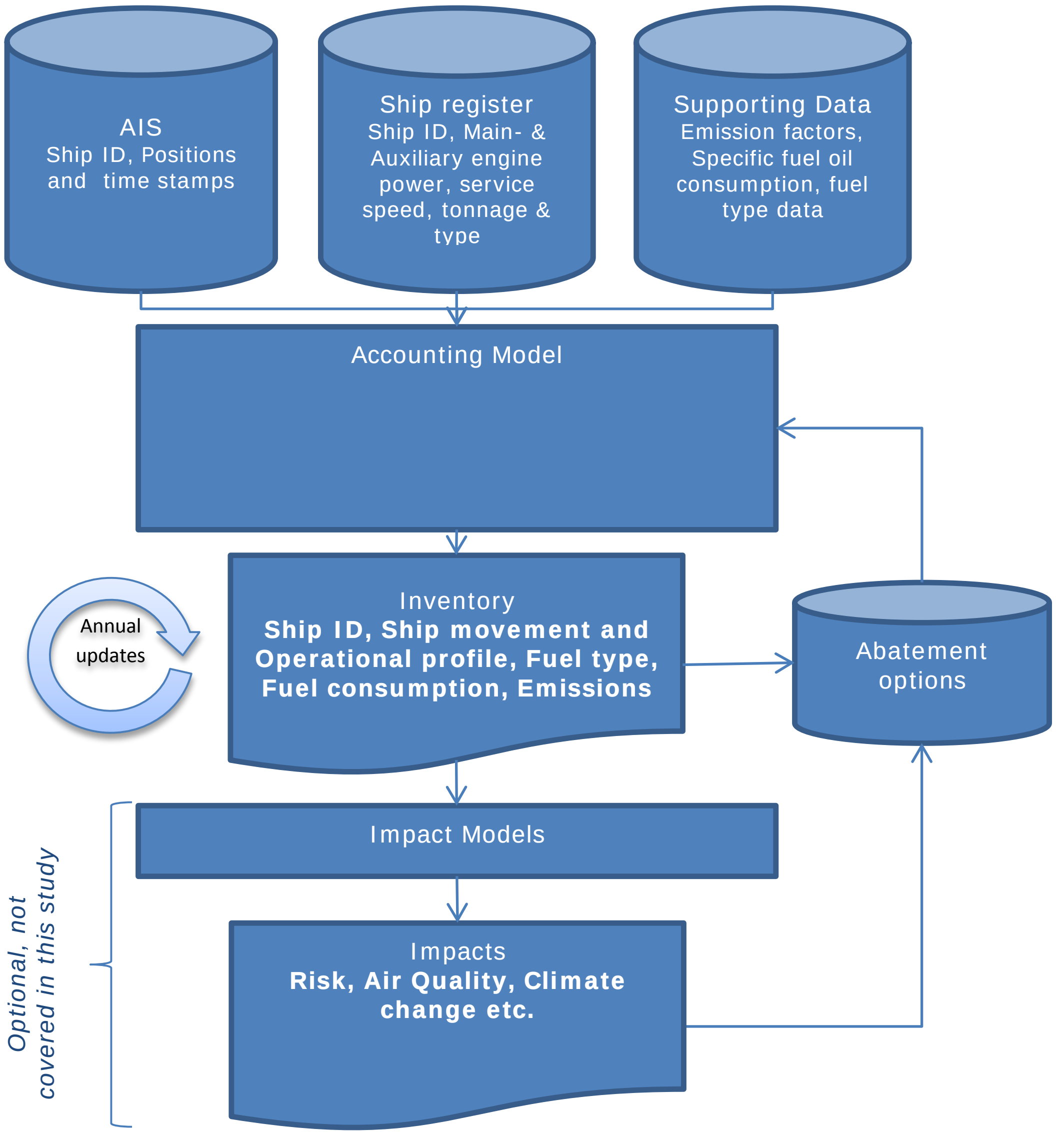

Figure 6-1: Framework for AIS-based environmental accounting and impact modelling

The fuel consumption and air emission estimates for main engines derive from the AIS ship movement data, including all AIS ship position records. Comparison of AIS-registered speed over ground (SOG) with the ship speed capabilities (service speed at 85 % power outtake) gives the main engine load factor, expressed as a percentage of power outtake at service speed. The main engine load factor together with installed main engine power, specific fuel oil consumption figures and period since last AIS observation gives the amount of fuel consumed since last AIS observation. The calculation of emissions to air is based on the fuel consumption and appurtenant emission factors for each pollutant; CO_2, NO_x, SO_x and particulate matter (i.e. PM10, PM2.5 etc.).

In addition to main engines, a ship also has auxiliary engines and usually boilers. Auxiliary engines are usually in operation for electric power production while the main engines are shut down, and the boiler generates steam by burning fuel oil. The electric power serves the accommodation unit, cranes and control systems on-board while in port; while the steam is typically used for heating the fuel oil, to drive cargo pumps and for heating the accommodation unit and hotel unit at cruise ships. The fuel consumption for boilers is dependent on the heat demand on various systems, such as heating of residual oils, running cargo pumps, tank cleaning, accommodation heating, etc. Auxiliary boilers are normally shut off in open sea since most vessels then rather use exhaust gas boilers for heat recovery.

The fuel consumption and emissions from auxiliary engines and boilers is not dependent of the ship movement, but rather the operational status of the ship (i.e. loading/unloading, operation of cranes, etc.). For both auxiliary engines and boilers, the load factors vary by ship type and mode. Traditionally, marine emission inventories differentiate between two modes “at sea mode” and “harbor mode”. The AIS source does not have a reliable AIS measure to set the actual mode, and the model differentiates between the two modes by checking the ship speed over ground (SOG). SOG larger than 0.3 knots equals “at sea mode” while SOG less than 0.3 knots equals “harbor mode”.

The calculation of fuel consumptions and emissions on auxiliary engines and boilers are similar as for main engines except for the load factors and emission factors, which differentiate by ship type and operational mode.

The emission factors denote the amount of pollutant as function of the fuel consumption (kg pollutant per tonne of fuel). The NOx emissions from an engine depend on several factors, such as combustion temperature, gas detention time in the combustion chamber and premixing of fuel and air. The NOx emission factors are therefore highly dependent on the specific engine installed. The NOx emission factors applied in the model derive from an analysis of engine installations in specified ship type and size categories and emission data from the Norwegian NOx fund and from NOx certificates for marine engines (EIAPP certificates). The applied NOx emission factors varies from 79 kg NOx per tonne fuel for engines having low revolutions per minute (RPM) <200 RPM, 53 kg NOx per tonne fuel for engines in the range 200 – 1000 RPM, 45 kg NOx per tonne fuel for engines in the range 1000 – 1500 RPM and 44 kg NOx per tonne fuel for RPM >1500. This applies for both main and auxiliary engines. The NOx emission factor for boilers is set to 6.9 kg per tonne of fuel (5).

The SO_2 emissions are dependent on sulphur content in the fuel used. Small vessels are generally using distillate fuels, which have low sulphur content. For this study, an average of 0.5 % by mass is used for vessels smaller than 1000 gross tonnes. For vessel sizes between 1000 and 5000 GT, traditionally using residual oil blends with lower viscosity, a sulphur content of 1 % by mass is assumed. The larger ocean going vessels are generally using residual fuels with high sulphur content. The global average is about

2.7 %[57] by mass and is applied for all vessels larger than 5000 gross tonnes. Boilers and auxiliary engines generally consume the same fuel type and quality as the main engines.

The formation of particulate matter is dependent on several factors such as fuel quality, engine loads, exhaust temperature, air humidity etc. which lead to great uncertainties in actual emission factors for particulate matter. For this study, the PM2.5 emission factors, range from 1.3 kg per tonne fuel to 6.7 kg per tonne fuel. The PM2.5 emission factor relates to fuel type and sulphur content.

The specific fuel oil consumptions factors used derive from the Second IMO GHG study in 2009 (4), differentiating on engine age and size. The fuel specific fuel consumption for main and auxiliary engines varies from an average of 175 grams fuel per kWh to 203 grams fuel per kWh. For boilers an average of 305 grams fuel per kWh is used.

6.3 Emission inventory

The modelling of fuel consumption and emissions for the Greater Metropolitan Area (GMA) is based on AIS data from January 1st to December 31st 2013. The 2013 dataset for the GMA contains approximately 4.6 million AIS ship position records, which are merged with the comprehensive DNV GL ship register and Lloyds Fairplay lists for adding relevant information on ship particulars, ship type and size categories. The procedures for calculating fuel consumption and emissions are as outlined in chapters 6.1 and 6.2. In the analysis, the results are aggregated into 12 main ship types and 7 size-groups based on gross tonnes. Table 6-1 presents the main ship type and size categories. Appendix A presents the full breakdown of the main ship types and sub-categories.

Table 6-1 - Ship type and size categories

Ship type	Size categories (gross tonnes)
Oil tankers	All ships types are divided into these size categories: <1,000 1,000-4,999 5,000-9,999 10,000-24,999 25,000-49,999 50,000-99,999 >100,000
Chemical/Prod tankers	
Gas tankers	
Bulk carriers	
General cargo vessels	
Container vessels	
RoRo vessels	
Reefers	
Passenger vessels	
Offshore supply vessels	
Other offshore service vessels	
Other activities	

57 See http://www.maritimeuk.org/2012/01/marine-fuel-sulphur-content/

6.4 Uncertainties in the AIS data flow

When interpreting the results one should keep in mind that everything is based on AIS data and typical fuel consumption data for the ship types observed; not from a long series of on-board measurements from an array of ships over time. Thus, it is possible to accurately identify and track the operational profile of all ships detectable by AIS, but since the exact engine particulars of each vessel are not known data from well-known databases for typical configurations of each fleet category have been used.

Although it is found that the AIS analyses very robust and accurate, errors occur. The following are identified as possible error sources for the AIS data flow:

- AIS system down-time (transponder, data lines, satellite and servers).
- The AIS ship identification data (Source MMSI, IMO number and CallSign) can occasionally be missing in the incoming raw AIS data flow, or the data set contains information non-recognizable by the ship register.
- The calculation of sailing distance and related time is based on incoming AIS data over a given time per ship. If the start and stop period for the incoming AIS data crosses midnight, the recordings are excluded from the dataset. Thus logging periods crossing midnight are excluded, these account for approximately 0.7% of registered time.

6.5 Geographical delimitation

The geographical areas covered by this work have been set in cooperation with NSW EPA.

6.5.1 Greater Metropolitan Area

The inventory results are dependent on boundary limits set for the analysis. For the Greater Metropolitan Area (GMA) the boundary was set to include the majority of ship traffic in the southern part of New South Wales, covering the area from Newcastle to Port Kembla. Most of the ship traffic operates inside a zone approximately 120 km from the coast, as shown in Figure 6-2. The eastern boundary was therefore set to 154.3 degrees east. Moving the eastern boundary further out at sea would have little impact on the results, as the majority of ship traffic is located close to shore. The western boundary was set to 150.3 degrees west, well inland, to ensure no loss of coastal traffic. The northern boundary was set to 32.4 degrees north making sure that Newcastle was included, while the southern boundary was set to 34.5 degrees south, which includes Port Kembla. Extension of the north/south boundaries would have great impact on the inventory results as the ship traffic in this area follows the Australian coast.

Figure 6-3 shows AIS registrations during 2013 for a section outside Sydney, along with the AIS grid used with 0.1 degree resolution. In this figure, the waiting areas for ships (oil tankers) can also be seen as clusters north of Port Jackson. There does not appear to be similar holding areas outside Port Botany, indicating that container ships typically go straight to port upon arrival.

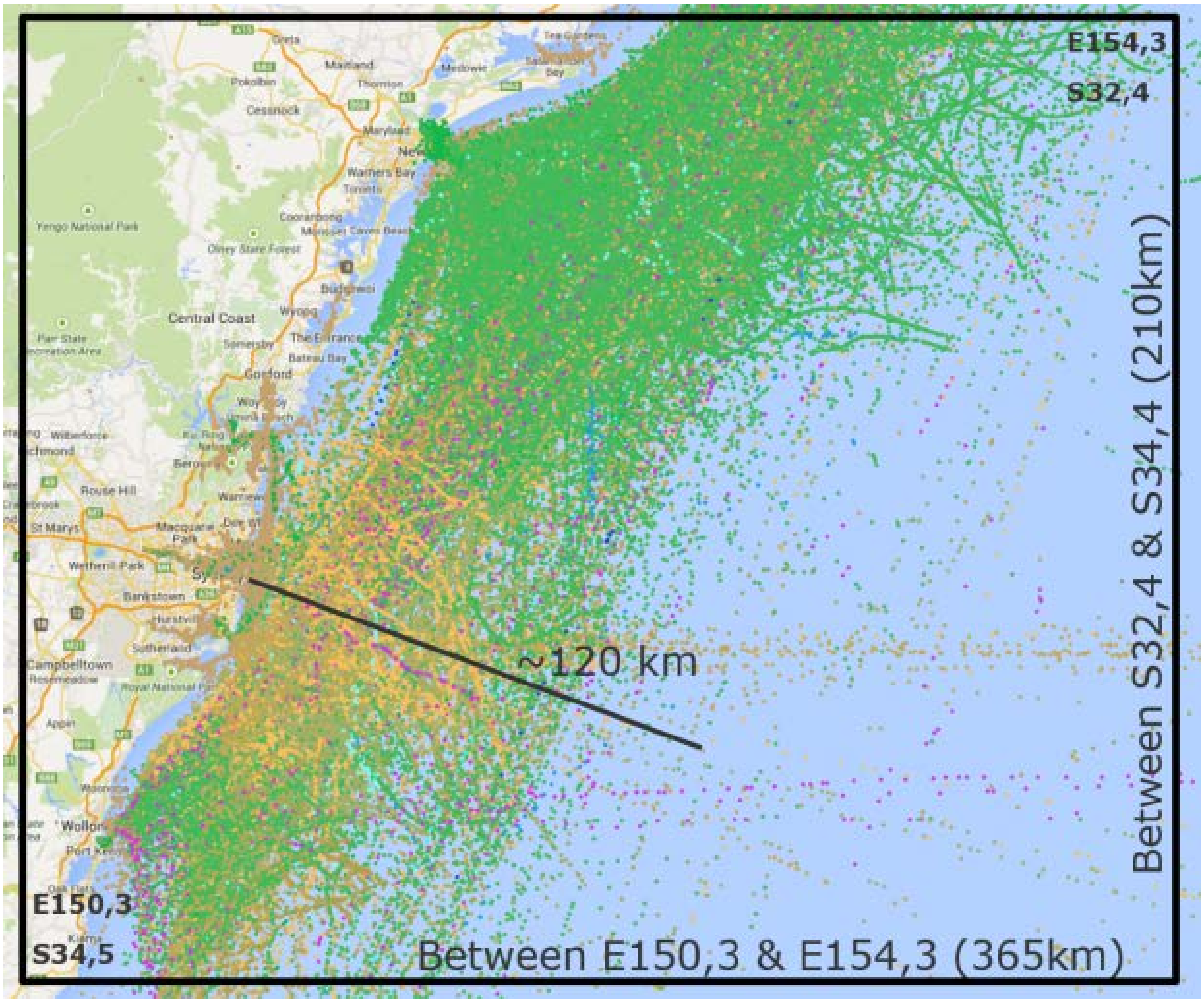

Figure 6-2: Greater Metropolitan Area

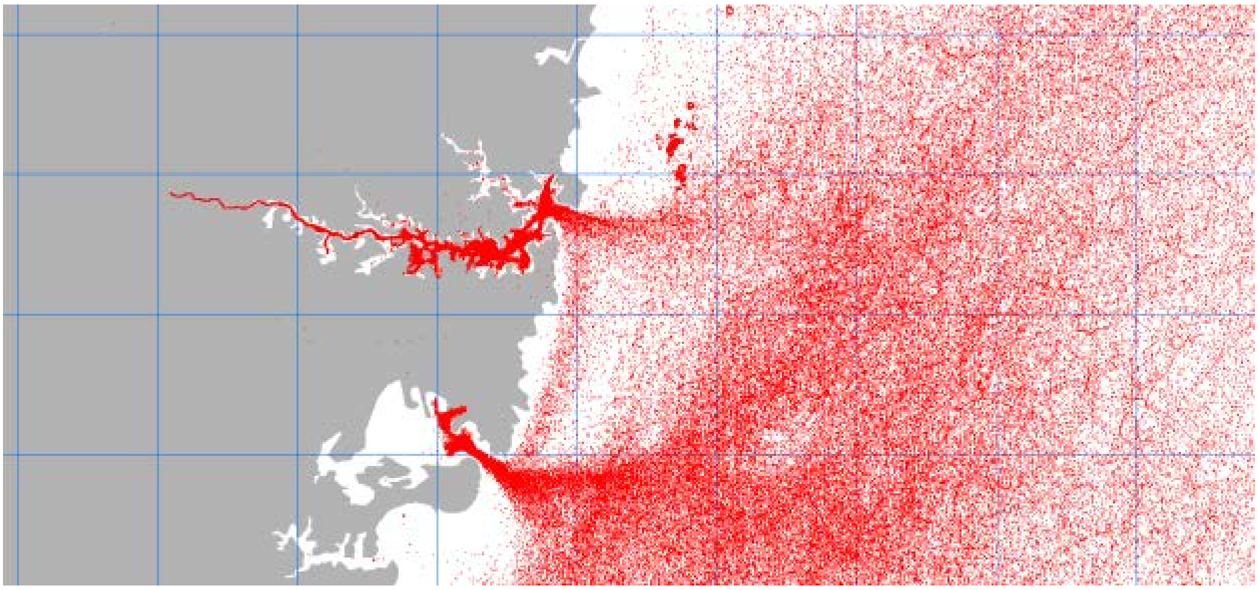

Figure 6-3: 2013 AIS data for a GMA section outside Sydney with 0.1 degree grid

6.5.2 Ports

Major populated cities in the NSW Greater Metropolitan Area (GMA) are adjacent to major NSW shipping ports of Port Jackson, Port Botany, Newcastle and Port Kembla. We also give attention to the new White Bay Cruise Passenger Terminal in Sydney, where local air pollution from cruise ships causes concerns in the local neighbourhood.

Port Jackson's ship traffic is dominated by tankers, cruise ships and a large number of small ferries in local operation. Figure 6-4 shows the area of Port Jackson as defined in this study, marked with a red line (also including berth locations).

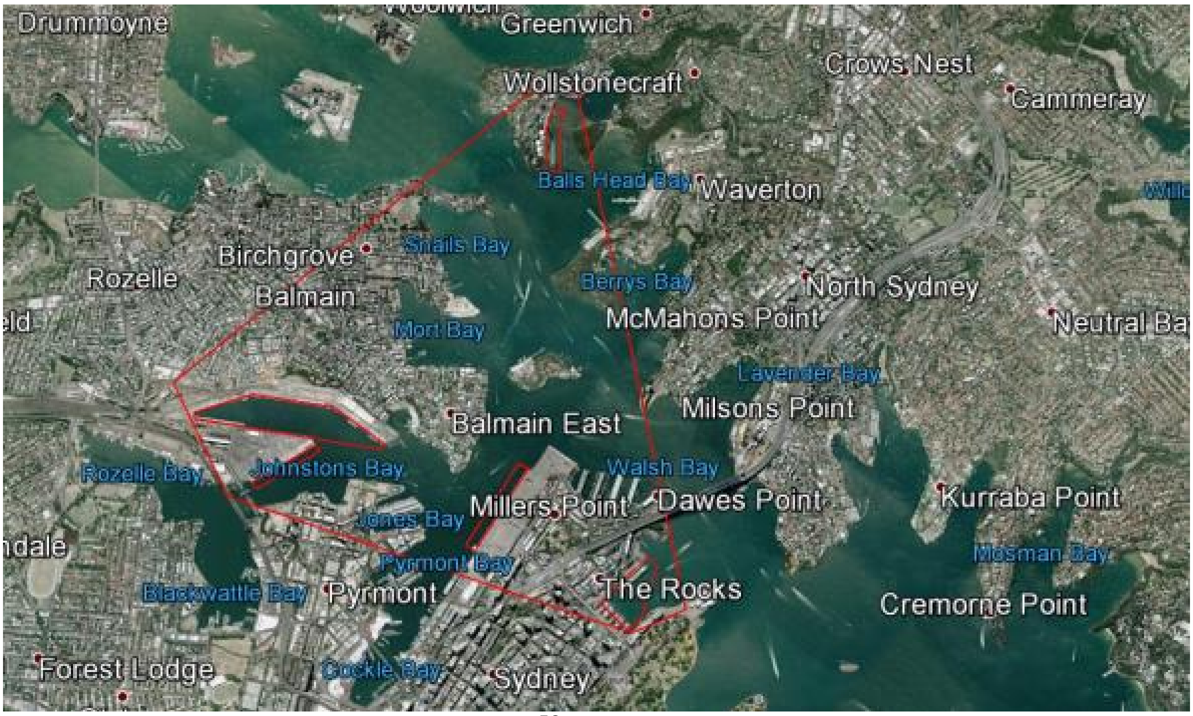

Figure 6-4: Port Jackson area (red line)[58]

Port Botany is a major commercial area serviced by road and rail networks, together with Sydney's nearby international and domestic airports. The two container terminal facilities are complemented by a bulk liquids facility and adjacent bulk liquids storage and distribution complex. Figure 6-5 shows the area of Port Botany as defined in this study, marked with a red line (also including berth locations).

[58] Source: Google Earth

Figure 6-5: Port Botany area (red line)[59]

The Port of Newcastle is the largest bulk shipping port on the east coast of Australia and probably the world's leading coal export port. The port handles more than 25 different cargoes and 4,600 ship[60] movements per annum. Figure 6-6 shows the area of Newcastle as defined in this study, marked with a red line (also including berth locations).

Figure 6-6 Newcastle area (red line)[46]

[59] Source: Google Earth

[60] See http://www.portofnewcastle.com.au/

Port Kembla just outside Wollongong was originally developed for coal exports and steel imports but has over the years diversified its trade base to include general and break bulk cargoes, containers, motor vehicle imports and grain exports. Figure 6-7 shows the area of Port Kembla as defined in this study, marked with a red line (also including berth locations).

Figure 6-7: Port Kembla area (red line)[61]

[61] Source: Google Earth

7 SHIP TRAFFIC AND EMISSIONS

The AIS based environmental accounting system registers all ship activities within the selected region (GMA or in port) enabling for relatively accurate calculations of the fuel consumption and emissions to air. Sections 6.1 to 6.3 give an overview of the method for calculating fuel consumption and emissions.

7.1 Fleet type composition

7.1.1 Number of ships, sailing distances and hours in the GMA

Throughout 2013, a total number of 2,452 unique vessels with an IMO number[62] made at least one voyage through the GMA. As may be seen in Table 7-1, the dominant ship type observed are bulk carriers representing about 56% of all identified vessels. Container vessels represent 11%, RoRo vessels 8%, general cargo vessels 7% and oil tankers 7% of the total number. The majority of identified vessels, 90%, are relatively large ocean going vessels greater than 10,000 gross tonnes.

There are 41 unique vessels classified as passenger vessels, representing approximately 1.7% of the total number of vessels. The category passenger vessels include vessels registered as passenger vessel (1 each), passenger cruise vessels (37 each) and passenger RoRo vessels (3 each). In addition, there are vessels in the AIS analysis without an IMO number. These are most likely vessels smaller than 100 gross tonnes, which also use AIS for safety purposes. However such vessels do not appear in the vessel numbers and analysis below.

The total number of identified unique AIS transponders (MMSI numbers) in the data set is approximately 2,500. The majority of MMSI numbers, not being linked to an IMO number, are located in the category for passenger vessels and size category <1,000 gross tonnes. This is mainly local operated passenger ferries operating in the harbor area. Sailed distance, operational hours, fuel consumption and emissions are included in the inventory as the vessels are included in our ship register.

Table 7-1 GMA - Number of unique ships having an IMO number

Ship type	Number of unique ships							
	<1000 GT	**1000 - 4999 GT**	**5000 – 9999 GT**	**10000-24999 GT**	**25000-49999 GT**	**50000-99999 GT**	**≥ 100000 GT**	**Totals**
Oil tankers		5	12		79	65		161
Chemical/Prod tankers		2	35	17	58			112
Gas tankers		8	3		18			29
Bulk carriers			1	199	656	503	15	1374
General cargo vessels		6	91	68	15			180
Container vessels			6	22	169	68		265
RoRo vessels			2	1	56	145		204
Reefers		4		1				5
Passenger vessels	4	1			12	20	4	41
Offshore supply vessels	2	5						7
Other offshore service vessels			1				1	2
Other activities	61	7	2	2				72
Totals	**67**	**38**	**153**	**310**	**1063**	**801**	**20**	**2452**

[62] IMO ship identification number scheme - IHS Fairplay is the originating source for the IMO Ship Number. The Numbers are issued from the global maritime databases maintained by IHS Fairplay and consist of a unique seven digit number. IHS Fairplay manages this scheme on behalf of the IMO.

Table 7-2 presents an overview of sailed distances within the GMA in 2013. The bulk carriers, which outnumber the other vessels, have the largest sailed distance with 37% of the total sailed annual distance in the GMA. Passenger vessels represent 18%, container vessels 14%, “other activities” 9% and the oil tankers 7% of the total sailed distance. Large oceangoing vessels greater than 10,000 gross tonnes contribute approximately 70% of the total sailed distance in the GMA. The small local operated vessels spend all time in the area, which will contribute significantly to sailed distance and operational hours.

Table 7-2 GMA - Sailed distances split on ship type and size categories

Ship type	Sailed distance (Nautical Miles)							
	<1000 GT	**1000 - 4999 GT**	**5000 – 9999 GT**	**10000-24999 GT**	**25000-49999 GT**	**50000-99999 GT**	**≥ 100000 GT**	**Totals**
Oil tankers		5698	13171		75858	33014		127740
Chemical/Prod tankers		6800	30062	5489	51445			93796
Gas tankers		10719	10979		3957		2	25657
Bulk carriers			681	72327	315794	283957	7712	680471
General cargo vessels		4455	41304	39900	12901			98560
Container vessels			16016	30868	141260	63097	0	251241
RoRo vessels			429	143	29845	59572		89989
Reefers		714	0	13				728
Passenger vessels	157858	104284			3683	55193	5388	326406
Offshore supply vessels	475	588						1062
Other offshore service vessels			2902				2	2904
Other activities	141219	15005	275	3452				159950
Totals	**299,551**	**148,263**	**115,819**	**152,192**	**634,743**	**494,832**	**13,105**	**1,858,504**

Table 7-3 presents an overview of operational hours within the GMA in 2013. As for sailed distance, the bulk carriers dominate with 36% of the total time spent in the area. The vessel type “Other activities” is represented with 24% of the total followed by oil tankers, container vessels and passenger vessels having 9%, 9% and 8% respectively. The vessel type “Other activities” consists of local operated tugs and yachts. The vessels are relative small and their contribution to the total fuel consumption and emissions are modest.

Table 7-3 GMA - Operational hours split on ship type and size categories

Ship type	Operational hours							
	<1000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥ 100000 GT	Totals
Oil tankers		29034	11157		50144	14946		105281
Chemical/Prod tankers		1940	13519	2803	33319			51581
Gas tankers		5223	7487		2251		0	14961
Bulk carriers			459	29549	198724	179617	5874	414224
General cargo vessels		3277	23014	24180	13362			63833
Container vessels			4324	8879	59353	27422	49	100027
RoRo vessels			143	8	5285	12994		18431
Reefers		60	1	1				62
Passenger vessels	52837	24566			1554	9558	1395	89910
Offshore supply vessels	842	174						1015
Other offshore service vessels			7741				0	7742
Other activities	259980	10307	406	1829				272522
Totals	**313,659**	**74,580**	**68,251**	**67,249**	**363,992**	**244,537**	**7,319**	**1,139,588**

7.1.2 Number of ships, sailing distances and hours in key ports

Figure 7-1 presents the ship types and time distribution for vessels operating in Port Jackson. Passenger vessels dominate with 40% of the total annual time ships spent in the area, followed by “other activities” accounting for 39%, and oil tankers 14%. For the category passenger vessels, the locally operated passenger vessels dominate by accounting for approximately 36% of the total time, followed by cruise vessels accounting for approximately 4% of the total time. For the vessel type “other activities”, tugs account for 32% followed by yachts with 6% of time. The oil tanker segment is dominated by product tankers (12%) followed by bunker tankers (1%) and crude oil tankers (1%). The distribution for fuel consumption differs from the time distribution since the amount of fuel consumed are heavily dependent on vessel type, operational settings and size.

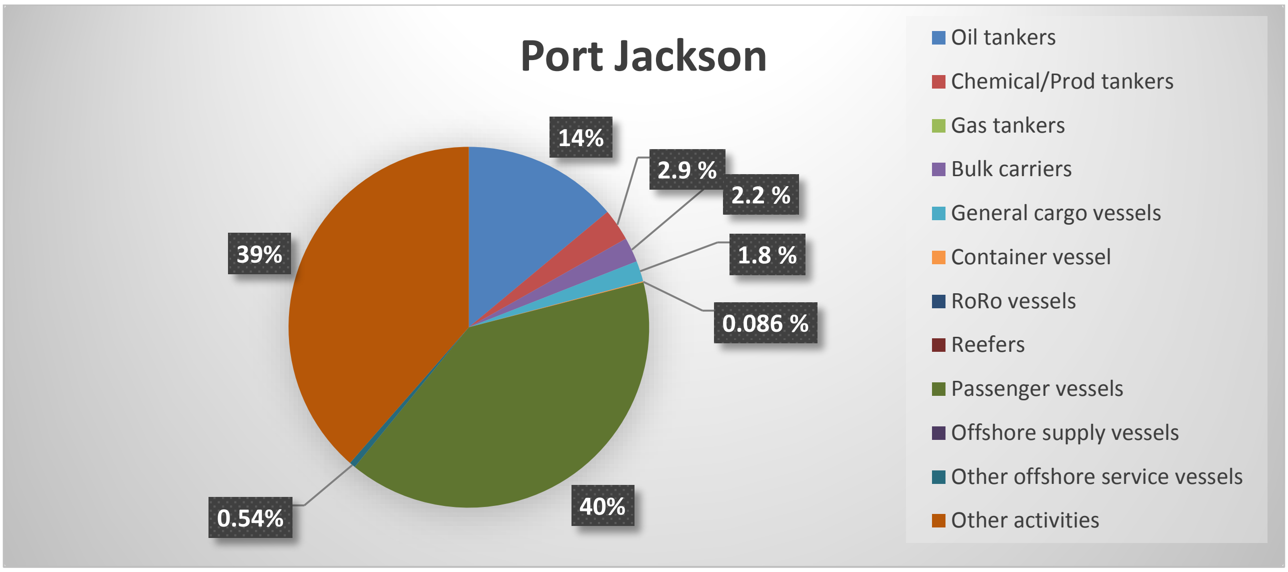

Figure 7-1 Share of total annual time spent in the harbour area – Port Jackson

Figure 7-2 presents the ship types and time distribution for vessels operating in Port Botany. The vessel type “other activities” (tugs) dominate with 40% of the time spent in the area, followed by container vessels 37% and oil tankers 16% of the time. For the vessel type oil tankers, the bunker tankers are largest with 7% followed by product tankers 4%, crude oil tankers 3%, crude oil/product tankers 1% and asphalt/bitumen tankers 1% of the total time ships spend in the port annually.

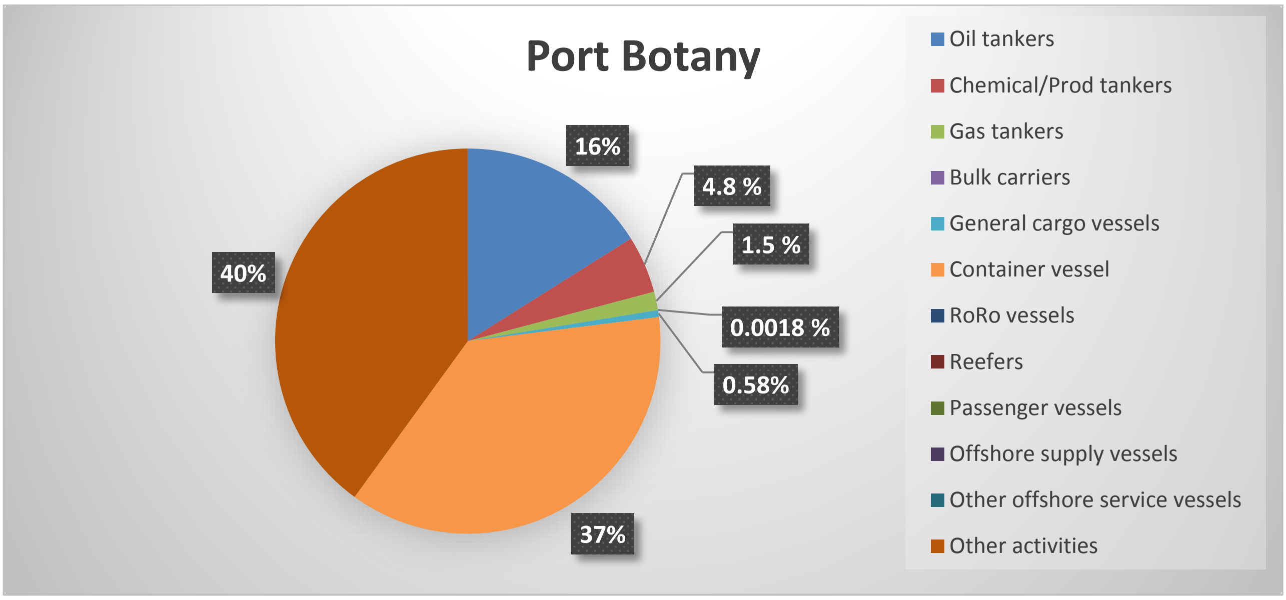

Figure 7-2 Share of total annual time spent in the harbour area – Port Botany

Figure 7-3 presents the ship types and time distribution for vessels operating in Newcastle. ‘Other activities’ dominate and account for 46% (tugs 41% and dredgers 4%) of the annual time in the area, followed by bulk carriers with 41% and general cargo vessels 9% of the time (general cargo 7% and open hatch cargo ship 2%).

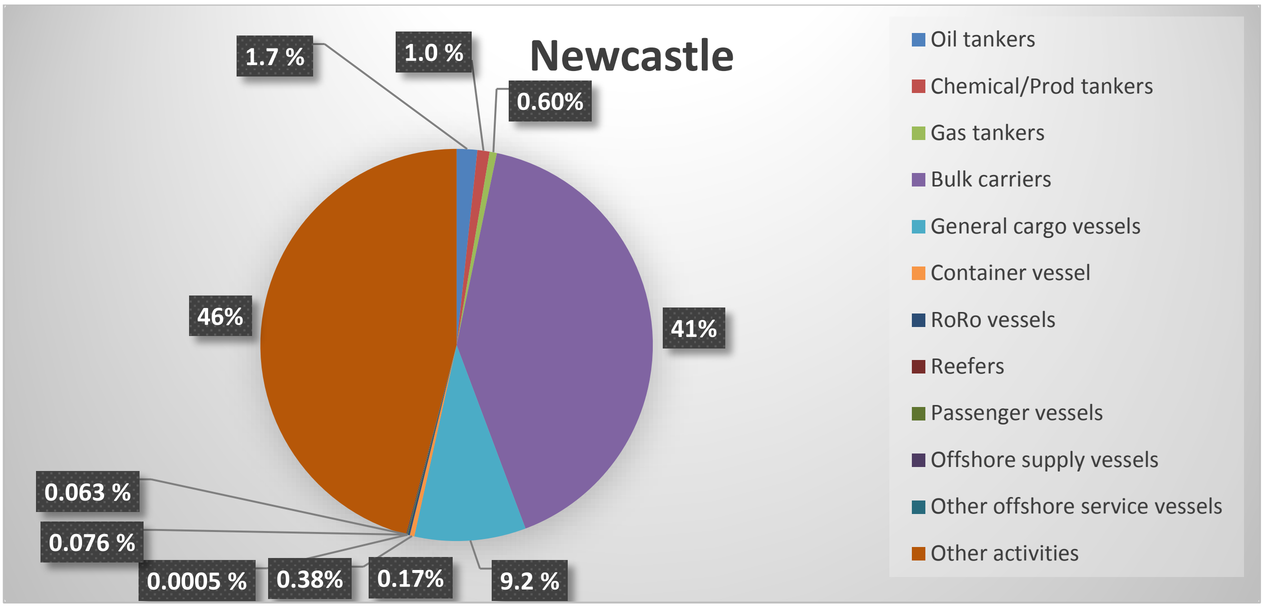

Figure 7-3 Share of total annual time spent in the harbour area - Newcastle

Figure 7-4 presents the ship types and time distribution for vessels operating in Port Kembla. Bulk carriers and “other activities” (tugs) dominate, both having 38% of the time spent in the area, followed by general cargo vessels 13% (general cargo 9%, general cargo ship self-discharging 2% and open hatch cargo ship 2%), RoRo vessels 9% of the total time (primarily vehicle carriers).

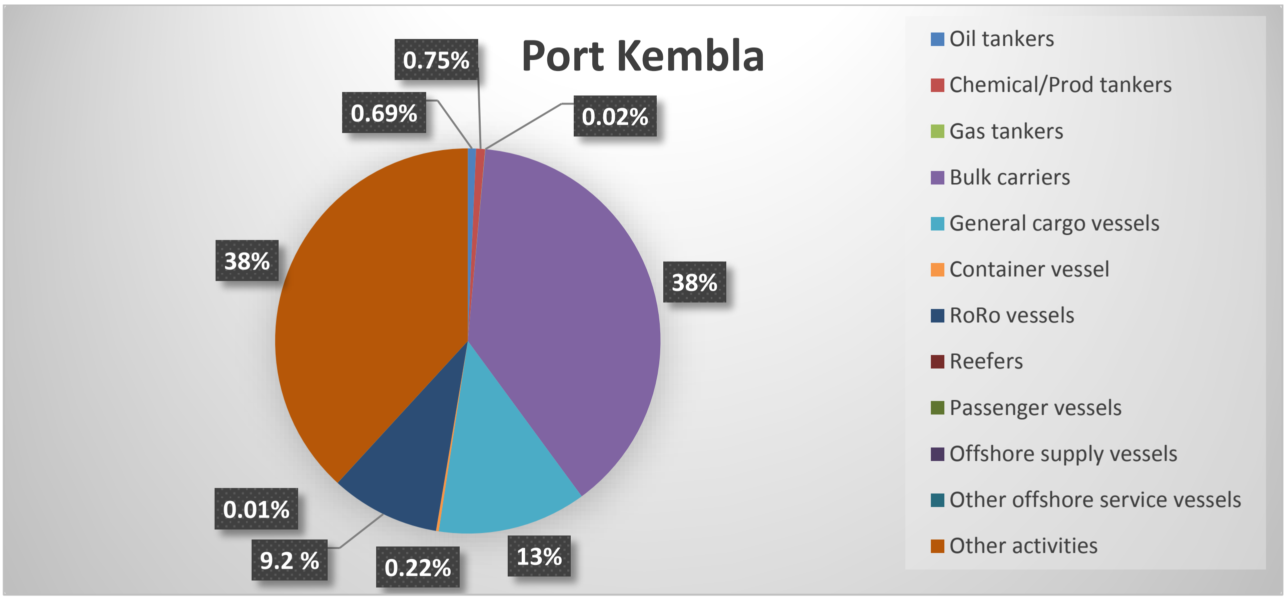

Figure 7-4 Share of total annual time spent in the harbour area – Port Kembla

7.2 Maritime fuel consumption

7.2.1 Maritime fuel consumption – Greater Metropolitan Area

For the base year 2013, the total maritime fuel consumption for all vessels operating inside the GMA was approximately 273,000 tonnes. The fuel consumption from main engines, auxiliary engines and boilers accounts for approximately 45%, 37% and 18%, respectively. The bulk vessels dominate with 33% of the total fuel consumption followed by container vessels (23%), oil tankers (14%) and passenger vessels (11%). As indicated earlier, the identified ships rely mostly on HFO for propulsion for their main engines, auxiliary engines and boilers.

In Table 7-4 the fuel consumption by main engines, auxiliary engines and boilers are summarized for the various ship categories operating in the GMA.

Table 7-4 GMA – Fuel consumption

Ship type	Fuel consumption (metric tonnes) Main engines	Auxiliary engines	Boilers	Totals
Oil tankers	7862	13185	17903	38950
Chemical/Prod tankers	5089	7965	4256	17310
Gas tankers	960	1645	907	3513
Bulk carriers	49270	31281	9898	90449
General cargo vessels	5735	5478	1648	12860
Container vessels	24631	26600	11852	63082
RoRo vessels	7100	2795	380	10275
Reefers	24	3	0	27
Passenger vessels	19640	6935	2429	29004
Offshore supply vessels	38	49	0	88
Other offshore service vessels	307	869	832	2008
Other activities	1997	3227	198	5422
Totals	**122,653**	**100,032**	**50,303**	**272,988**

Figure 7-5 presents the monthly variations of fuel consumption for the GMA throughout 2013 presenting the combined numbers for main engines, auxiliary engines and boilers.

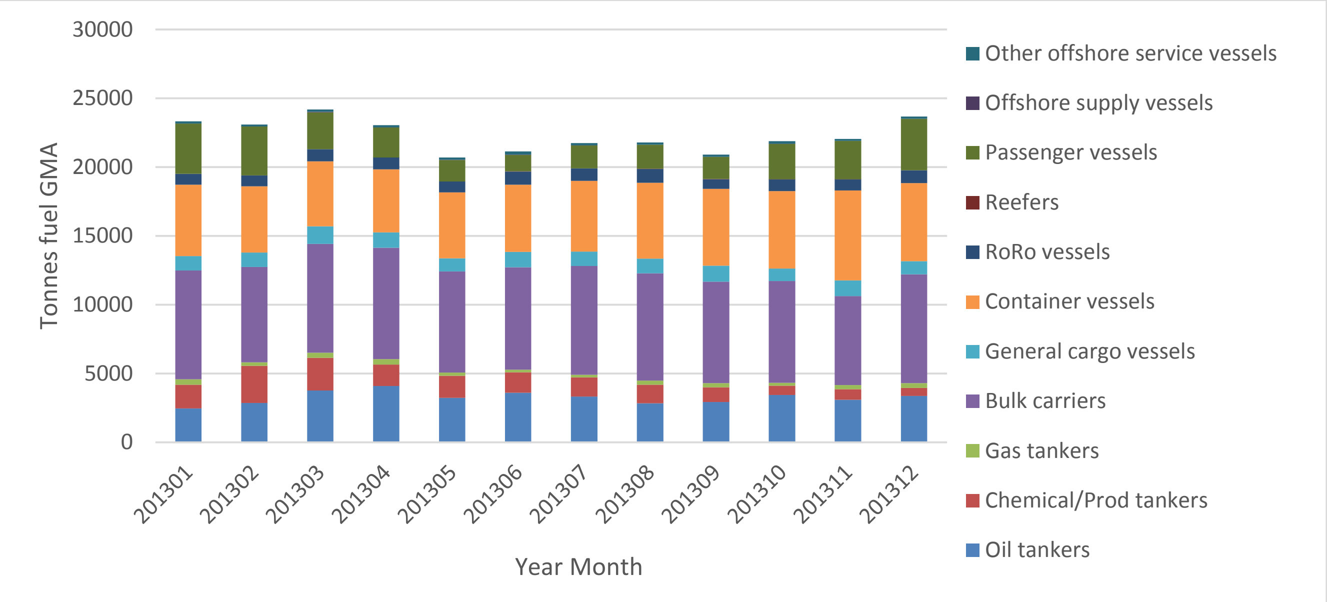

Figure 7-5 Monthly variations of fuel consumption in the GMA for main engines, auxiliary engines and boilers

Figure 7-6 and Figure 7-7 show the 2013 geographical distribution of fuel consumption for passenger cruise vessels as a “heat diagram”. The heat diagram is made using a geographical information tool and in this case calculates the density of fuel consumed around each output raster cell. Conceptually, a neighbourhood is defined around each raster cell and the results that fall within the neighbourhood is totalled and divided by the area of the neighbourhood. By setting same the intensity on each heat diagram (max value of fuel per unit area), the results are comparable.

The figures show that the traffic and related fuel consumption is concentrated in a corridor towards Sydney, indicated by dark blue-green colour. The fuel consumption per unit area is higher closer to Sydney (green) where the passenger cruise vessels naturally follow the same path. The highest fuel use per unit area is inside Sydney harbour (red) where vessels for longer periods are at berth with auxiliary engines and boilers in operation. This also shows that the annual fuel consumption per unit area is denser in the harbour area compared to values out at sea.

In addition to the passenger cruise vessels, there are locally operated passenger vessels in the Sydney harbour area. These locally operated passenger vessels are not included in the heat maps in Figure 7-6 and Figure 7-7, but included in the numeric emission inventory analysis and results.

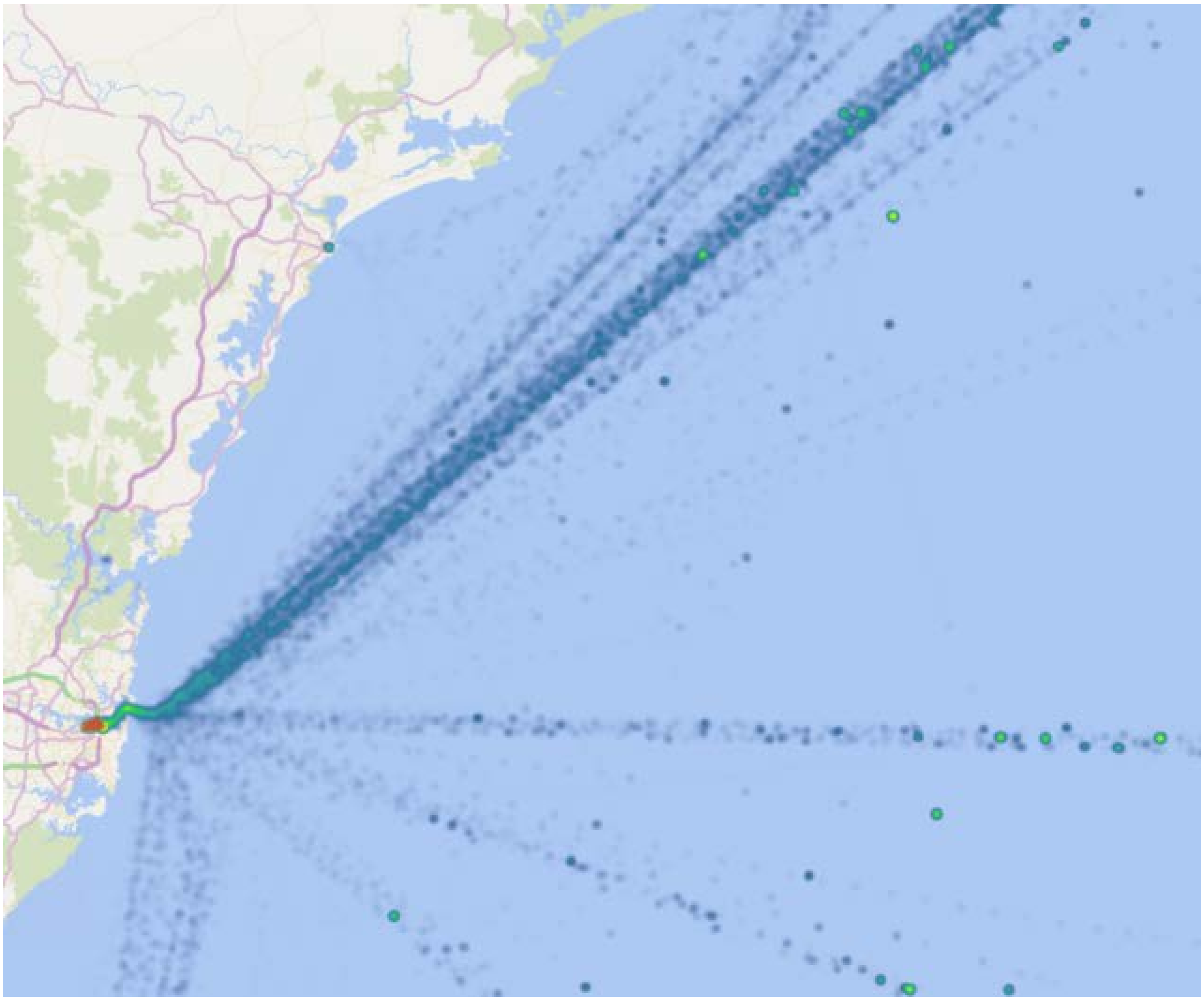

Figure 7-6 Passenger/cruise vessels - fuel distribution for GMA (annual 2013 consumption)

When examining Figure 7-7, keep in mind that the figure represents 2013 ship movement data. The new White Bay Cruise Terminal at Balmain opened in April 2013. This means that traffic to the Barangaroo terminal at the tail end of the 2012/13 summer season is now repositioned to the new White Bay terminal. This relocation, along with an expected forward increase in cruise ship traffic, may lead to increased emissions in the White Bay area if emission reduction measures are not implemented.

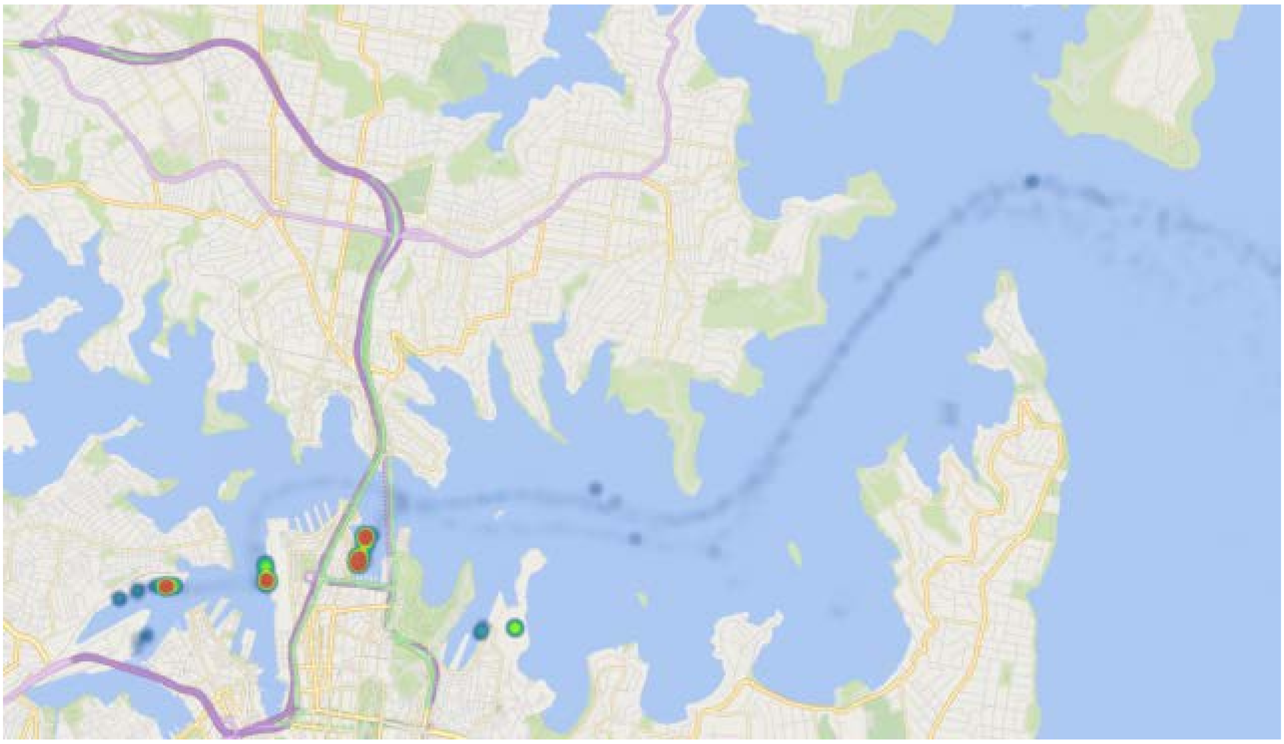

Figure 7-7: Passenger/cruise vessels - fuel distribution for Sydney (annual 2013 consumption)

Figure 7-8 below shows the monthly variations for passenger cruise vessels. The traffic is highest in the period from December to February and lowest in the period from May to September. The figure differentiates on fuel consumed in main engines, auxiliary engines and boilers. The fuel consumption for the harbor areas is mainly from auxiliary engines and boilers, with a small contribution from main engines during arrival. There are small monthly variations in auxiliary engine and boiler fuel consumption, which relates to time spent at berth and power demand for the actual ship. The most common fuel used is most probably heavy fuel oil.

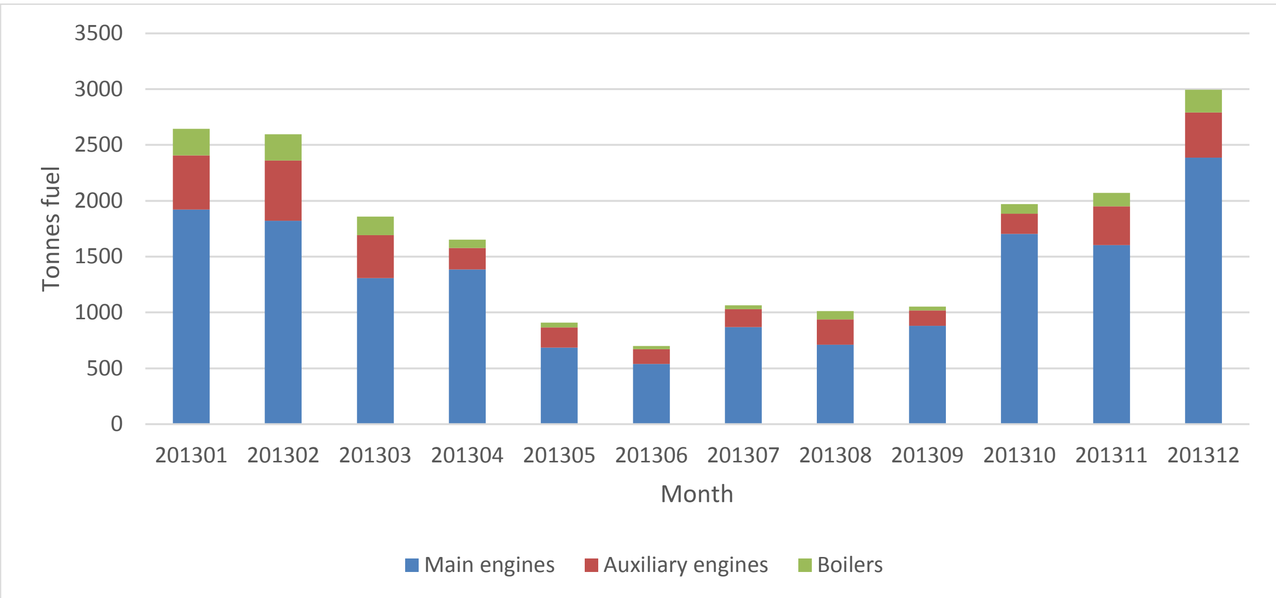

Figure 7-8: Passenger/cruise vessels – Monthly variations of fuel consumption (GMA)

Figure 7-9 shows the speed profile for passenger cruise vessels operating in the GMA. The speed profile clearly illustrates that passenger cruise vessels in the GMA spend the majority of time at berth. The passenger cruise vessels have relatively fixed time schedules, normally arriving early morning and departing at sunset. The profile also shows that the passenger ships on average spend an equal amount of time moving at speeds ranging between 1 and 13 knots. We also observe that the main engines operate at relatively low loads, since the typical service speed for large passenger cruise vessels is above 13 knots. Since the cruise vessels already operate at low speeds inside the GMA the potential for further fuel and emission reductions by further slow steaming will have little impact.

During the relatively long time in port (~56% of the time) it can be assumed that the ships have shut down their main engines, only running auxiliary engines and boilers, all presumably HFO fuelled.

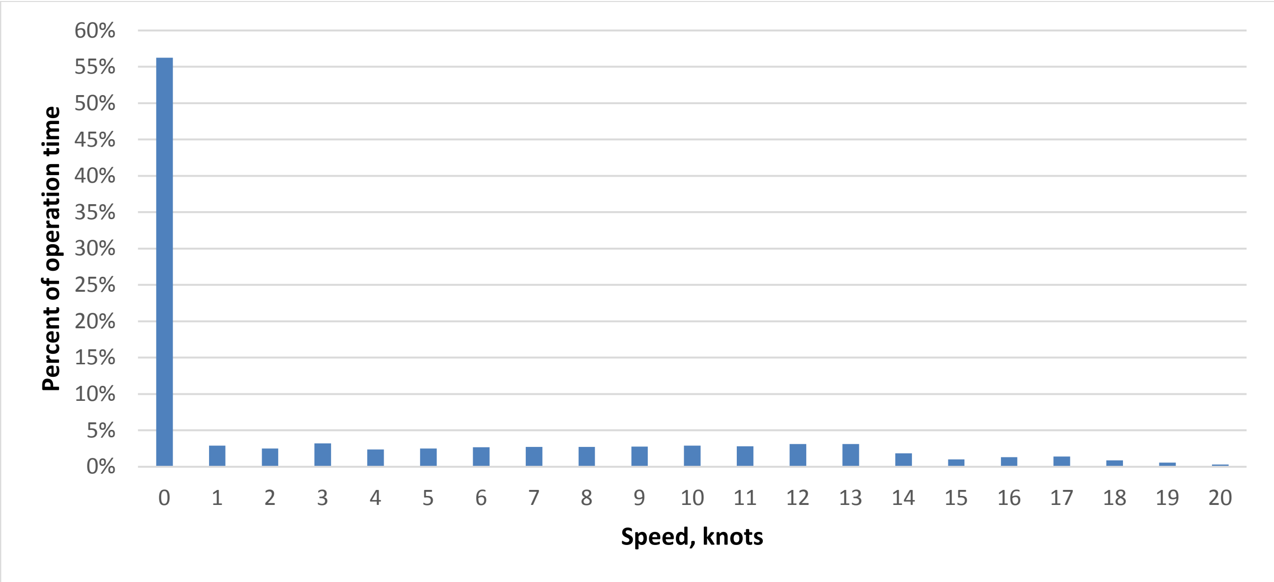

Figure 7-9 : Passenger cruise vessels speed profile in the GMA – 2013 data

7.2.2 Maritime fuel consumption – Port Jackson

Table 7-5 presents the maritime fuel estimates for Port Jackson. The fuel estimates includes only results for vessels that are stationary in port. The main reason for this is that the estimates represent fuel consumptions on auxiliary engines and boilers that potentially can be reduced by introducing local abatement measures. The base line fuel consumption for Port Jackson amounts to approximately 10,650 tonnes for 2013 (presumably HFO for all larger ships), representing approximately 3.9% of all maritime fuel consumed in the GMA. Oil tankers and passenger/cruise vessels dominate the fuel consumption in the port, accounting for approximately 46% and 33% respectively. Figure 7-10 presents the monthly variations of fuel consumption for the port.

Table 7-5 Fuel consumption Port Jackson (main engines shut down)

Ship type	Fuel consumption (metric tonnes)		
	Auxiliary eng.	Boilers	Totals
Oil tankers	1284	3643	4927
Chemical/Prod tankers	673	346	1019
Gas tankers			
Bulk carriers	222	79	301
General cargo vessels	204	64	268
Container vessels	27	14	41
RoRo vessels			
Reefers			
Passenger vessels	2378	1156	3533
Offshore supply vessels			
Other offshore service vessels	67	66	133
Other activities	425	0	425
Totals	**5,280**	**5,367**	**10,647**

Blank = no vessel in this category

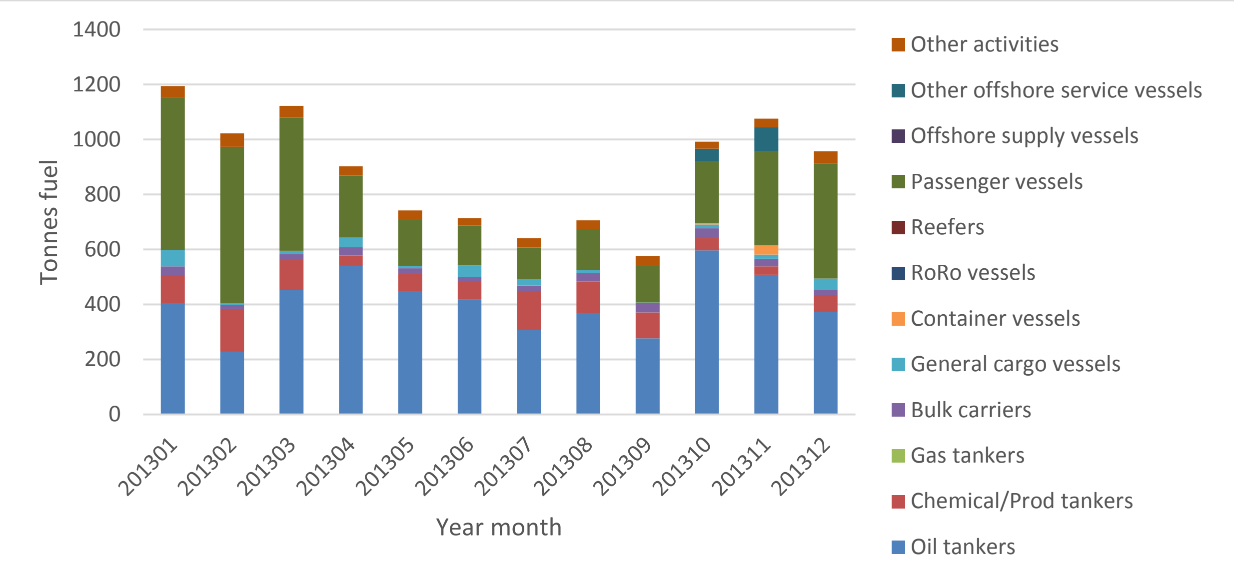

Figure 7-10 Monthly variations of fuel consumption in Port Jackson

Figure 7-11 shows the 2013 geographical distribution of maritime fuel consumption for all vessels operating in Port Jackson as a "heat diagram". The figure shows a corridor towards the harbours and the highest fuel use per unit area when the vessels are alongside running auxiliary engines and boilers.

Also Figure 7-11 is affected by the move of cruise traffic from the Barangaroo terminal at the end of the 2012/13 season to the White Bay Cruise Terminal at Balmain, opening in April 2013. The heat diagram also shows that the fuel consumed by oil tankers at the Gore Bay Terminal is a significant source of air emissions in Port Jackson. The authors understand that this terminal in the future will store lighter products rather than crude and heavy fuel[63], which may also influence the associated ship traffic.

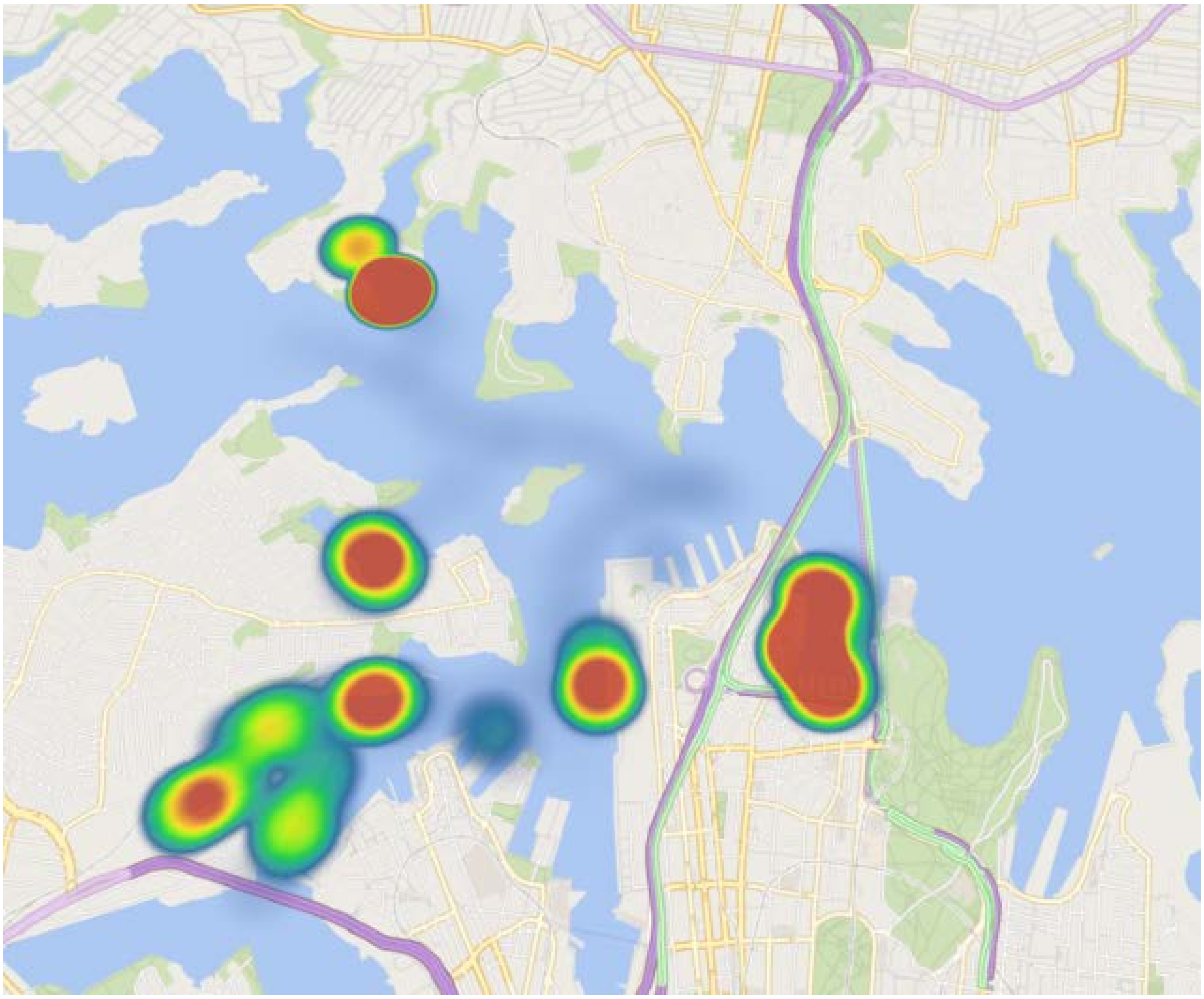

Figure 7-11 Geographical distribution of fuel consumed in Port Jackson. The consumption is dominated by HFO

[63] VIVA Energy state that the Gore Bay Terminal is currently operating as a solely finished fuels import Terminal rather than a predominant Crude Oil import facility. For more information see http://www.vivaenergy.com.au/operations/gore-bay/modification-project

7.2.3 Maritime fuel consumption – Port Botany

Table 7-6 presents the fuel estimates for vessels that are stationary in Port Botany. The base line fuel consumption for Port Botany amounts to approximately 28,000 tonnes for 2013 (presumably HFO), representing approximately 10.3% of all maritime fuel consumed in the GMA. Container vessels dominate the fuel consumption in the port, accounting for approximately 58% of the fuel consumed within Port Botany. Figure 7-12 presents the monthly variations of fuel consumption for the port.

Table 7-6 Fuel consumption Port Botany (main engines shut down)

Ship type	Fuel consumption (metric tonnes)		
	Auxiliary eng.	**Boilers**	**Totals**
Oil tankers	2138	7621	9759
Chemical/Prod tankers	869	530	1399
Gas tankers	255	118	373
Bulk carriers	0	0	0
General cargo vessels	56	18	74
Container vessels	10578	5568	16146
RoRo vessels			
Reefers			
Passenger vessels			
Offshore supply vessels			
Other offshore service vessels			
Other activities	274	0	274
Totals	**14,170**	**13,855**	**28,025**

Blank = no vessels of this category

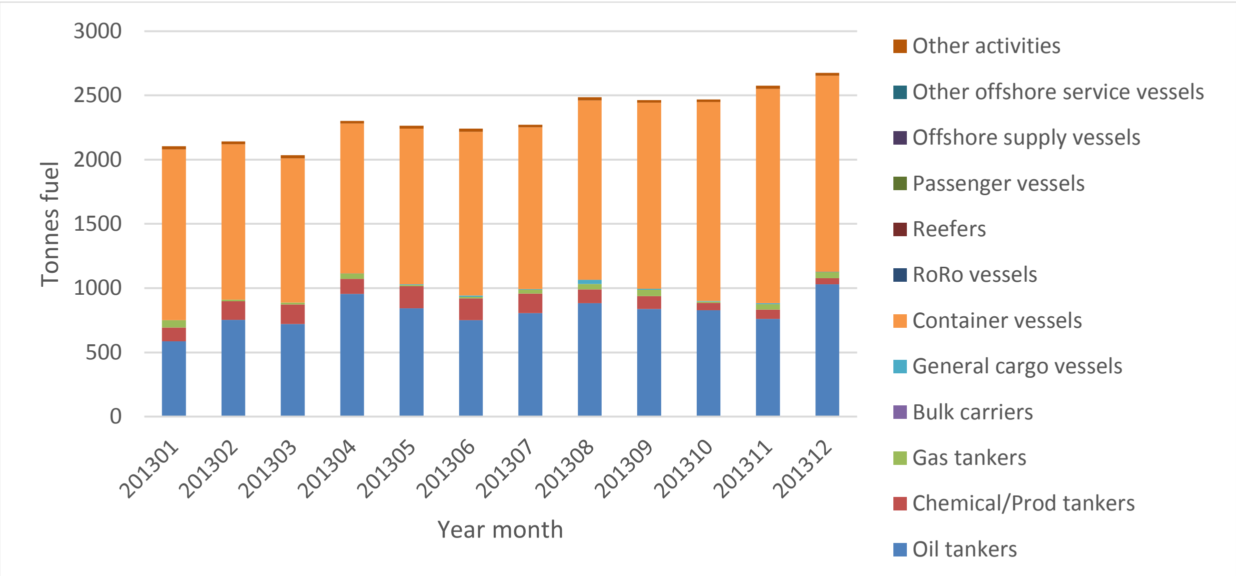

Figure 7-12 Monthly variations of fuel consumption in Port Botany

Figure 7-13 shows the 2013 geographical distribution of maritime fuel consumption for all vessels operating in Port Botany as a “heat diagram”. The figure shows a corridor towards the harbour and the highest fuel use per unit area when the vessels are alongside running auxiliary engines and boilers in the Port of Botany bay and the Kurnell berths.

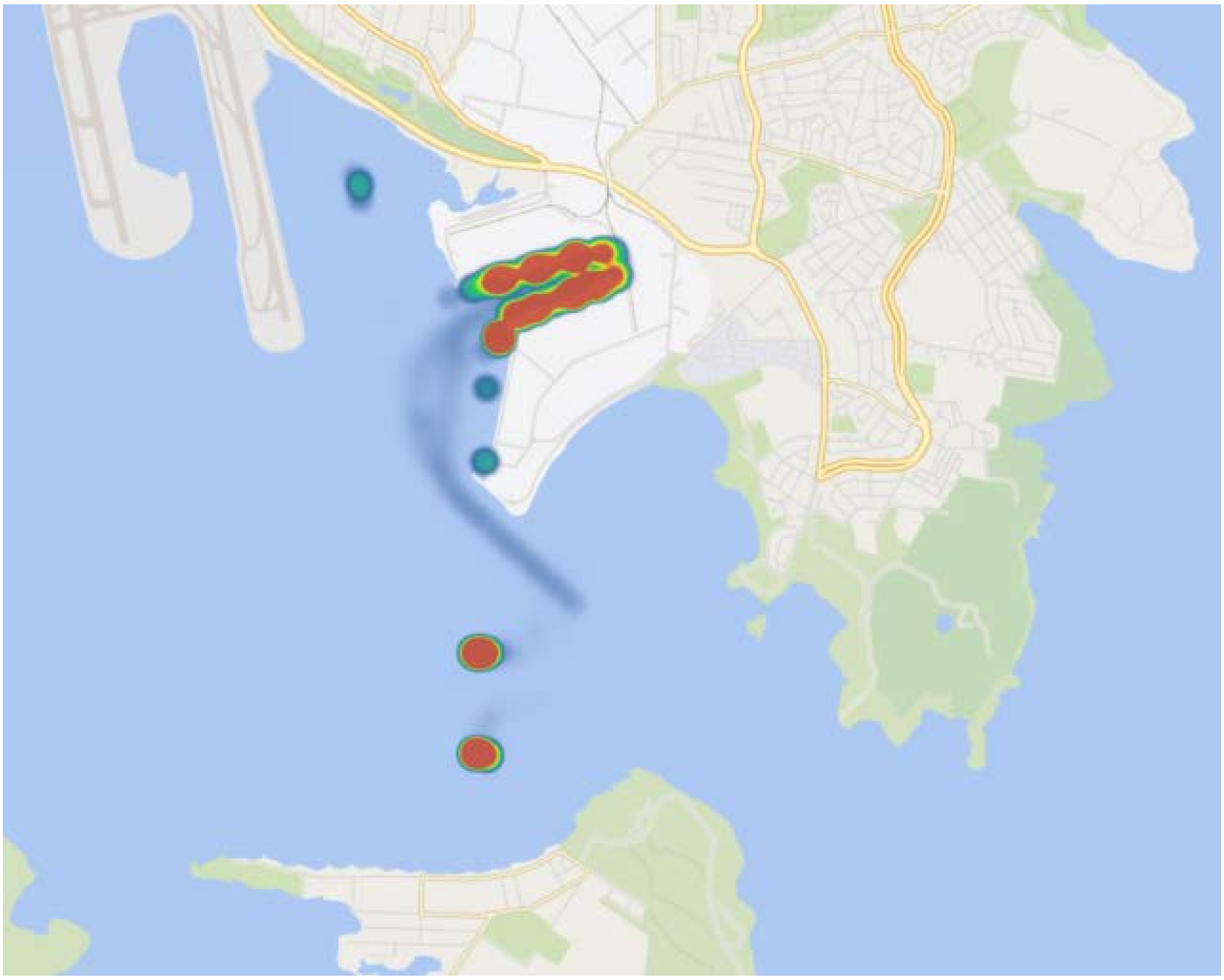

Figure 7-13 Geographical distribution of fuel consumed in Port Botany

7.2.4 Maritime fuel consumption – Newcastle

Table 7-7 presents the fuel estimates for vessels that are stationary in Newcastle. The base line fuel consumption for Port Botany amounts to approximately 12,200 tonnes for 2013 (presumably mostly HFO), representing approximately 4.5% of all maritime fuel consumed in the GMA. Bulk carriers dominate the fuel consumption in the port, accounting for approximately 55%. Figure 7-14 presents the monthly variations of fuel consumption for the port.

Table 7-7 Fuel consumption Newcastle (main engines shut down)

Ship type	Fuel consumption (metric tonnes)		
	Auxiliary eng.	Boilers	Totals
Oil tankers	585	1661	2246
Chemical/Prod tankers	191	69	260
Gas tankers	109	97	207
Bulk carriers	4725	1971	6696
General cargo vessels	1139	387	1526
Container vessels	65	85	150
RoRo vessels	44	8	52
Reefers	0	0	0
Passenger vessels	15	27	41
Offshore supply vessels	4	0	4
Other offshore service vessels			
Other activities	992	0	992
Totals	**7,869**	**4,305**	**12,173**

Blank = no vessels of this category

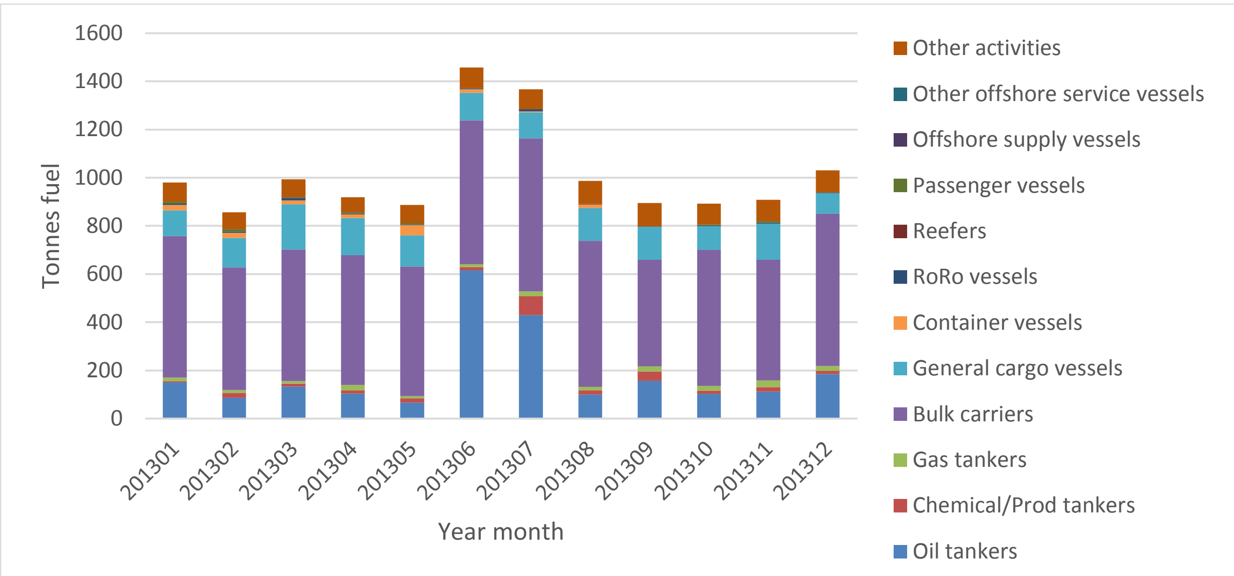

Figure 7-14 Monthly variations of fuel consumption in Newcastle

Figure 7-15 shows the 2013 geographical distribution of maritime fuel consumption for all vessels operating in Newcastle as a “heat diagram”. The figure shows a corridor towards the harbour and the highest fuel use per unit area when the vessels are alongside running auxiliary engines and boilers.

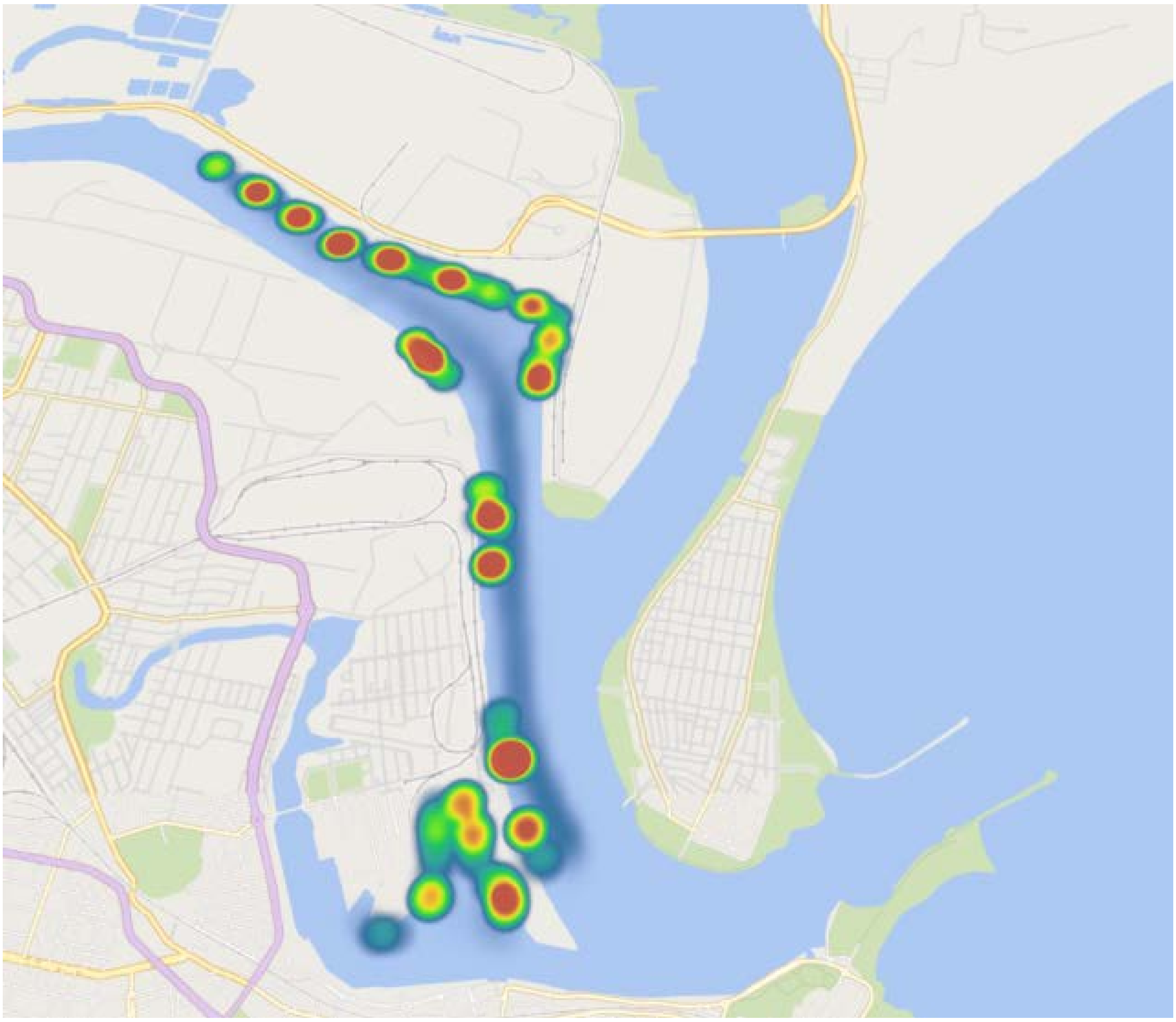

Figure 7-15 Geographical distribution of fuel consumed in Newcastle

7.2.5 Maritime fuel consumption – Port Kembla

Table 7-8 presents the fuel estimates for vessels that are stationary in Port Kembla. The base line fuel consumption for Port Kembla amounts to approximately 5,350 tonnes for 2013 (presumably dominated by HFO), representing approximately 2.0% of all maritime fuel consumed in the GMA. Bulk carriers dominate the fuel consumption in the port, accounting for approximately 48% of all maritime fuel consumed in Port Kembla. Figure 7-16 presents the monthly variations of fuel consumption for the port.

Table 7-8 Fuel consumption Port Kembla (main engines shut down)

Ship type	Fuel consumption (metric tonnes)		
	Auxiliary eng.	**Boilers**	**Totals**
Oil tankers	74	357	431
Chemical/Prod tankers	59	26	85
Gas tankers	1	0	1
Bulk carriers	1829	756	2585
General cargo vessels	698	238	936
Container vessels	15	20	35
RoRo vessels	910	180	1090
Reefers			
Passenger vessels			
Offshore supply vessels			
Other offshore service vessels			
Other activities	184	0	184
Totals	**3,771**	**1,578**	**5,349**

Blank = no vessels of this category

Figure 7-16 Monthly variations of fuel consumption in Port Kembla

Figure 7-17 shows the 2013 geographical distribution of maritime fuel consumption for all vessels operating in Port Kembla as a “heat diagram”. The figure shows a corridor towards the harbour and the highest fuel use per unit area when the vessels are alongside running auxiliary engines and boilers.

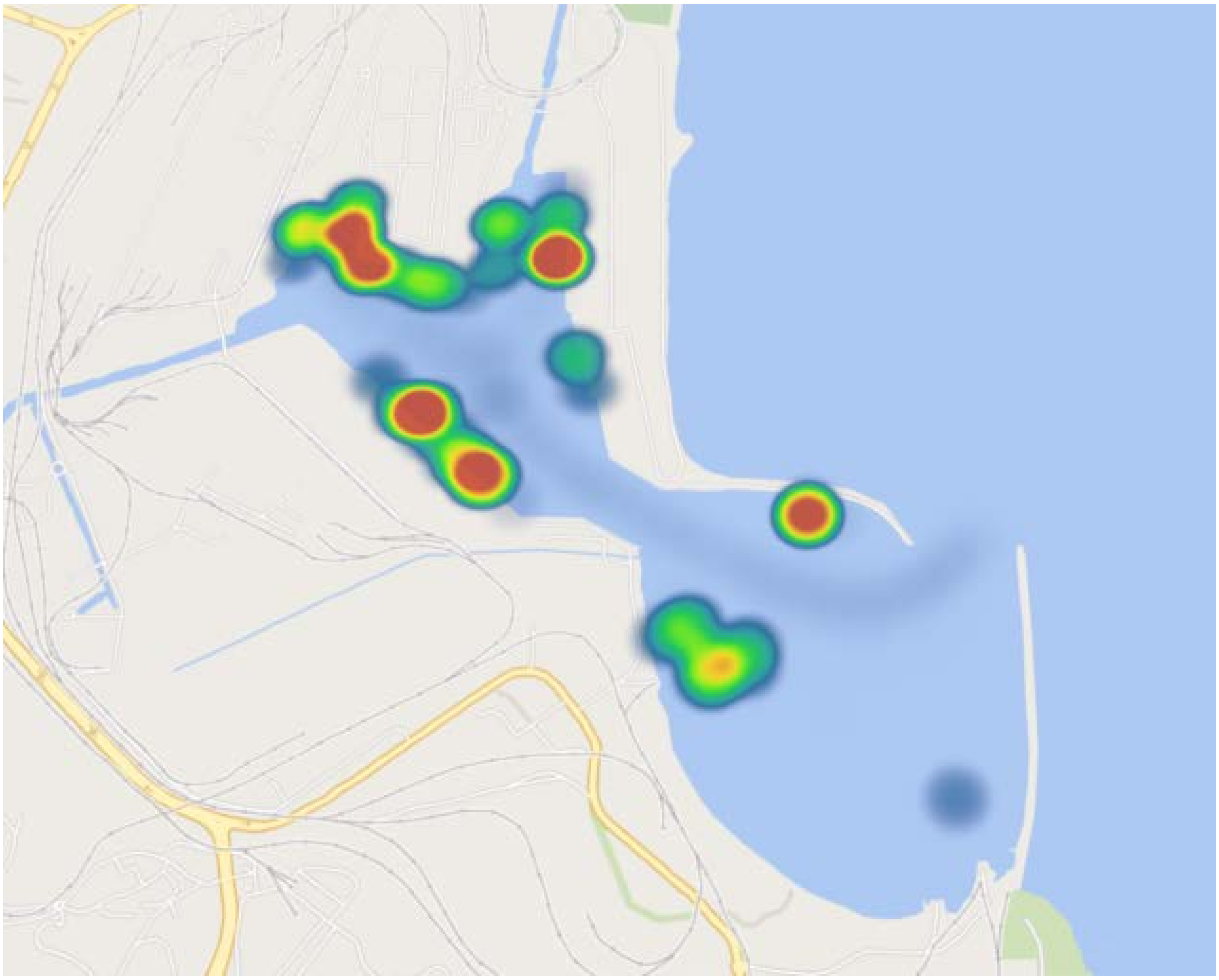

Figure 7-17 Geographical distribution of fuel consumed in Port Kembla

For comparison purposes, an interesting new Australian study on fuel consumption and emissions was undertaken by the Australian Maritime College, University of Tasmania (27).

7.3 Typical fuel consumption for individual ships

Fuel consumption and annual fraction of time spent in the GMA has been calculated for six different main ship categories. Actual unique vessels that visited the GMA in 2013 (as per Table 7-1) were used in the analysis for each of the ship segments. From this information the relative impact of individual ships and ship types is observed and this also forms the basis for the investment analysis where the low sulphur fuel case is compared with the HFO+scrubber case from a ship owner's point of view.

The individual ships operating within the GMA have great variations in their respective annual fuel consumption. The variations are closely linked to ship type, time spent in the area, operation mode, sailed distance, speed dureing voyage, engine size, boiler usage, etc. The following sections present the fuel consumption for main engines, auxiliary engines and boilers for each ship split into 6 ship categories. Moreover, the percentage of the year's hours each vessel operates within the GMA in 2013 is shown for each ship cateory.

7.3.1 Passenger vessels

The annual fuel consumption for individual passenger vessels is ranked according to each ship's fuel use in the GMA and presented in Figure 7-18 below. The median annual fuel use is approximately 135 tonnes per year (hereafter tonnes/year), meaning that the ship in the middle of the group consumes about 135 tonnes/year in the GMA and represents a 'typical passenger ship'. Three ships have significantly higher fuel consumption than the rest. The random ship identification numbers are given to avoid revealing the ships' ID.

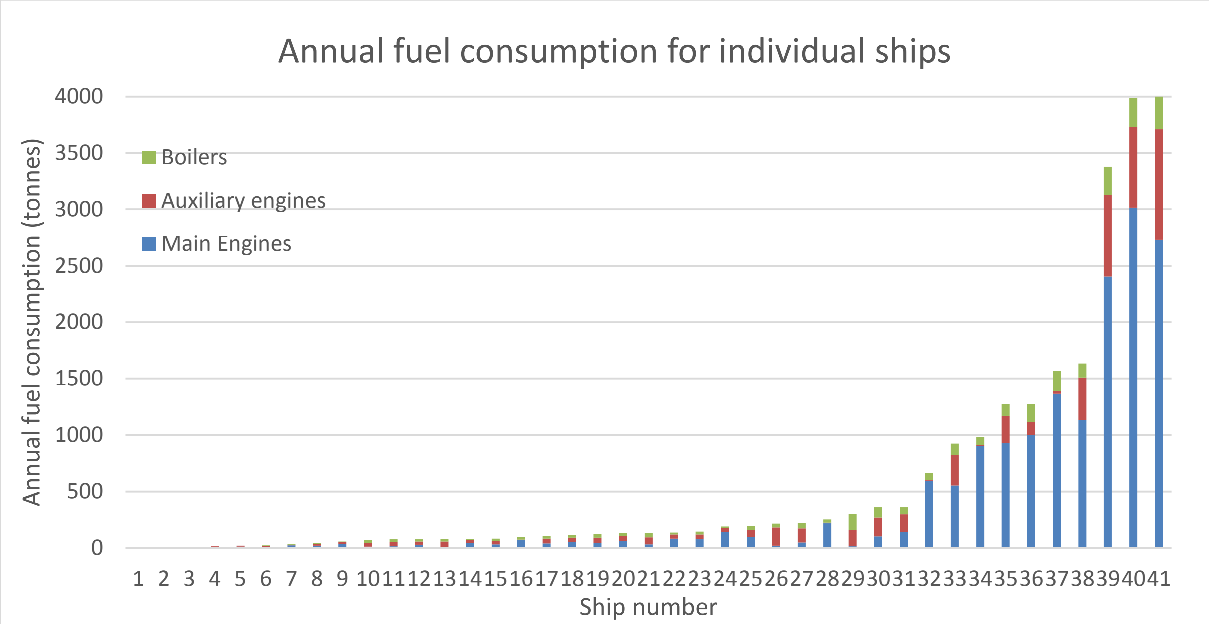

Figure 7-18 Annual fuel consumption for passenger ships in the GMA sorted by fuel use

Figure 7-19 shows that 68% of the passenger ships visiting the GMA spend 3% or less of the year in the GMA (i.e. <3% of a year is equivalent to less than 11 days annually). Capital intensive installations such as scrubbers are best suited for ships spending much time in strictly regulated areas.

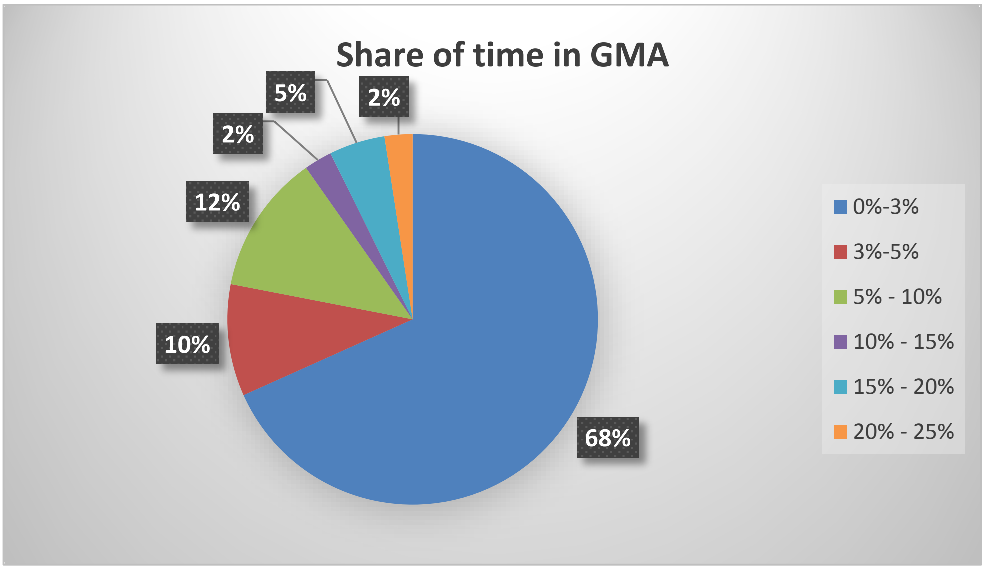

Figure 7-19 Yearly time distribution for passenger ships in the GMA

7.3.2 Oil tankers

The annual fuel consumption for individual oil tankers is shown in Figure 7-20. The median figure for annual fuel consumption is approximately 135 tonnes per year, meaning that the ship in the middle of the ranked list consumes about 135 tonnes/year in the GMA and represents a 'typical oil tanker'. It should also be noted that these ships use their boilers quite a lot, along with auxiliary engines in the GMA. The ships are here identified by random numbers.

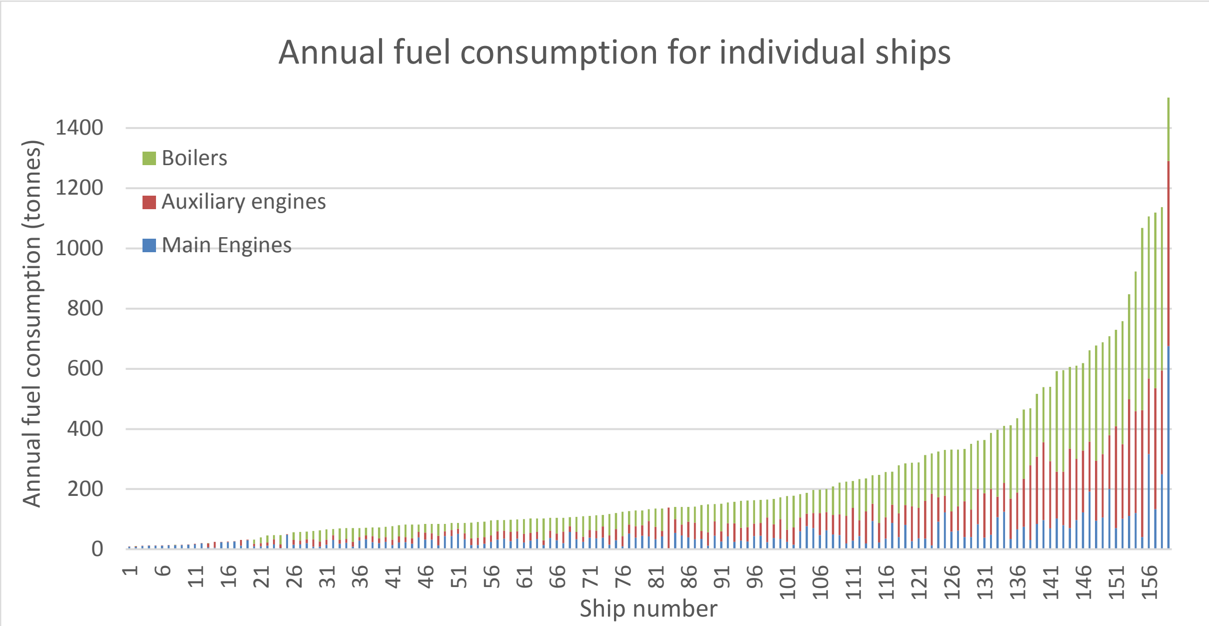

Figure 7-20 Annual fuel consumption for oil tankers in the GMA sorted by fuel use.

Figure 7-21 shows that 54% of the oil tankers visiting the GMA spend 3% or less of the year in the GMA, while 28% of the vessels spend between 3 and 10% of the year in the GMA. Large ships waiting at anchor and smaller ships in local trade typically contribute to the increased yearly presence in the GMA.

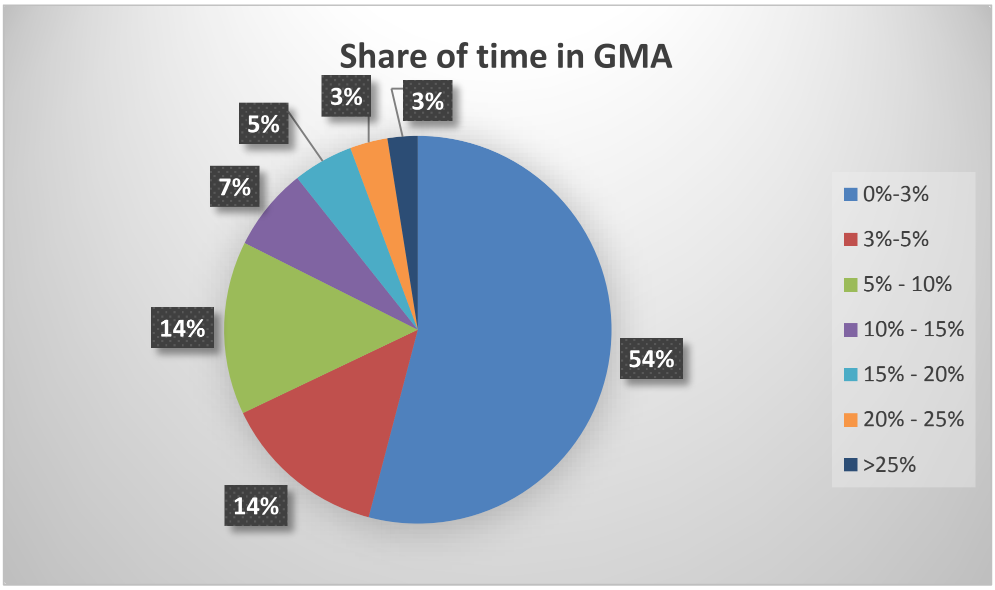

Figure 7-21 Yearly time distribution for oil tankers in the GMA

7.3.3 Chemical/product tankers and gas carriers

The median annual fuel consumption for individual product/chemical tankers and gas carriers is approximately 80 tonnes per year, as shown in Figure 7-22. The ships are identified by random numbers in the figure. Four ships (#138, 139, 140, 141) use significantly more fuel than the others, these are probably large ships that spend much of their time operating in the GMA. It is observed that these ships also use their boilers, but not as much as the oil tankers above.

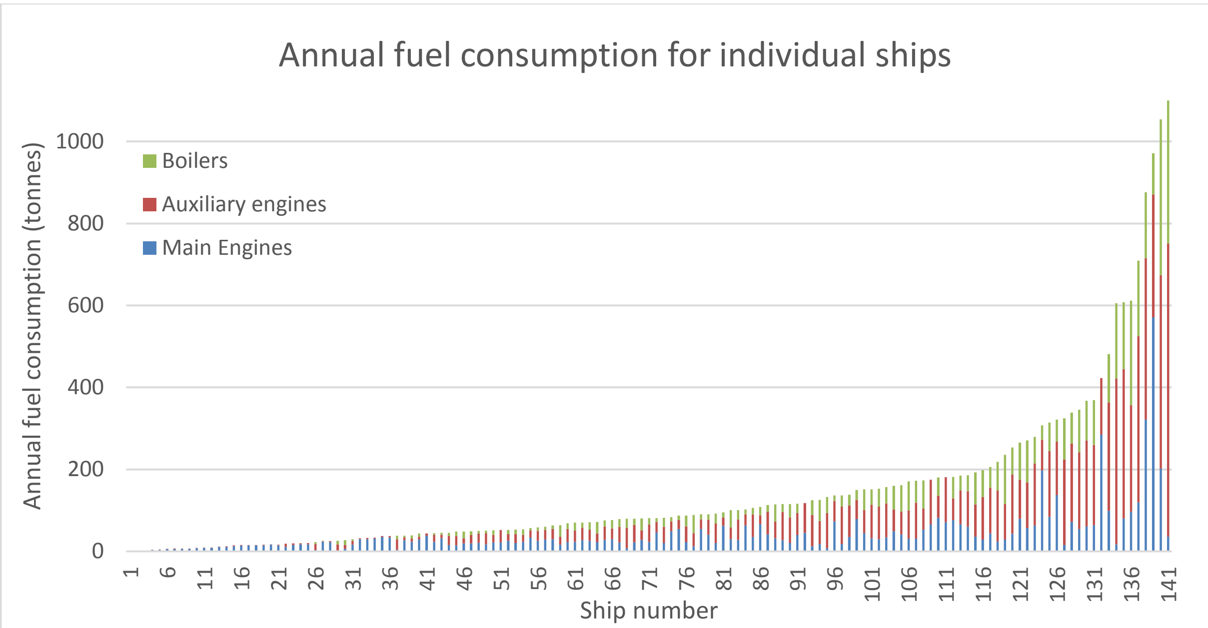

Figure 7-22 Annual fuel consumption for product/chemical/gas tankers in the GMA

Figure 7-23 shows that 52% of these ships visiting the GMA spend 3% or less of the year in the GMA, while 33% of the vessels spend between 3 and 10% of the year in the GMA. Large ships waiting at anchorage and smaller ships in local trade typically contribute to the high yearly presence in the GMA.

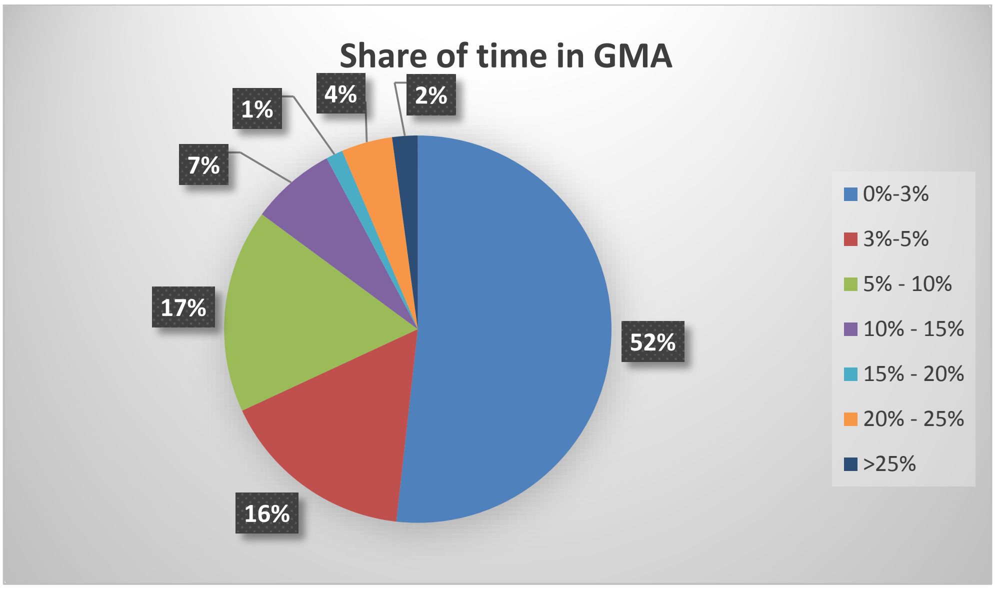

Figure 7-23 Yearly time distribution for product / chemical / gas tankers in the GMA

7.3.4 Bulk carriers

The median annual fuel consumption for individual bulk carriers is approximately 42 tonnes per year, as shown in Figure 7-24. It was observed that the total number of different bulk ships visiting the GMA during a year is very high, with 1 693 identified ships. There are some ships using significantly more fuel than the others in the GMA. The bulk carriers are identified by random numbers in the figure below.

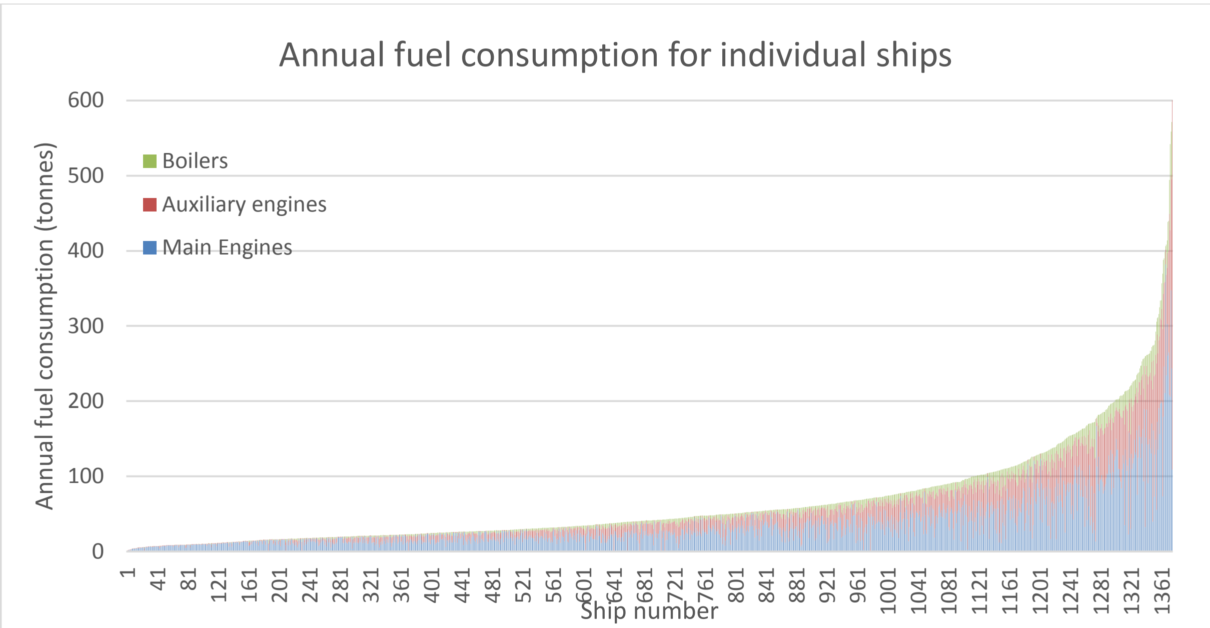

Figure 7-24 Annual fuel consumption for bulk carriers in the GMA

Figure 7-25 shows that 63% of the bulk carriers visiting the GMA spend 3% or less of the year in the GMA, while 30% of the vessels spend between 3 and 10% of the year in the GMA. Large ships waiting at anchor and smaller ships in local trade typically contribute to the increased yearly presence in the GMA.

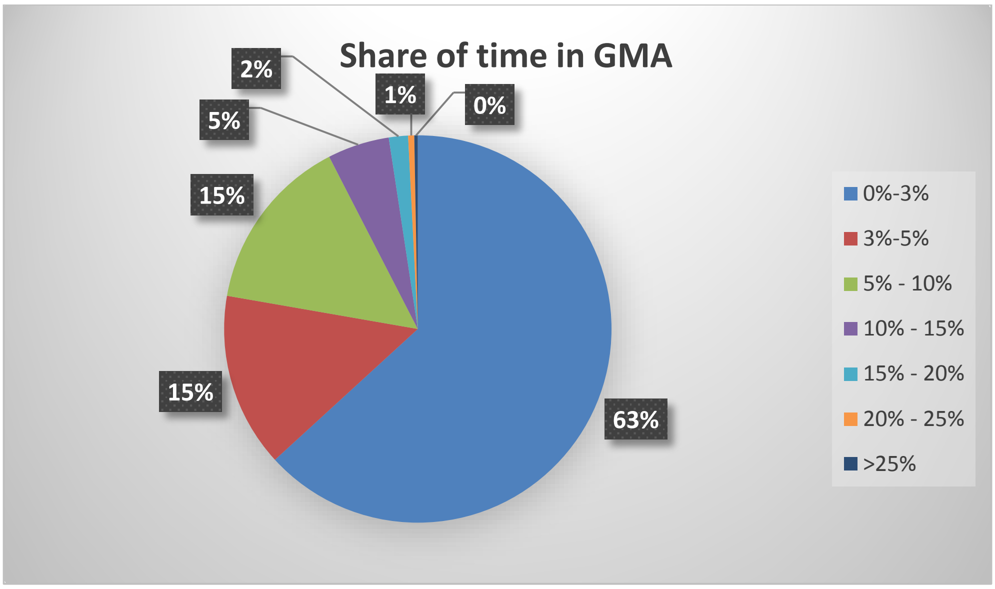

Figure 7-25 Yearly time distribution for bulkers in the GMA

7.3.5 General cargo, roro and refrigerated cargo

The median annual fuel consumption for the combination of cargo/ro-ro ships and reefers is approximately 62 tonnes per year, as shown in Figure 7-26. The fuel consumption originates mostly from main engines, followed by the auxiliary engines. The ships here are identified by random numbers.

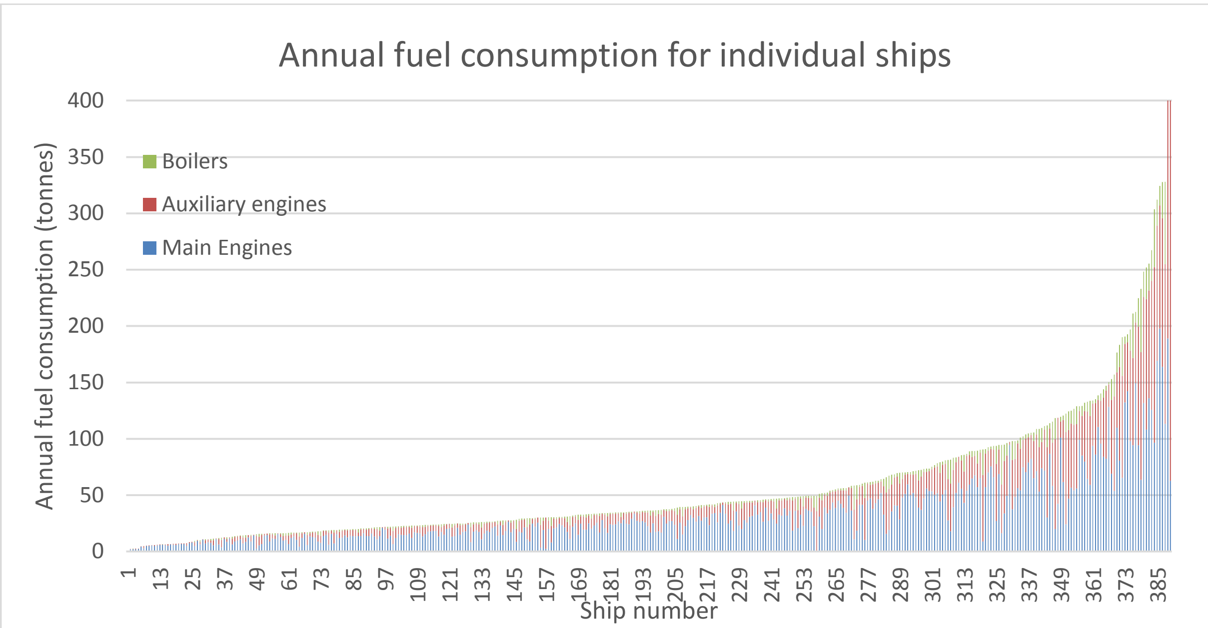

Figure 7-26 Annual fuel consumption for cargo/ro-ro ships and reefers in the GMA

Figure 7-27 shows that 80% of these cargo/ro-ro ships visiting the GMA spend 3% or less of the year in the GMA, so these ships have very efficient port stays. Only 17% of the vessels spend between 3 and 10% of the year in the GMA.

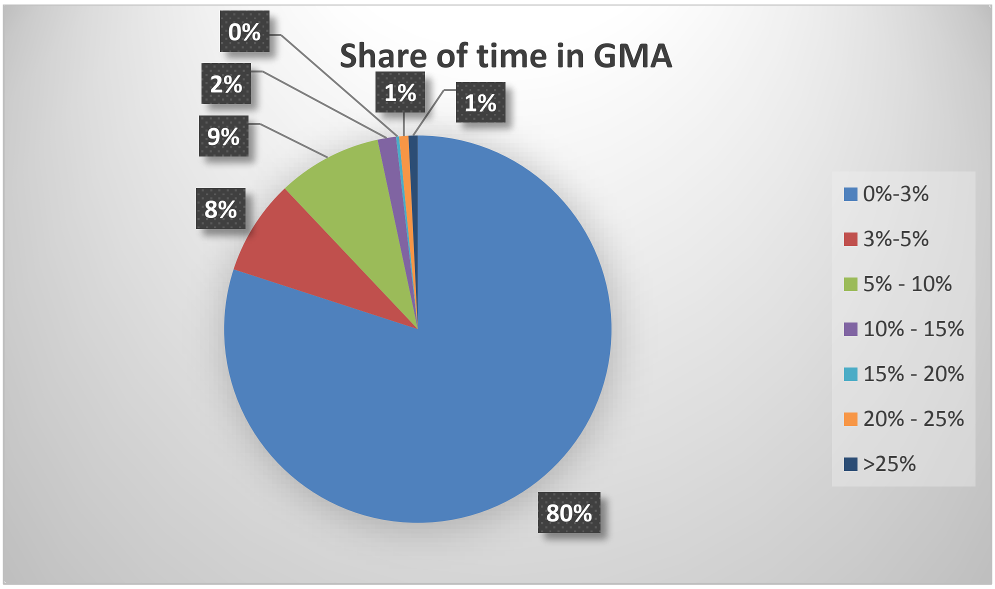

Figure 7-27 Yearly time distribution for cargo/ro-ro and reefers in the GMA

7.3.6 Container vessels

The median annual GMA fuel consumption for the container ships is quite high, approximately 162 tonnes per year, as shown in Figure 7-28. The fuel consumption originates mostly from main engines, followed by the auxiliary engines and boilers to some extent. Each ship is given a random number.

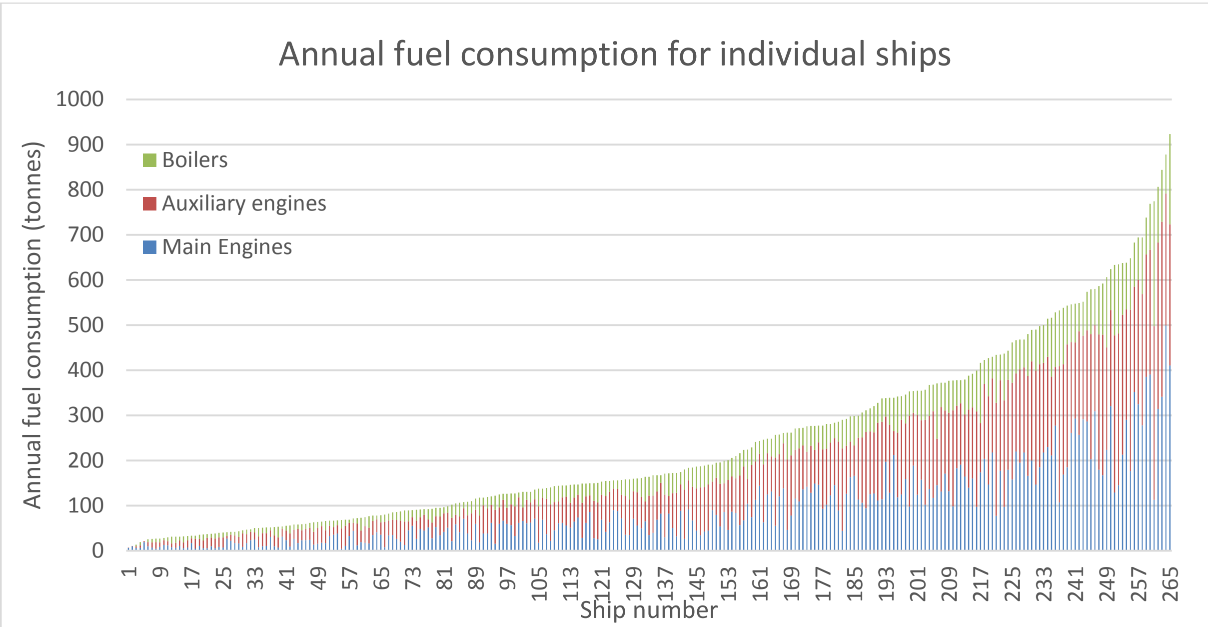

Figure 7-28 Annual fuel consumption for container ships in the GMA

Figure 7-29 shows that only 44% of the container ships visiting the GMA spend 3% or less of the year in the GMA. Many of these ships have relatively long port stays, nearly 50% of them spend between 3 and 10% of the year in the GMA.

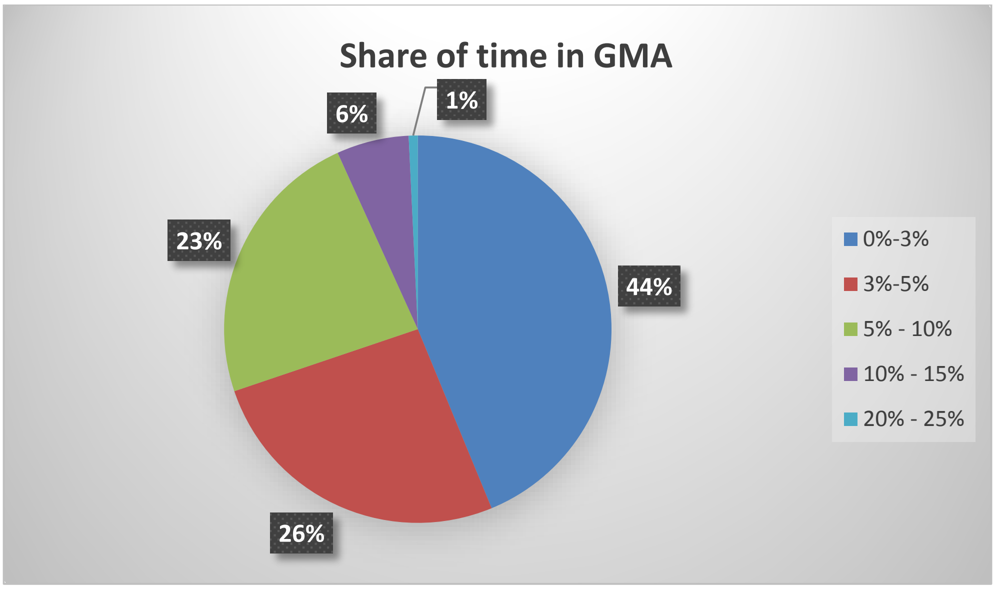

Figure 7-29 Yearly time distribution for container ships in the GMA

The financial case for implementing abatement measures on-board a selection of these ship types is presented in section 7.7.

7.4 Ship emissions, year 2013

For the year 2013, the emissions from passenger vessels in the GMA were approximately 870,000 tonnes of CO_2, 14,500 tonnes of NOx, 14,000 tonnes of SO_2 and 1,550 tonnes of particulate matter ($PM_{2.5}$). Bulk ships dominate ship emissions in the GMA (33% of all ship CO_2 emissions), followed by container vessels (23%).

For comparison, NSW EPA in 2012 reported total anthropogenic NOx, SOx and PM2.5 emissions in the GMA to be 309,000, 289,000 and 32,000 tonnes/year[64] during the 2008 calendar year. Estimated ship emissions calculated represent approximately 4.7%, 4.8% and 4.8% of the total anthropogenic NOx, SOx and PM2.5 emissions from ships in the GMA, respectively (2013 and 2008 numbers combined).

Section 6.1 presents the method of quantifying emissions and appurtenant emission factors for the various fuel consumers. Table 7-9 presents emission estimates by vessel type and emission source.

[64] 2008 Calendar Year Air Emissions Inventory for the Greater Metropolitan Region in NSW http://www.epa.nsw.gov.au/air/airinventory2008.htm

Table 7-9 Ship emissions in the GMA 2013, sum of all on-board engines and boilers

Ship type	Emissions (metric tonnes)			
	CO_2	NOx	SO_2	$PM_{2.5}$
Oil tankers	124198	1341	2047	202
Chemical/Prod tankers	55083	748	920	96
Gas tankers	11169	138	170	17
Bulk carriers	288436	5490	4883	553
General cargo vessels	40809	658	686	74
Container vessels	201002	3277	3406	370
RoRo vessels	32788	706	555	65
Reefers	86	1	1	0
Passenger vessels	92225	1787	1365	158
Offshore supply vessels	277	4	1	0
Other offshore service vessels	6390	60	40	6
Other activities	17184	233	88	10
Totals	**869,649**	**14,443**	**14,162**	**1,553**

Table 7-10, Table 7-11, Table 7-12 and Table 7-13 present the 2013 ship emissions for Port Jackson, Port Botany, Newcastle and Port Kembla respectively.

The total ship emissions in Port Jackson represent approximately 3.9%, 2.0%, 3.5% and 3.0% of the total emissions of CO_2, NOx, SOx and PM2.5 from all ships in the GMA, respectively. Even if these fractions are low, it is worth keeping in mind that Port Jackson is in the centre of Sydney with a corresponding elevated risk for human exposure.

Oil tankers are the dominant source of CO_2, SOx and PM2.5 emissions in Port Jackson, followed by passenger ships (i.e. cruise ships). Passenger ships actually emit more NOx than the oil tankers over the year. The main reason for this is that auxiliary engines used on passenger ships, serving utility systems and accommodation, have higher specific NOx emissions than oil tankers which traditionally use boilers for powering steam driven pumps when discharging oils.

Information received recently suggests that major cruise ship operators will phase in some of the newest and technologically most advanced ships from the 2016/17 season. These will more than likely have lower emissions per passenger than the current ships.

Table 7-10 Emissions for Port Jackson, sum of all on-board engines and boilers

Ship type	Emissions (metric tonnes)			
	CO_2	NOx	SO_2	$PM_{2.5}$
Oil tankers	15729	83	247	21
Chemical/Prod tankers	3240	33	55	5
Gas tankers				
Bulk carriers	957	10	16	2
General cargo vessels	852	9	14	1
Container vessels	130	1	2	0
RoRo vessels				
Reefers				
Passenger vessels	11129	124	160	16
Offshore supply vessels				
Other offshore service vessels	422	3	3	0
Other activities	1346	19	4	1
Totals	**33,804**	**283**	**502**	**47**

Blank = no vessel in this category

Container vessels and tankers, dominate the emissions in Port Botany. The total ship emissions in Port Botany represent approximately 10.3%, 5.3%, 10.5% and 9.0% of the total emissions of CO_2, NOx, SOx and PM2.5 from all ships in the GMA, respectively. The emissions in Port Botany are more than double of the Port Jackson emissions, while emissions in Port of Newcastle are approximately on par with Port Jackson.

Table 7-11 Emissions for Port Botany, sum of all on-board engines and boilers

Ship type	Emissions (metric tonnes)			
	CO_2	NOx	SO_2	$PM_{2.5}$
Oil tankers	31163	154	511	44
Chemical/Prod tankers	4450	43	76	7
Gas tankers	1187	12	19	2
Bulk carriers	1	0	0	0
General cargo vessels	234	3	4	0
Container vessels	51349	545	872	86
RoRo vessels				
Reefers				
Passenger vessels				
Offshore supply vessels				
Other offshore service vessels				
Other activities	868	12	3	0
Totals	**89,252**	**769**	**1,484**	**140**

Blank = no vessels of this category

The total ship emissions in Port of Newcastle represent approximately 4.5%, 2.8%, 4.3% and 3.9% of the total emissions of CO_2, NOx, SOx and PM2.5 from all ships in the GMA, respectively. Table 7-12 confirms that the traffic in Port of Newcastle is totally dominated by bulk carriers.

Table 7-12 Emissions for Newcastle, sum of all on-board engines and boilers

Ship type	Emissions (metric tonnes)			
	CO_2	NOx	SO_2	$PM_{2.5}$
Oil tankers	7170	37	121	11
Chemical/Prod tankers	825	9	11	1
Gas tankers	658	5	11	1
Bulk carriers	21286	247	362	36
General cargo vessels	4849	53	81	8
Container vessels	477	4	8	1
RoRo vessels	165	2	3	0
Reefers	1	0	0	0
Passenger vessels	132	1	2	0
Offshore supply vessels	11	0	0	0
Other offshore service vessels				
Other activities	3145	44	13	2
Totals	**38,719**	**402**	**612**	**60**

Blank = no vessels of this category

The emissions in Port Kembla are relatively modest and bulk carriers dominate the traffic. The total ship emissions in Port Kembla represent approximately 2.0%, 1.3%, 2.0% and 1.8% of the total emissions of CO_2, NOx, SOx and PM2.5 from all ships in the GMA, respectively.

Table 7-13 Emissions for Port Kembla, sum of all on-board engines and boilers

Ship type	Emissions (metric tonnes)			
	CO_2	NOx	SO_2	$PM_{2.5}$
Oil tankers	1378	6	23	2
Chemical/Prod tankers	270	3	4	0
Gas tankers	4	0	0	0
Bulk carriers	8217	94	140	14
General cargo vessels	2974	33	51	5
Container vessels	113	1	2	0
RoRo vessels	3461	48	59	6
Reefers				
Passenger vessels				
Offshore supply vessels				
Other offshore service vessels				
Other activities	584	8	2	0
Totals	**17,002**	**192**	**280**	**28**

Blank = no vessels of this category

7.5 Forecasting growth in marine traffic

The objective of this chapter is to assess the likely growth in NSW marine traffic. The main source for this assessment is a report published by Bureau of Infrastructure, Transport and Regional Economics (BITRE) in 2010 (2). Other industry specific sources, where considered reliable, were also included in final calculations.

BITRE (2010) presents forecasts of Australian exports and imports of containerised and non-containerised freight. In addition to coastal freight movements, temporary arrivals and departures of passengers by sea, and vessel movements are forecasted. The general approach uses per capita real GDP or real final demand as predictors in demand equations for per capita import and export volumes, coastal freight volumes, and inbound and outbound seaborne passengers.

BITRE (2010) presents forecasts for Australia as a whole, and separately for Australia's five mainland capital city ports. Figures specific to NSW as a region are not presented. For the purposes of this report, the general Australian numbers and the specific Sydney figures to predict growth rates for NSW are combined.

First an overview of the current NSW port structure and associated trade volumes is presented, then a discussion of the forecast presented by BITRE (2010) for Australia and Sydney in relation to growth in NSW.

7.5.1 Cargo throughput in NSW Ports

There are six ports in NSW included in the cargo statistics of Ports Australia (formerly The Association of Australian Port & Marine Authorities Inc. - AAPMA). Table 7-14 presents the cargo throughput for NSW.

Table 7-14 - NSW ports Total Throughput (mass tonnes) for 2012/2013

	Imports	Exports	Total
Eden (Sydney Ports)	0	244,241	244,241
Newcastle Port Corporation	3,233,535	145,628,032	148,861,567
Port Botany (NSW Ports)	14,159,414	7,423,442	21,582,856
Port Kembla (NSW Ports)	5,414,621	18,520,447	23,935,068
Sydney Harbour (Sydney Ports)	3,915,537	158,896	4,074,433
Yamba (Sydney Ports)	23	3,587	3,610
New South Wales total	**26,723,130**	**171,978,645**	**198,701,775**

Source: Ports Australia[65]

As is evident from Table 7-14, Newcastle is by far the largest port in NSW, measured in cargo volume. Newcastle is Australia's second largest bulk port, and the dominant bulk port in NSW handling 83% of NSW bulk cargo[66].

[65] See http://www.portsaustralia.com.au/aus-ports-industry/trade-statistics/?id=1&period=13

Port Botany and Port Kembla are almost tied for the rank of NSW's second largest port. Port Botany is Australia's second largest container port, and the dominant container port in NSW handling 150 times more containers than NSW's second largest port[67].

Port Kembla, is Australia's largest vehicle import facility, and serves as a key export facility for grain, coal and other bulk products[68]. Sydney Harbour, with Eden and Yamba ports included, make up the remainder of cargo throughput from NSW.

7.5.2 Growth in NSW

It is not entirely clear which ports in the Sydney region are allocated to "Sydney" in the report by BITRE (2010). The numbers for container imports seem to indicate that Port Botany is included in BITRE's "Sydney"[69].

The numbers for bulk export seem to indicate that Port Kembla is *not* included in BITRE's "Sydney". Thus, for container trade, BITRE's "Sydney" growth numbers are taken to be representative for NSW. For bulk shipping, BITRE's "Sydney" is *not* representative for NSW. In this case one has to resort to BITRE's compounded numbers for Australia for an estimate of NSW growth.

7.5.3 Overall growth for Australia

Figure 7-30 shows that Australian containerized exports are expected to increase fourfold by 2030. Australian containerised exports in 2007–08 totalled 1.50 million TEU (twenty foot equivalent unit containers). This is forecast to increase to 6.32 million TEU by 2029–30. Containerised imports are expected to double by 2030. Australian containerised imports in 2007–08 totalled 2.46 million TEU. This is forecast to increase to 5.17 million TEU by 2029–30. Total container throughput (which includes empty containers not captured by the export/import volumes[70] in the preceding sentences) in 2007–08 totalled 6.28 million TEU, while by 2029-30, 15.45 million TEU are expected (i.e. a 2.5 times growth).

Non-containerized exports are expected to double by 2030. Australian non-containerised exports in 2007–08 totalled 685 million tonnes. This is forecast to increase to 1.35 billion tonnes by 2029–30. Non-containerized imports are expected to increase by 50% in the same period. Australian non-containerised imports in 2007–08 totalled 61.5 million tonnes. This is forecast to increase to 89.7 million tonnes by 2029–30.

There is a minor between-ports transport in addition to the above figures. But since this volume is insignificant compared to the main port throughput data, we have omitted this traffic from further analysis and discussion. The assumptions for future growth herein rest on the assumption that Australia's economy will develop positively and no major unexpected negative events will occur. The recent drop in oil price, giving financial relief to some but additional burdens to other players, caught most industries by surprise. However, many analysts now believe the oil price will move towards $70-80

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66 See http://www.portsaustralia.com.au/aus-ports-industry/trade-statistics/?id=3&period=13

67 See http://www.portsaustralia.com.au/aus-ports-industry/trade-statistics/?id=5&period=13).

68 See http://www.nswportskembla.com.au/assets/Trade-Reports/FINAL-NSW-Ports-Trade-Report-2012-2013-Low-Res.pdf

69 See http://www.portsaustralia.com.au/aus-ports-industry/trade-statistics/?id=5&period=13

70 /2/, pp. 8-10

USD/barrel in the near term[71]. Other important factors for Australia are the export industries for coal, iron ore and LNG. All these commodity prices are currently depressed, but there is an underlying assumption that these market will grow, predominantly depending on China.

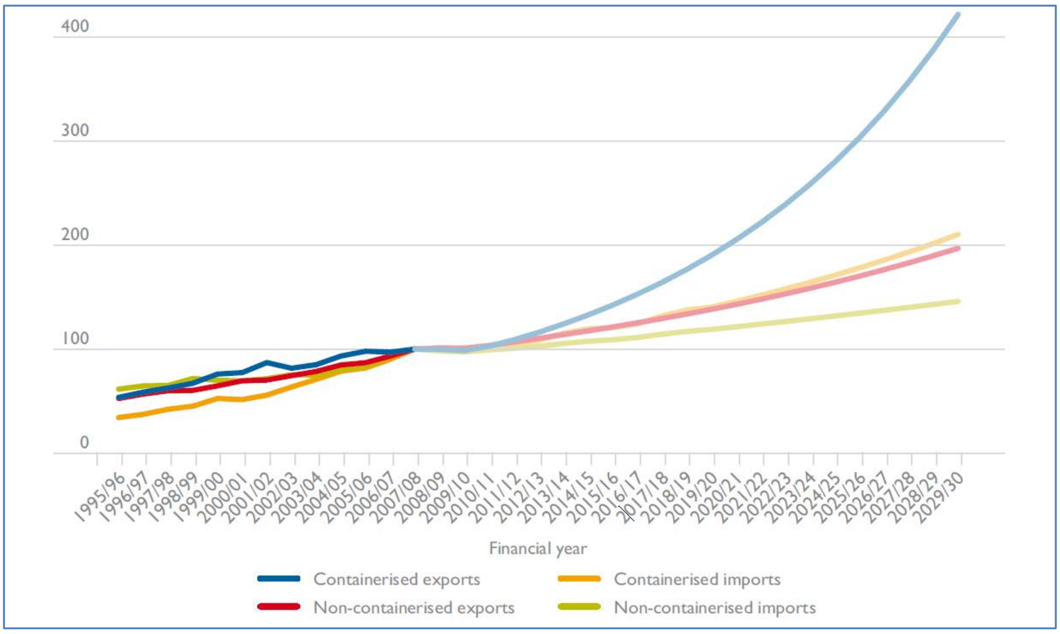


Figure 7-30: Historical and forecasted seaborne exports and imports for Australia, normalized to 2008 levels (2)

Figure 7-31 shows how the number of port calls is expected to change as a result of the changes in trade volumes towards 2030. Bulk carriers are expected to increase their port calls by approximately 50%, while container ships are expected to double the number of port calls. The expected growth in port freight volumes exceeds the growth of number of port calls; this is a clear indication of the expectation of larger ships serving Australian ports.

[71] There are many sources speculating on the price of fuel in the near term that it will remain low for 2015/16. One such view is held by Bill Conerly in Forbes (see http://www.forbes.com/sites/billconerly/2014/12/18/oil-price-forecast-2015-2016/) in which he suggests that a price of $60 USD per barrel could persist for two years.

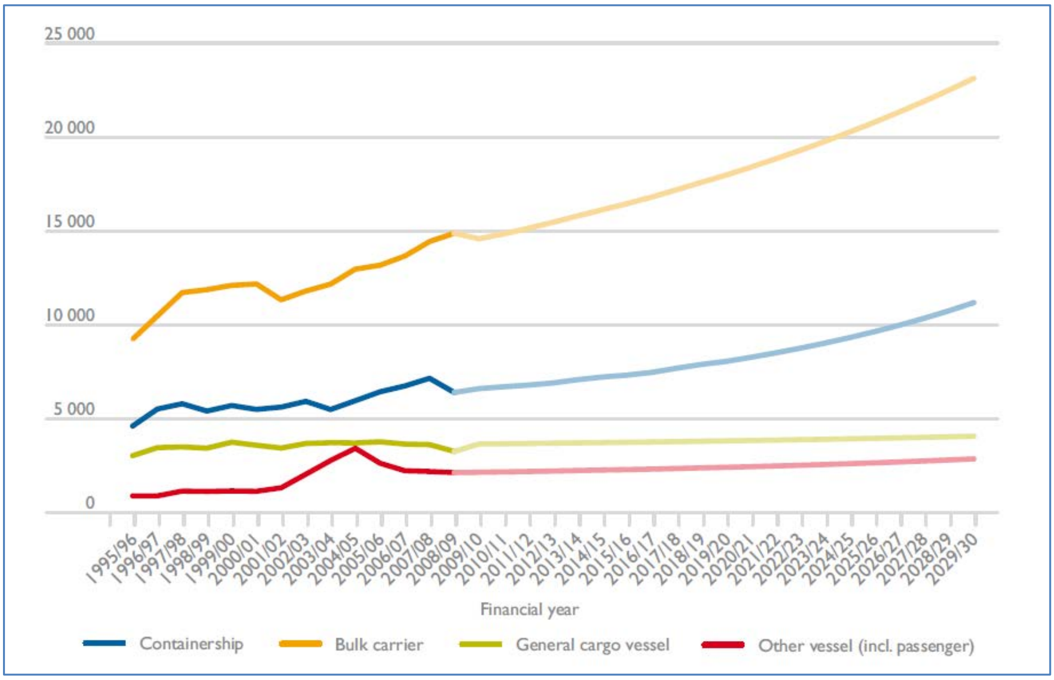


Figure 7-31: Historical and forecasted number of calls to Australian ports, per main ship category (2)

7.5.4 Sydney growth

Table 7-15- Growth in NSW containerised and non-containerised volumes

Goods type	2014–15:	2030:	Growth	Comment
Containerised exports	466 513 TEU	1 516 556 TEU	More than three-fold increase.	
Containerised imports	950 005 TEU	1 722 683 TEU	80% increase.	
Container throughput	1 963 078 TEU	3 579 432 TEU	80% increase.	Indicates that import volume define the ports' ship traffic.
Non-containerised exports	652 061 000 Tonnes	694 768 000 Tonnes	Stable volumes.	
Non-containerised imports	10 123 613 000 Tonnes	13 273 248 000 Tonnes	30% increase	Imports are much larger than exports, and thus are a factor for ship traffic.

Table 7-16- Growth in NSW marine traffic towards 2030, container and bulk ship traffic

Ship type	NSW growth (2014-2030)	Source	Comment
Container	80 %	BITRE's "Sydney" – containerized	-
Bulk	100 %	BITRE's "Australia" – non containerized	-

The numbers above show a significant growth in containerised volumes, and a doubling of the bulk traffic in NSW although the current bulk ship market is down. We also see optimism for the cruise ship industry.

From industry consultation it is understood that approximately 270 cruise ship visits are expected to visit Sydney Harbour in 2015. Ships passing under Sydney Harbour Bridge (48.5 m air draft) will probably berth at White Bay Terminal. Further, it is understood that about 2/3 of the port calls will be directed to White Bay, and the remaining ships that will not fit under the bridge will typically berth at the Overseas Passenger Terminal.

It is also understood that most new cruise ships[72] are too large to pass the Harbour Bridge, and in about 10 years from now the majority of cruise ships may have to berth elsewhere than at the OPT. However, the international cruise fleet is also composed of a growing number of smaller 'boutique style' vessels as well as large numbers of mid-sized slightly aging vessels, so it is foreseen that the White Bay Terminal will still be active in the future. The largest new cruise ships are being adapted to ECA operations with increased holding capacities for low sulphur distillates or scrubbers. During the northern hemisphere winter season many of these vessels visit NSW, potentially outfitted to pollute less than older ships.

As ship sizes grow, the relative share of ships going to OPT will increase. Sources in the cruise ship industry[73] indicate that the current 270 annual port calls will grow to about 500 calls in 2025, i.e. an 85% growth in port calls. Since the new ships are larger than the current fleet, the growth of fuel consumption (and passengers) in Port Jackson may increase even more. We understand[74] that new future cruise ports at Garden Island or Port Botany are being flagged for further investigation.

7.6 Emissions forecasting

7.6.1 Introduction

Future CO_2 emissions from shipping have been reported in a limited number of studies. These studies have investigated the issue from different vantage points, and also cover fleet growth and technology advancements. Much of the work available is characterized by "what-if scenarios" rather than presenting probable scenarios, so this is not enough to form a totally clear picture. Some direction is given by The Second IMO GHG study (4) and DNVGL's Shipping 2020 (28). Another good reference includes Eyring *et al.* where emissions are estimated from the world fleet towards 2050 using four different ship traffic demand scenarios in combination with four technology scenarios (29). In a report from the EU project Quantify, Eide *et al.* report on projections of emissions from shipping in the years 2025, 2050 and 2100 based on the IPCC scenarios (30). Buhaug *et al.* also report emissions for the world fleet in 2020 and 2050 using the IPCC scenarios and including improvements of ship energy efficiency towards 2050 (4).

Figure 7-32 presents normalized historic and projected future CO_2 , SOx and NOx emissions from international shipping in the case where no new regulations are implemented ("business as usual") and where shipping adopts and adheres to the coming IMO MARPOL emission regulations. The data in the figure are compiled by DNV GL based on the Second IMO GHG Study (4), Bazari & Longva (31), and MARPOL (1). Much of the work behind this chart was for the Second IMO GHG study in 2009.

72 Stakeholder comment received

73 Stakeholder comment received

74 Stakeholder comment received

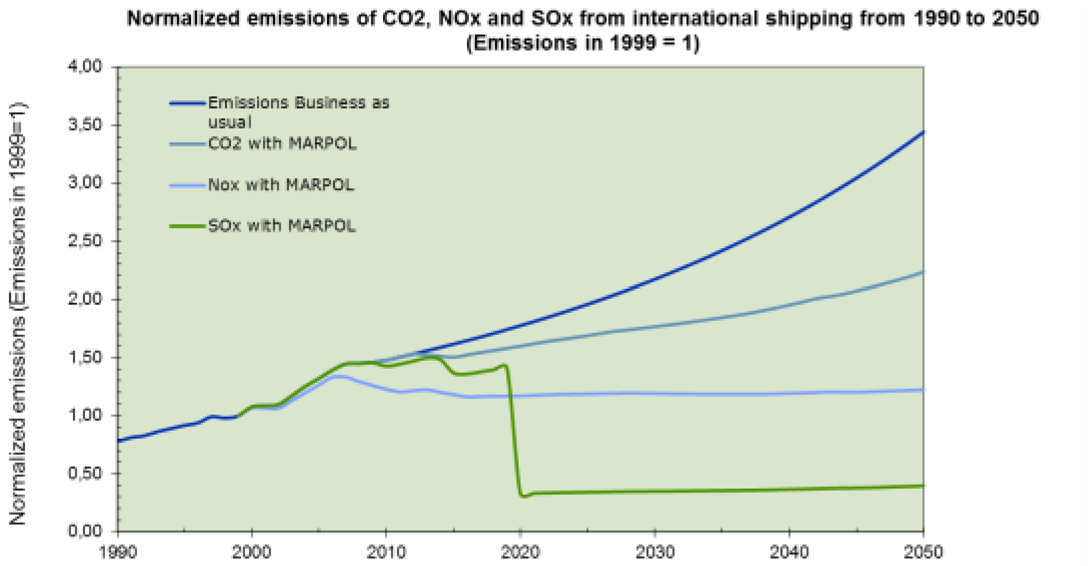


Figure 7-32 Normalized historic and projected future CO_2, SOx and NOX emissions from global shipping industry

Ship emissions in the GMA stem from a large number of ships and most of the emissions originate from large vessels burning residual fuels. A major part of the emissions originate from ships that are stationary, running only auxiliary engines and boilers while at berth or waiting at anchorage. While some parts of the fleets are on fixed routes e.g. shuttling iron ore from Newcastle to China, many are in the spot market or have occasional trips to the GMA.

Most ships have international owners and fly foreign flags. In such a situation IMO (MARPOL) is the predominant regulator on the environmental side, and the next new MARPOL emission reducing measure affecting GMA emissions is the global 0.5% sulphur limit of fuel which enters into force between 2020 and 2025. Some visiting new-builds prepared for NOx-ECA operations (currently in North America), will also be outfitted with Tier III NOx reducing technologies. New-builds are also increasingly fuel-efficient, and hence have lower relative CO_2 emissions, due to the gradually stringent EEDI requirements. It is not likely that the dominant share of ships in the GMA will go beyond the requirements of the MARPOL regulations, unless there are strict local regulations coupled to attractive financial support schemes. This is in line with what we see in comparable waters with international shipping.

Since the number of ships in the GMA is so large, much of the emissions are at berth or at anchorage and many of the ships are not immediately ideal candidates for using LNG as fuel. DNV GL believes that switching to low sulphur distillates or using HFO together with a scrubber will be the typical solutions for meeting the upcoming SOx and PM requirements for the ship types dominating the GMA traffic. We realize that this solution will not significantly reduce NOx and CO_2, but without targeted measures, preferably followed by a subsidizing regime, ship owners' main emission attention will only remain on the global 2020-2025 sulphur cap.

Shore-side power systems can also reduce all the emission components discussed here. But since this development will take several years with both land-side and on-board investments, we do not foresee that shore power will spread rapidly unless a massive financial support programme is launched. A challenge here is also that there are many vessels trading in 'tramp'[75] trade, with limited motivation for

[75] A vessel on a tramp trade operates without fixed schedule/itinerary

investing in shore-side power connection systems which they rarely may use. Important to also keep in mind that ships that are prepared with shore-side power connections also need additional investments and preparations if operating in ECA regulated waters. From a ship owners' point of view, low sulphur distillates, scrubbers or LNG fuel are often preferred over shore-side power due to cost-efficiency.

Under a Business As Usual (BAU) scenario whereby no additional local regulations are required, implementation by ship owners of the various abatement measures is likely to follow the lead from abroad driven by the IMO and upcoming global sulphur regulations. Table 7-17 on the following page, summarises the uptake of abatement measures in preparation for a lowering of the global sulphur limit to 0.5% by 2020-2025. This summary is derived from DNV GL experience worldwide and stakeholder information gathered in the course of this project.

Table 7-17 – Abatement forecasting under the BAU scenario (no local regulations)

Option	Estimated realistic uptake by ships in AUS by 2017	Estimated realistic uptake by ships in AUS by 2020	Comments
Various technical and operational measures primarily to curb emission reduction <u>while sailing</u>	We expect that most ship operators have a continuous focus on fuel efficiency and are implementing measures to reduce fuel consumption and consequently also the CO_2 emissions by 5-10%.	Most ship operators who pay own fuel have implemented measures to reduce fuel consumption; where instead charterer pays fuel he may have implemented fuel saving clauses in charter contract. EEDI requirements will significantly reduce fuel consumption for new ships.	A possible global MRV regime and/or specific abatement measures for Australia, NSW or GMA will accelerate implementation of fuel reducing measures.
Various technical and operational measures primarily to curb emission reduction <u>while at berth</u>	We expect that few operators will implement any port specific measures to curb emissions unless enforced by law or fiscal stimuli (shore power etc).	Some technology uptake may be registered in ships originating in EU or the US. Uptake is fully dependent on regulations/stimuli.	New initiatives from local or national authorities are required to boost implement^{n} of 'green ship' initiatives in the GMA.
LNG as fuel	We do not expect ships trading in NSW to be LNG fuelled during the next few years.	By 2020 we expect that a few ships trading in the GMA waters will be LNG fuelled, probably smaller vessels as demo projects.	IMO's global limit of 0.5% sulphur in marine fuel, coming between 2020 and 2025, will likely boost LNG as fuel.
Switch to 0.5% Low Sulphur Distillates	Albeit low sulphur distillates are readily available in NSW, it is not expected that the international fleet will use this fuel unless required.	By 2020 or 2025 IMO's global limit of 0.5% sulphur in fuel will apply, and low sulphur fuel will be the dominant solution, at least in the early years.	IMO's global limit of 0.5% sulphur in marine fuel, coming between 2020 and 2025, will drive up the demand for low sulphur fuels. Suppliers say the required volumes are already avail.
Scrubbers	We do not expect ships trading in NSW will use scrubbers by 2017 except for those installing these due to trading also in ECAs.	By 2020 or 2025 IMO's global limit of 0.5% sulphur in fuel will apply, and HFO+scrubber will be an attractive solution.	IMO's global limit of 0.5% sulphur in marine fuel, coming between 2020 and 2025, will drive up the demand for scrubbers. Any new NSW regulations may boost scrubber installation rates.
Shore-side power	Not considered a widely used solution by 2017.	Limited uptake by 2020 due to roll-out of alternative abatement measures which work also while sailing.	More likely an option for Sydney-based vessels only.
SCR	All these are NOx reducing measures, and as long as no NOx specific emission regulation regime is planned in NSW we do not expect these measures to be implemented.		
EGR			
Direct water injection			
HAM / Humid Air Motor			
Engine Modification			

7.6.2 Approach for predicting future emissions

Since emissions in the GMA predominantly originate from a large variety of ships in international trade, it is taken for granted that most of these will follow the upcoming MARPOL requirements. The forecasted emission profile for global shipping presented in IMO's Second GHG study reproduced in Figure 7-32 (4) can also represent year-to-year changes of ship emissions in the GMA. Figure 7-32 accounts for the net increase in number of ships of each category, improved fuel efficiency through EEDI and other fuel saving initiatives, emission reduction measures as a result of stricter demands, as well as expectations for the marine transportation market. In Figure 7-32 one can see that the CO_2 emissions, if no abatement measures are in play, will increase by approximately 50% from 2015 to 2035. This corresponds to a 50% increase in fuel consumption and activity.

In section 7.5 it was found that the activity of container and bulk ships in NSW will increase by 80% and 100% respectively up to 2035, and that this is also representative for GMA. Since the number of ships in the GMA is large and many are in spot trade there spears to be no feasible way for a bottom-up analysis where it is possible to assume a specific emission-reducing technology uptake rate for each ship segment by a given year. Instead, there is a case for the 2009 IMO GHG study emission development rates can be applied directly on the reported 2013 GMA emission data for forecasting purposes. Although the growth rate for fuel might be lower in the IMO study than the expected activity growth for container and bulk ships, the estimated effects of the current sudden market slow-down in container and bulk shipping compensates for these potential differences, at least to a reasonable extent. This is based on assuming that the ship traffic to industrial terminals in the various ports and the entire GMA will remain relatively stable. Including, for instance, that ship activity associated with the Gore Bay Terminal will remain as is.

In this report is assumed that PM2.5 emissions will follow the SOx emission curve, with 80% and 96% reduction for the 0.5% and 0.1% sulphur limit cases respectively, under the assumption that the new sulphur requirements will be met by the use of scrubbers or low sulphur distillates. Since the focus on ship PM emissions have been far lower than for on other exhaust gas constituents, the knowledge and reduction rates for PM for different ship engines, operational conditions and fuels are limited. To reflect this uncertainty the lines for PM in the following charts are given by dotted lines. Additionally, the PM reduction will be less if low sulphur 'hybrid fuels' get widely used (presumably approx. 20% reduction).

It is worth noticing the steep reduction in SOx emissions around 2020 in the IMO GHG study; this may be delayed until 2025 although the magnitude of the reduction is likely to remain the same. A reduced growth rate of future CO_2 emissions caused by EEDI, in-phasing of larger ships and other fuel saving measures can also be seen; a reduced growth of NOx emissions primarily due to the North American NOx-ECA is also noted. This reduced NOx generation rate will probably not be fully mirrored in the GMA fleet but as a basis for estimations this should be sufficient. Table 7-18 shows forecasted emissions.

Table 7-18: Current and forecasted emissions in GMA and selected ports, BAU scenario

All ship emissions, BAU *(metric tonnes)*	GMA				Port Jackson				Port Botany				Newcastle				Port Kembla			
	CO_2	NOx	SO_2	$PM_{2.5}$	CO_2	NOx	SO_2	$PM_{2.5}$	CO_2	NOx	SO_2	$PM_{2.5}$	CO_2	NOx	SO_2	$PM_{2.5}$	CO_2	NOx	SO_2	$PM_{2.5}$
2013	869 649	14 443	14 162	1 553	33 804	283	502	47	89 252	769	1 484	140	38 719	402	612	60	17 002	192	280	28
2015	826 167	13 721	12 038	1 320	32 114	269	427	40	84 789	731	1 261	119	36 783	382	520	51	16 152	182	238	24
2017	869 649	12 999	12 746	1 398	33 804	255	452	42	89 252	692	1 336	126	38 719	362	551	54	17 002	173	252	25
2019	913 131	12 277	13 454	1 475	35 494	241	477	45	93 715	654	1 410	133	40 655	342	581	57	17 852	163	266	27
2020	930 524	12 421	2 691	295	36 170	243	95	8,9	95 500	661	282	27	41 429	346	116	11	18 192	165	53	5,3
2025	1 000 096	12 999	3 399	373	38 875	255	120	11	102 640	692	356	34	44 527	362	147	14	19 552	173	67	6,7
2030	1 043 579	13 721	4 107	450	40 565	269	146	14	107 102	731	430	41	46 463	382	177	17	20 402	182	81	8,1
2040	1 174 026	13 721	4 815	528	45 635	269	171	16	120 490	731	505	48	52 271	382	208	20	22 953	182	95	10

With the use of low sulphur distillates or scrubbers from 2020 onwards, SOx emissions from all ship traffic in the GMA will under the BAU scenario go from the current 14 160 tonnes/year to about 2,700 tonnes by 2020 and then up to 4800 tonnes/year by 2040. PM2.5 will go from 1550 tonnes/year to about 300 tonnes/year then to 530 tonnes/year by 2013, 2020 and 2040 respectively.

7.6.3 Predicting future emissions from passenger ships, BAU case

The figures below show how the prediction of emissions from passenger ships in the GMA, Port Jackson and Newcastle (the only two ports with recorded passenger traffic in 2013), as well at merchant shipping in the GMA and all ports studied develop towards 2040 in a Business-as-usual (BAU) case based on the upcoming IMO MARPOL 0.5% sulphur limit for fuel followed up by an active inspection and control regime. As mentioned above, it can be foreseen that the development follows the shape of the IMO curves. Figure 7-33 for the GMA illustrates that the CO_2 emissions will climb towards 124,000 annual tonnes by 2040 for passenger ships, SOx emissions drop to 464 tonnes, while the NOx emissions remain relatively steady towards 2040. PM2.5 will presumably drop approx. 80% with 0.5% sulphur distillates.

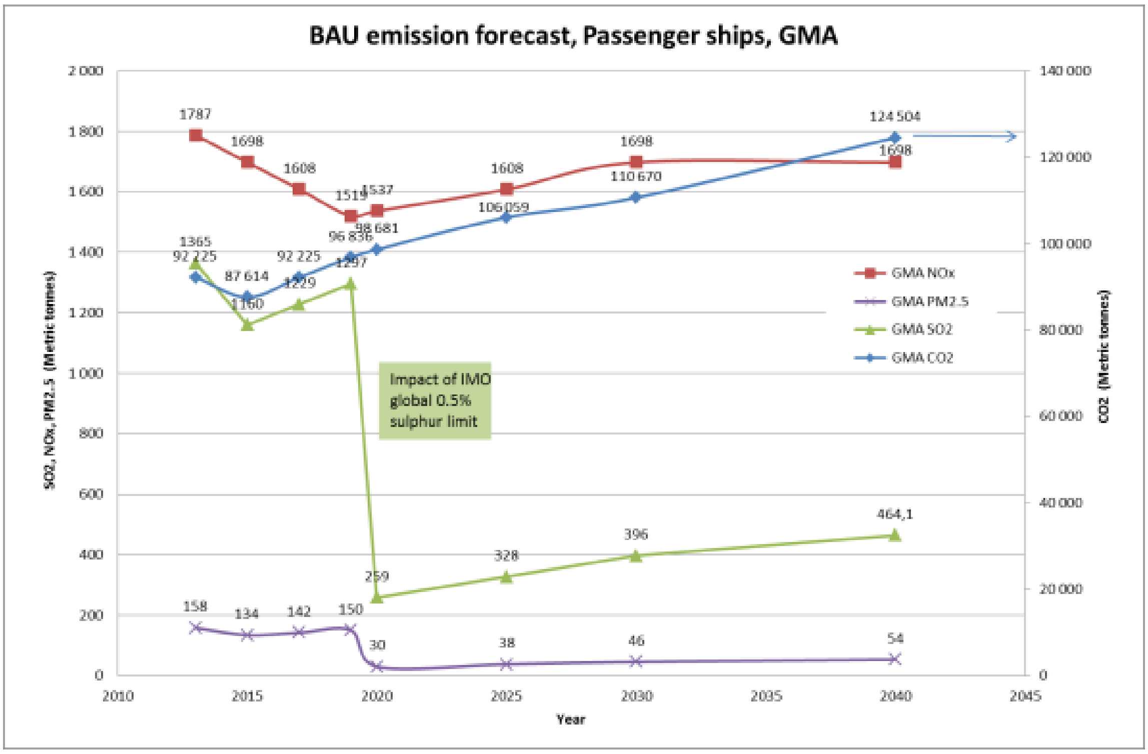


Figure 7-33: GMA emission forecast, Passenger ships, no special NSW initiatives

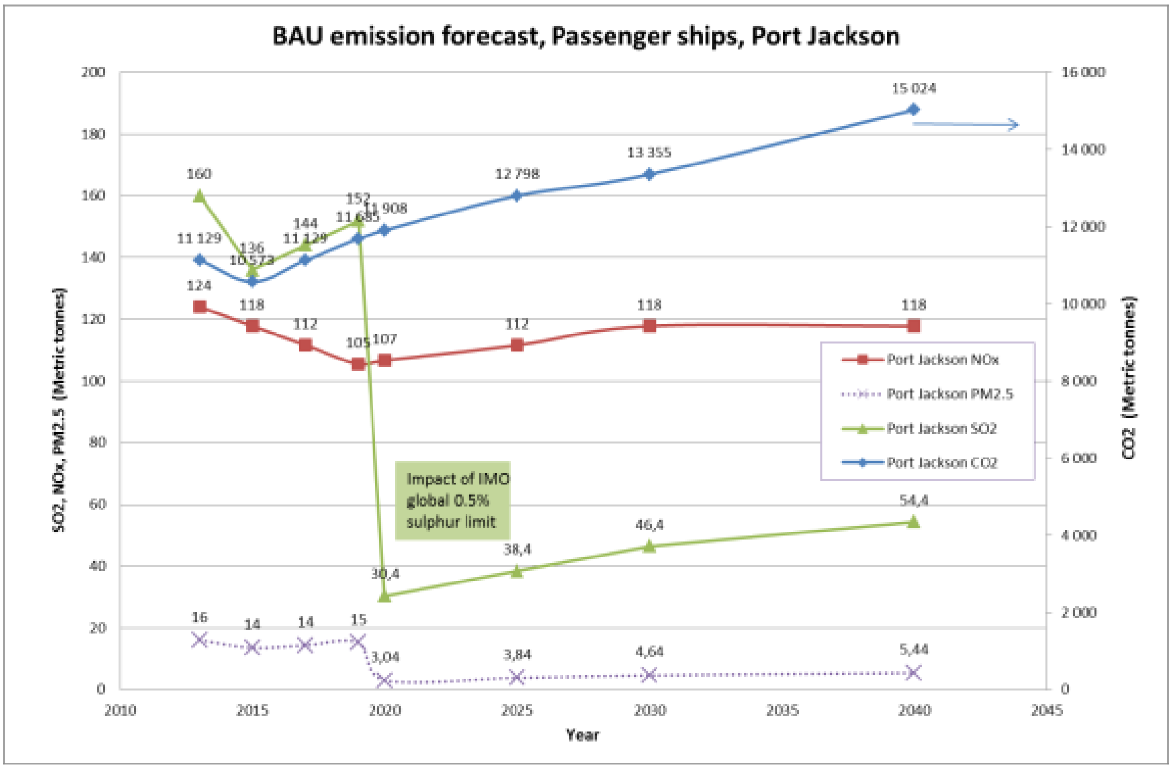


Figure 7-34: Port Jackson emission forecast, Passenger ships, no special NSW initiatives

Figure 7-34 for Port Jackson illustrates that the CO_2 emissions will exceed 15,000 annual tonnes by 2040 for passenger ships, SOx emissions drop to around 54 tonnes, while the NOx emissions remain relatively unchanged towards 2040. PM2.5 is also expected to drop.

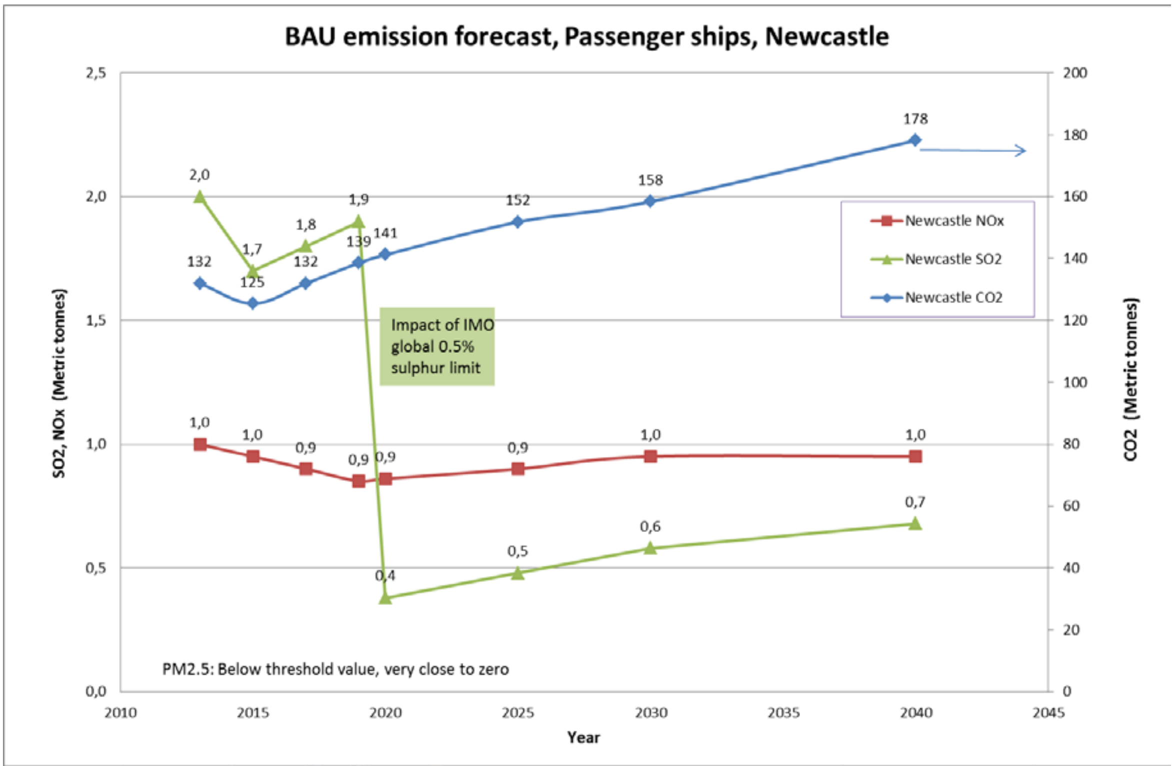


Figure 7-35: Port of Newcastle emission forecast, Passenger ships, no special NSW initiatives

Figure 7-35 shows low emissions for passenger ships in Port of Newcastle due to very limited activity.

7.6.4 Predicting future emissions from merchant ships and 'other', BAU

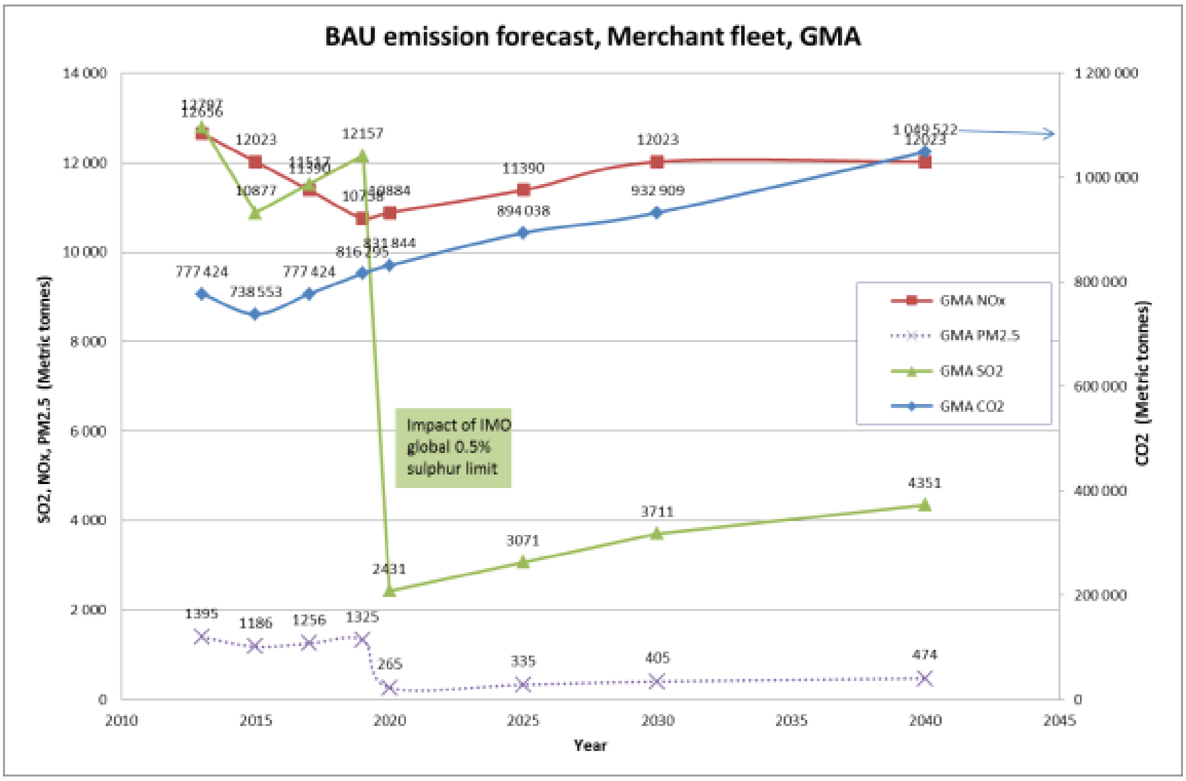


Figure 7-36: GMA emission forecast, Merchant ships, no special NSW initiatives

Figure 7-36 illustrates projections for all non-passenger ship emissions in the GMA. These emissions are approximately 10 times higher than the emission levels from passenger ships. For merchant ships in the GMA the CO_2 emissions will pass a million tonnes per year by 2040, while the SOx emissions drop from about 12,700 tonnes to about 2,400 tonnes by implementing the IMO 0.5% sulphur limit, thereafter SOx will rise to 4,350 tonnes by 2040. The NOx emissions remain relatively steady, while PM2.5 will drop from current levels. We base all these forecasts on implementation of low sulphur distillates or scrubbers.

When summing up ship emissions in the four studied ports and compare this sum to the GMA emissions, it appears that emissions of CO2 and SOx in ports only account for about 20% of the overall GMA ship emissions. Emissions of PM2.5 and NOx from ships in ports account for about 18% and 10% of NOx from ships in the GMA, respectively. The remaining 80-90% of GMA emissions is probably dominated by fuel use during offshore anchorage and by ships in transit through the GMA.

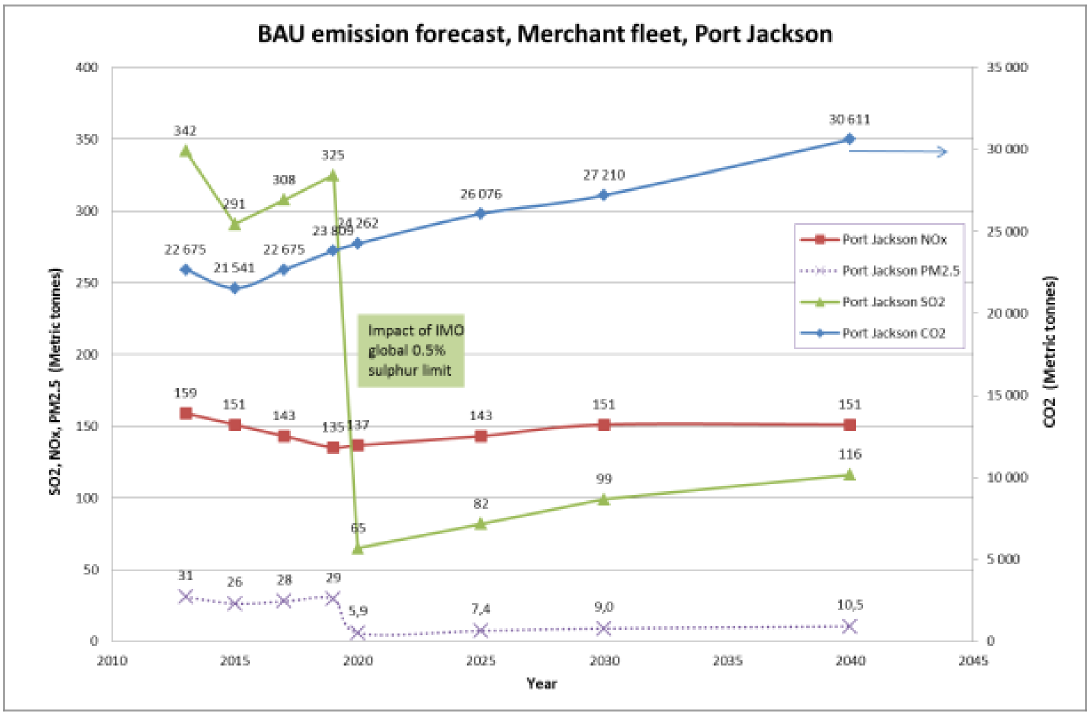


Figure 7-37: Port Jackson emission forecast, Merchant ships, no special NSW initiatives

Figure 7-37 illustrates projections for merchant fleet emissions in Port Jackson. Here, the CO_2 emissions will pass 30,000 tonnes per year by 2040, while the SOx emissions drop from about 340 tonnes to about 65 tonnes with the implementation of the 0.5% sulphur limit in 2020, thereafter rise to 116 tonnes by 2040. The NOx emissions remain relatively steady, while PM2.5 will drop from current levels.

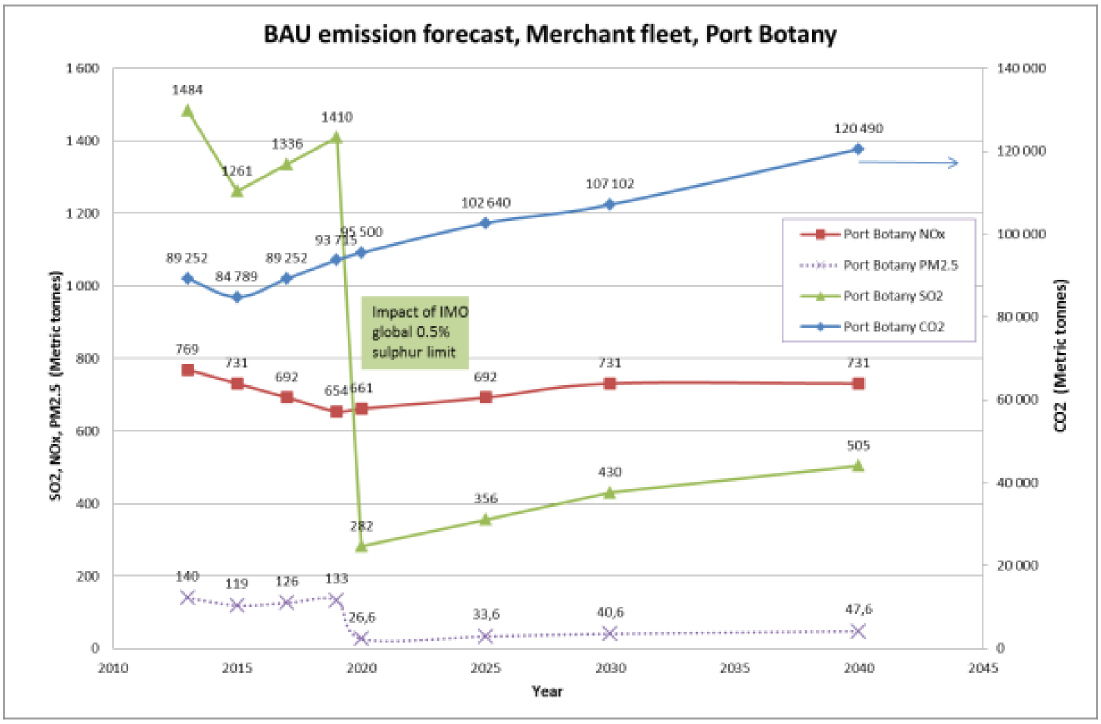


Figure 7-38: Port Botany emission forecast, Merchant ships, no special NSW initiatives

Figure 7-38 illustrates projections for merchant fleet emissions in Port Botany. Here, the CO_2 emissions will pass 120,000 tonnes per year by 2040, while the SOx emissions drop from about 1,480 tonnes to about 280 tonnes with the 0.5% sulphur cap in 2020, thereafter rise to roughly 500 tonnes by 2040. NOx emissions remain relatively steady, while PM2.5 will drop from current levels.

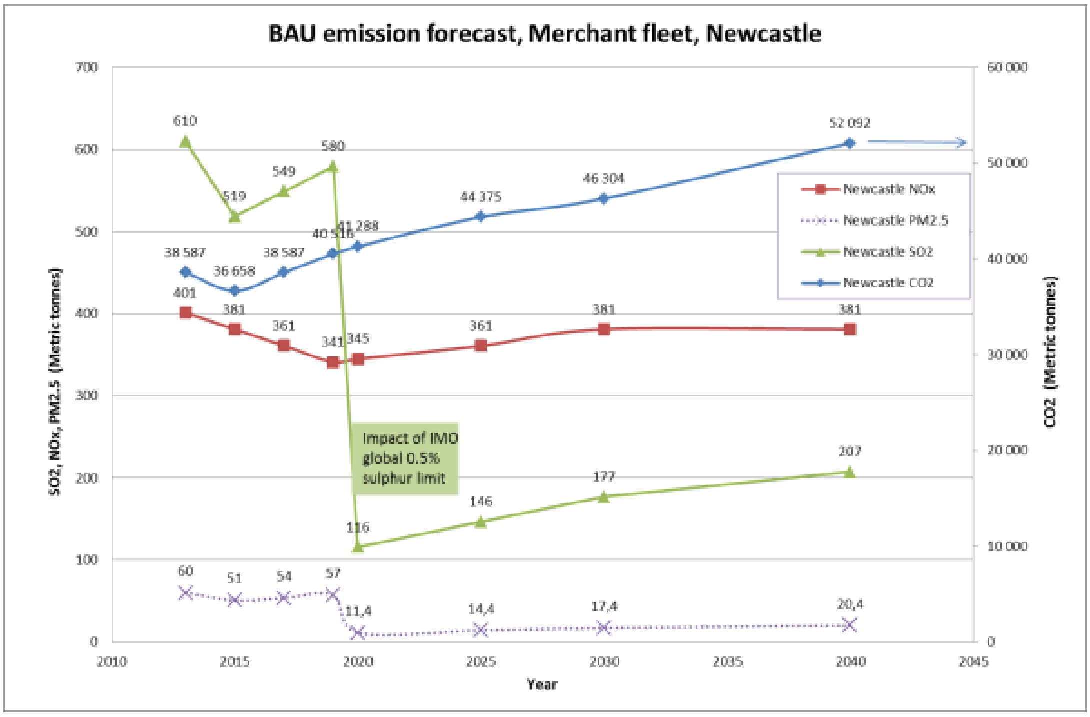


Figure 7-39: Port of Newcastle emission forecast, Merchant ships, no special NSW initiatives

Figure 7-39 illustrates projections for merchant fleet emissions in Port of Newcastle. Here, the CO_2 emissions will pass 52,000 tonnes per year by 2040, while the SOx emissions drop from about 600 tonnes to below 120 tonnes with the 0.5% sulphur cap in 2020, thereafter rise to above 200 tonnes by 2040. NOx emissions remain relatively steady, while PM2.5 will drop from current levels.

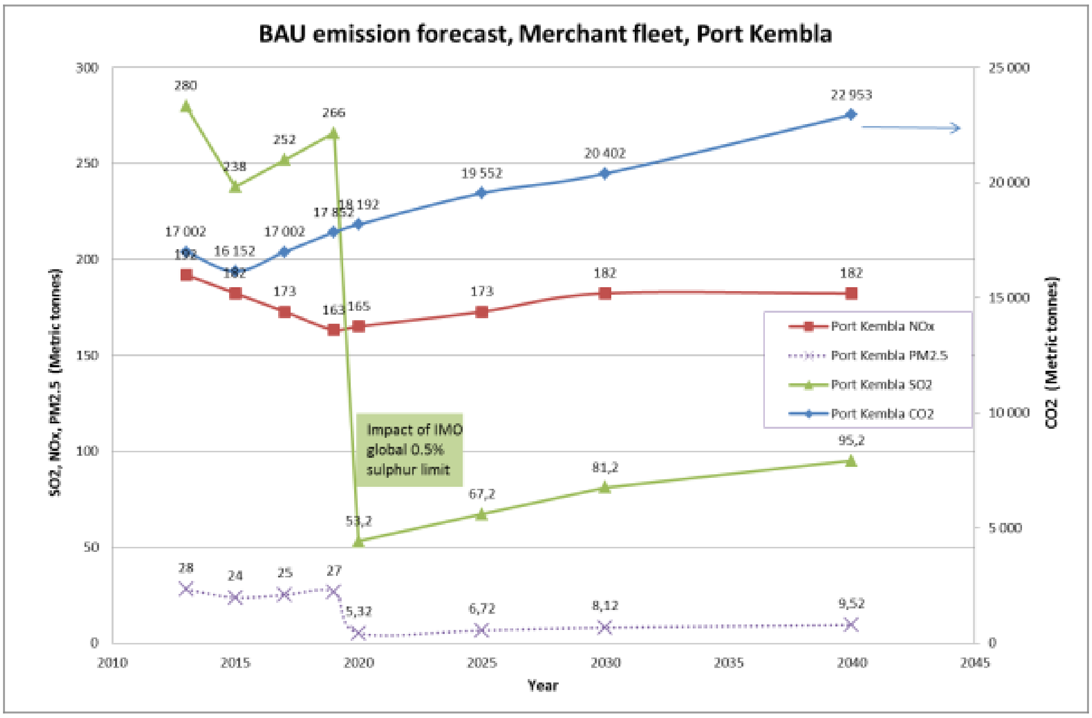


Figure 7-40: Port Kembla emission forecast, Merchant ships, no special NSW initiatives

Figure 7-40 illustrates projections for merchant fleet emissions in Port Kembla. Here, the CO_2 emissions will reach nearly 23,000 tonnes per year by 2040, while the SOx emissions drop from about 280 tonnes to below 55 tonnes with the 0.5% sulphur cap in 2020, thereafter rise to above 95 tonnes by 2040. NOx emissions remain relatively steady, while PM2.5 will drop from current levels.

7.6.5 Predicting further emissions reductions with special NSW initiatives

Figures 7-33 through 7-40 present the BAU scenario, based on strict compliance with the 2020 (2025) IMO global 0.5% limit of sulphur in fuel. Strict compliance is based on proper rule enforcement from the regional port state authorities.

Nevertheless, NSW can go beyond the MARPOL regulations but the options are limited due to the international profile of the typical ships operating in GMA waters. Since 80-90% of the GMA ship emissions occur outside inner port areas, measures should also provide benefits outside the quay areas.

Scenario 1: 2016 implementation of 0.5% low sulphur regulations in a) GMA b) only Port Jackson

If implementation of the 0.5% limit on sulphur in fuel (or equivalent treatment of exhaust gas by scrubber, by using LNG fuel or shore side power) occurs by 2016 as suggested by NSW politicians, the SOx and PM reductions shown in the BAU scenario will be 5-10 years advanced in time compared with MARPOL regulations. Other components (CO_2 and NOx) remain unchanged. Change over to low sulphur fuel or installing scrubbers is among measures ship owners already have on their agenda in order to prepare for the global sulphur cap and/or the current ECA zones.

Table 7-19 shows SO2 and PM2.5 emissions with a potential local 0.5% sulphur regulation, provided that main abatement measures are low sulphur distillates or scrubbers. For reference, the BAU case is shown in Table 7-18.

Table 7-19: Emission forecasts if implementation of local 0.5% low sulphur regulations

	Passenger vessels				Merch fleet & all other			
Unit: metric tonnes	0.5% S limit, GMA		0.5% S limit, Port Jackson		0.5% S limit, GMA		0.5% S limit, Port Jackson	
	SO_2	$PM_{2.5}$	SO2	PM2.5	SO2	PM2.5	SO2	PM2.5
2013	1365	158	160	16	12797	1395	342	31
2015	1160	134	136	14	10877	1186	291	26
2017	259	30	30,4	3,0	2431	265,1	65,0	5,9
2019	259	30	30,4	3,0	2431	265,1	65,0	5,9
2021	259	30	30,4	3,0	2431	265,1	65,0	5,9
2025	328	38	38,4	3,8	3071	334,8	82,1	7,4
2030	396	46	46,4	4,6	3711	404,6	99,2	9,0
2040	464	54	54,4	5,4	4351	474	116,3	10,5

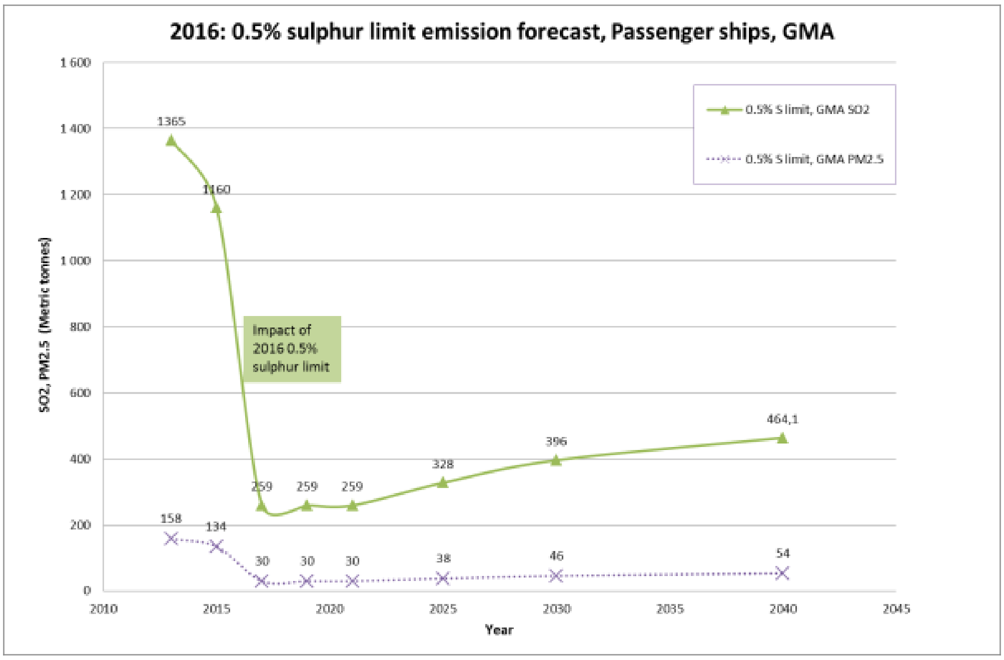


Figure 7-41: Predicted passenger ship emissions in the GMA if 2016 0.5% S limit

2016 implementation of a 0.5% limit for sulphur in fuel for passenger ships in the GMA will provide significant emission reductions prior to IMO's global sulphur limit being implemented. Early implementation will, for instance in 2017, achieve reductions of approximately 970 tonnes/year of SO2 and 110 tonnes/year of PM2.5. Such significant emission savings can occur for many years if IMO's global 0.5% limit is delayed.

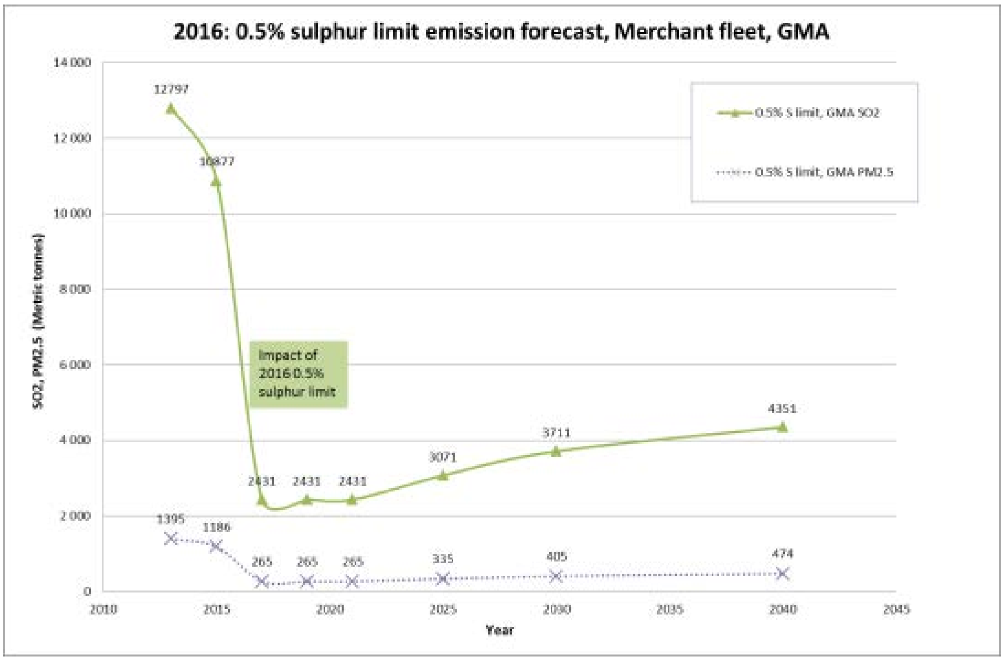


Figure 7-42: Predicted merchant ship emissions in the GMA if 2016 0.5% S limit

2016 implementation of a 0.5% limit for sulphur in fuel for merchant ships in the GMA will provide significant emission reductions prior to IMO's global sulphur limit being implemented. Early implementation will, for instance in 2017, achieve reductions of more than 9,000 tonnes/year of SO2 and about 1,000 tonnes/year of PM2.5.

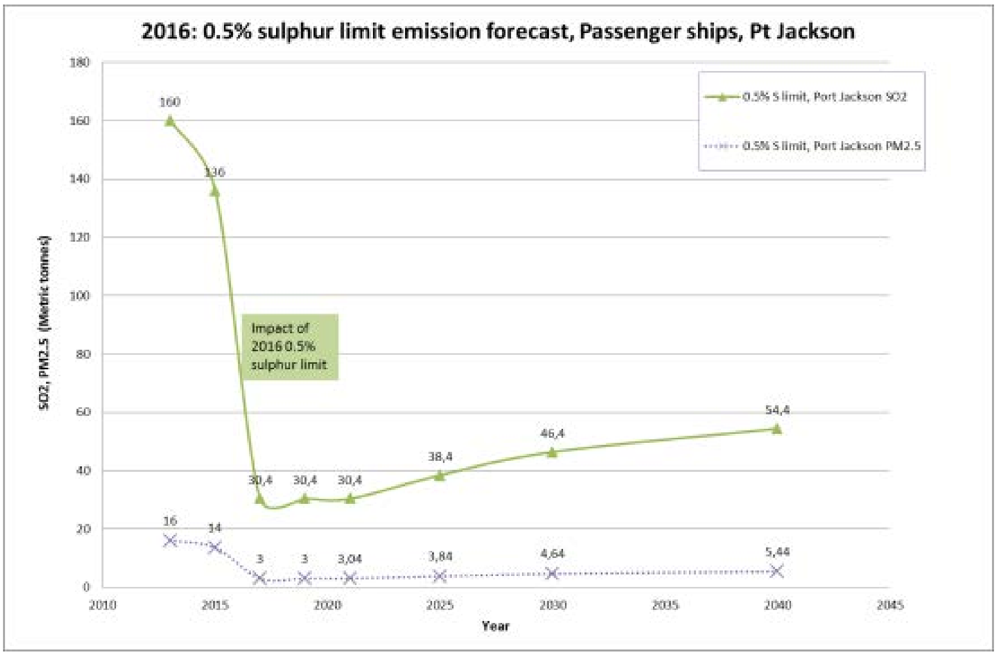


Figure 7-43: Predicted passenger ship emissions in Port Jackson if 2016 0.5% S limit

2016 implementation of a 0.5% limit for sulphur in fuel for passenger ships in Port Jackson will provide emission reductions prior to IMO's global sulphur limit being implemented. Early implementation will, for instance in 2017, achieve reductions of approximately 110 tonnes/year of SO2 and 11 tonnes/year of PM2.5.

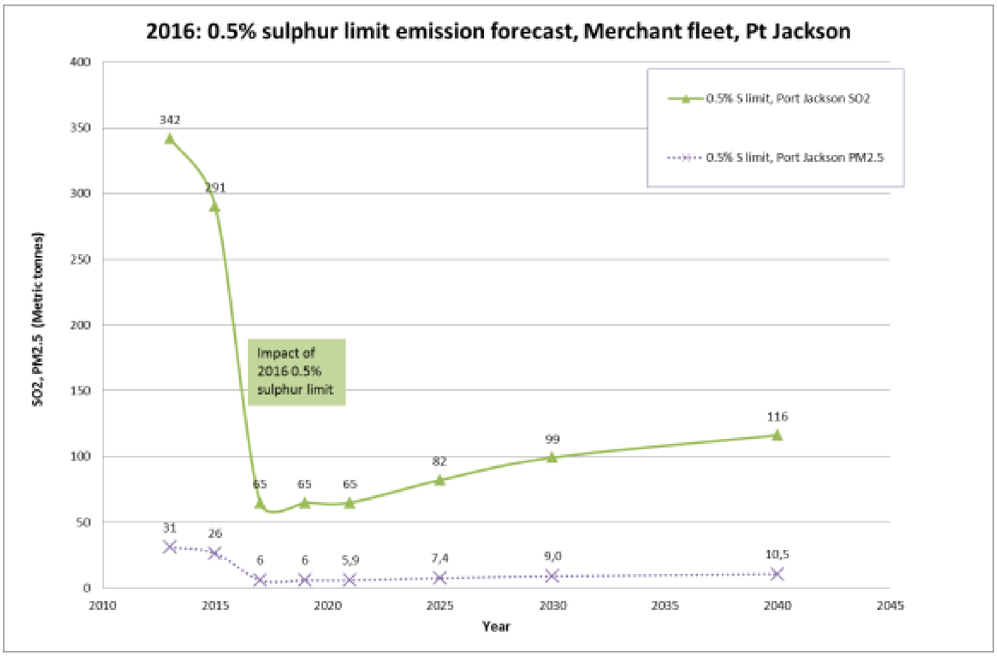


Figure 7-44: Predicted merchant ship emissions in Port Jackson if 2016 0.5% S limit

2016 implementation of a 0.5% limit for sulphur in fuel for merchant ships in Port Jackson will provide emission reductions prior to IMO's global sulphur limit being implemented. Early implementation will, for instance in 2017, achieve reductions of approximately 240 tonnes/year of SO2 and 22 tonnes/year of PM2.5. We have not gone into depth about the possible legal constraints or effects on freight rates for Australian shipping of such a proposal, but consider such a scenario is possible.

Scenario 2: Implementation of 0.1% low sulphur regime (ECA equivalent) in the GMA and/or in Port Jackson

If the upcoming low-sulphur limit is set to 0.1% instead of 0.5%, the SOx emission level in the GMA will go from 14,160 to a minimum of around 500 tonnes per year instead of a low-point of around 2,600 tonnes per year under a 0.5% sulphur limit regime. 0.1% LSF may be slightly more expensive than 0.5% LSF, and to operate a scrubber to clean the exhaust from HFO down to the equivalent of 0.1% LSF will require more effort than the equivalent of 0.5% LSF. But the difference between these two low sulphur regimes will not be dramatic. Both regimes will be costly and require time for implementation.

Table 7-20: Emission forecasts if implementation of local 0.1% low sulphur regulations

	Passenger vessels				Merch fleet & all other			
	0.1% S limit, GMA		0.1% S limit, Port Jackson		0.1% S limit, GMA		0.1% S limit, Port Jackson	
Unit: metric tonnes	SO_2	$PM_{2.5}$	SO2	PM2.5	SO2	PM2.5	SO2	PM2.5
2013	1365	158	160	16	12797	1395	342	31
2015	1160	134	136	14	10877	1186	291	26
2017	52	6,0	6,1	0,6	486	53	13	1,2
2019	52	6,0	6,1	0,6	486	53	13	1,2
2021	52	6,0	6,1	0,6	486	53	13	1,2
2025	66	7,6	7,7	0,8	614	67	16	1,5
2030	79	9,2	9,3	0,9	742	81	20	1,8
2040	93	11	11	1,1	870	95	23	2,1

The following table summarizes annual reductions of SOx and PM2.5 emissions for year 2017 for the case with local implementation of low-sulphur regimes in 2016, well before IMO's global sulphur cap.

Table 7-21: Relative emission reductions if implementing low sulphur regime in 2016 instead of waiting for the global regulations. All values refer to 2017 emissions in BAU scenario.

Emission type Tonnes/year	Annual emission reduction in 2017 (metric tonnes/year)			
	GMA, passenger traffic	GMA, merchant shipping	Pt Jackson, passenger traffic	Pt Jackson, merchant shipping
SO2 reduction, 0.5% regime	970	9086	114	243
PM2.5 reduction, 0.5% regime	112	990	11.3	22
SO2 reduction, 0.1% regime	1177	11031	138	295
PM2.5 reduction, 0.1% regime	136	1202	14	27

Table 7-21 shows that the significant emission reductions can be achieved with low sulphur fuels or comparable SOx abatement technologies. However, for establishing such a regime the industry must have time enough to react and set aside funds for investments.

The timing effect of advancing the low-sulphur initiatives from 2020 (2025) to 2016 is significant, provided all ships comply with the regulation and do not reduce the services in the GMA. With an early implementation of a low-sulphur fuel regime in the GMA anchored on local regulations the emission reductions add up over several years until IMO's global sulphur cap is initiated. 0.5% and 0.1% sulphur limit fuels constitute an 80% and 96% reduction in SO2 emissions, respectively compared with the typical current fuel with 2.7% sulphur.

The following four figures show the forecast for SO2 and PM2.5 for a potential 0.1% limit for sulphur in fuel from July 2016.

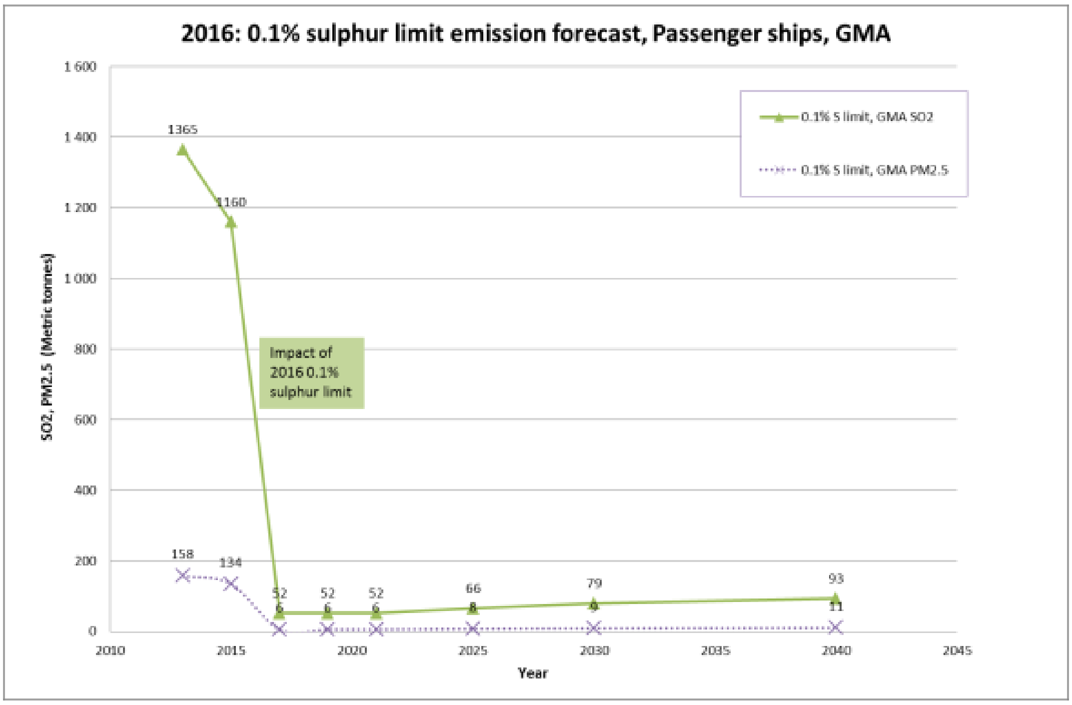


Figure 7-45: Predicted passenger ship emissions in the GMA if 2016 0.1% S limit

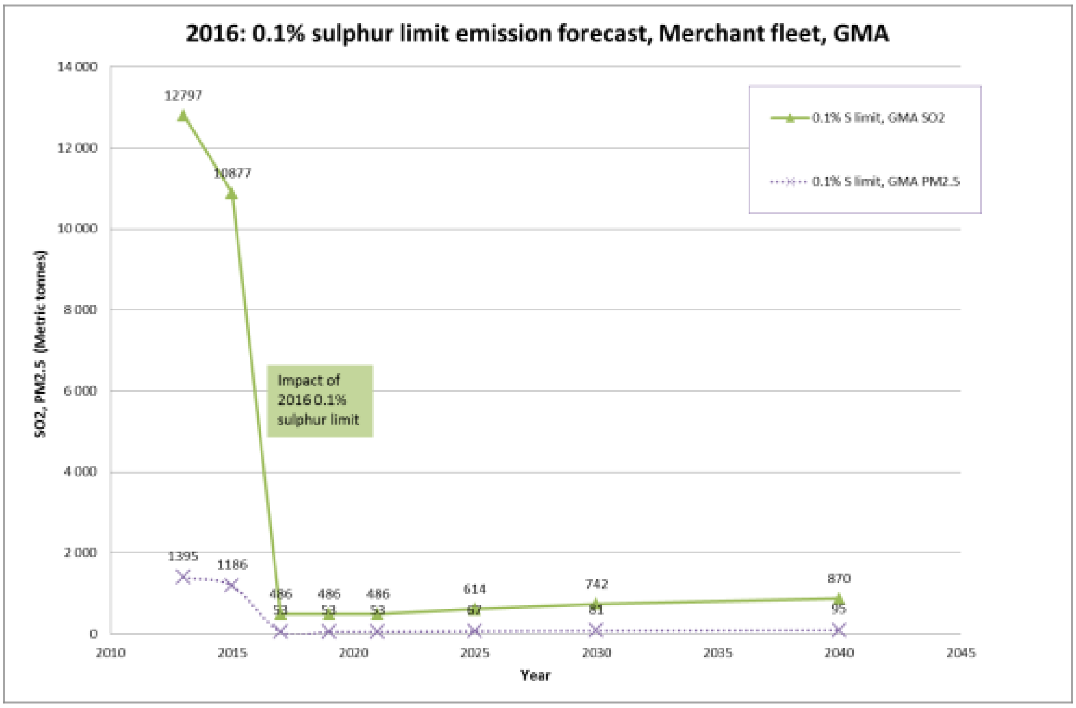


Figure 7-46: Predicted merchant ship emissions in the GMA if 2016 0.1% S limit

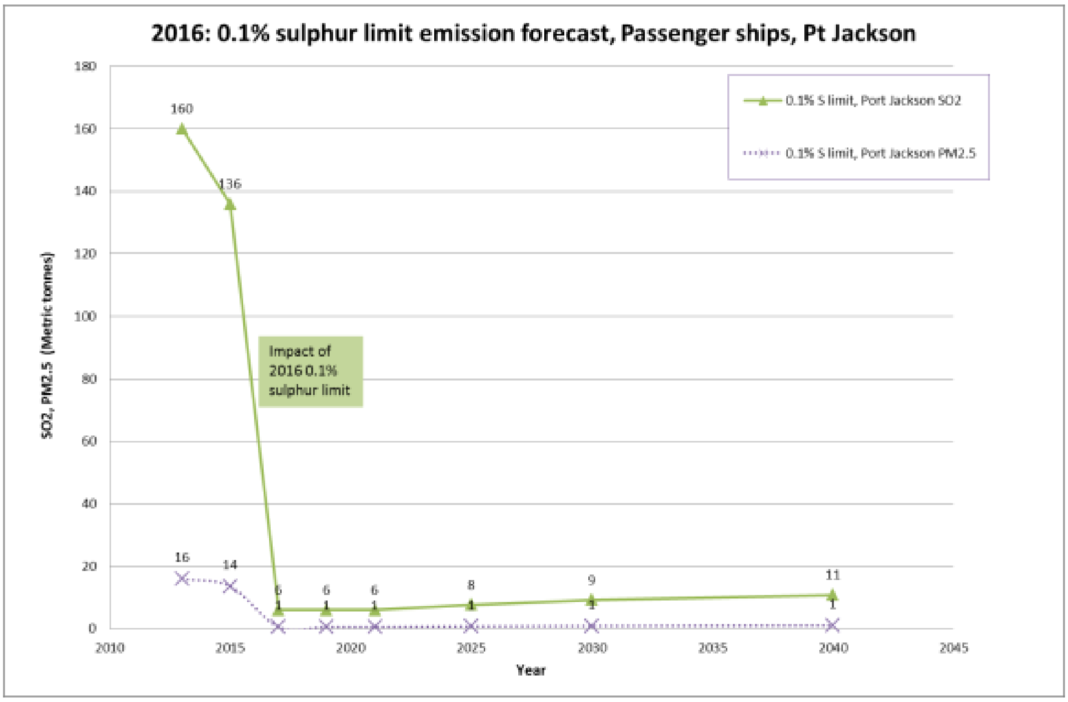


Figure 7-47: Predicted passenger ship emissions in Port Jackson if 2016 0.1% S limit

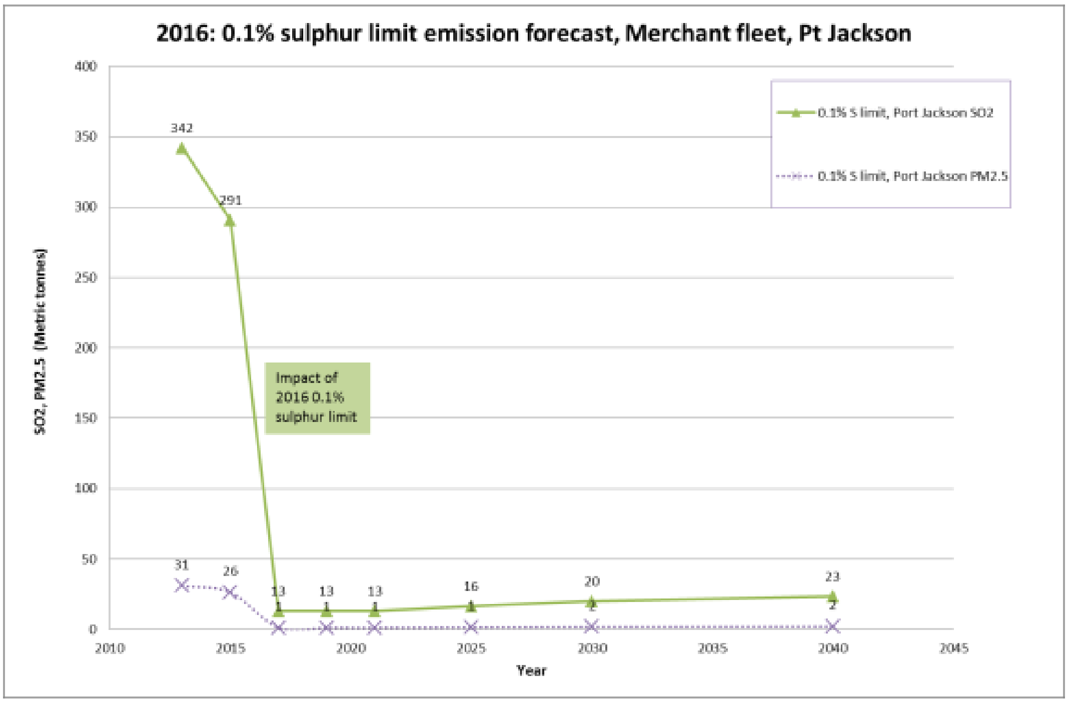


Figure 7-48: Predicted merchant ship emissions in Port Jackson if 2016 0.1% S limit

Discussion

Given the short timeframe to mid-2016, the realistic SOx abatement solution is low sulphur fuels. But some owners may still choose equivalently efficient solutions like scrubbers or even LNG fuel due to lower operational costs.

If the low sulphur requirement will only be required while moored at berth, the ships only need to prepare for use of low sulphur distillates for the auxiliary engines and boilers. If the entire GMA is regulated to a low-sulphur area, also the main engines and corresponding fuel tanks must be outfitted to run on distillates.

After a few years, other low SOx solutions will come into the picture, like LNG, scrubbers and others. Having a fair and transparent enforcement regime and dialogue with the maritime industry, are key requirements here.

It will take time and huge costs to develop an efficient shore-side power grid and matching on-board connectors. And an on-site or barge-mounted system for collecting and treating emissions from a bulk part of the ships will also take time and money. Hence, the effect of these measures will not be significant in the short term, and these solutions only curb emissions at berth. Keeping in mind that 80-90% of the GMA emissions occur outside the port area, and the coming IMO sulphur cap will require other measures that also have effect while sailing, one must question the cost-efficiency of shore-side power or off-ship treatment of exhaust gases. On the positive side, shore-side power eliminates nearly all ship emissions while at berth.

7.7 Cost of abatement measures.

A simple NPV analysis has been carried out to judge ship owners' burden of IMO's global sulphur cap, assumed to be implemented in 2020, and additional NPV by implementing a potential LSF regime from 1 July 2016.

7.7.1 Background information

From the AIS analysis the operational profile and selection of a 'typical' ship size of five selected ship categories has been done. Representative fuel consumption for the 'typical' ships in the GMA is then based on the median fuel consumption of each ship category and time spent in the GMA. By examining the technical specifications of vessels of a representative type and size operating in the GMA it is possible to determine 'typical' installed engine power. Data on typical specific fuel consumption for the 'typical' vessels originates from IMO's second GHG study from 2009 (4). Annual fuel volumes used in the GMA and globally are then calculated and used in the further analysis.

The selected ship categories are passenger (cruise) ships, tankers, bulk ships, general cargo and container ships. All ships are analysed and categorized as 'typical' ship based on their median fuel consumption. In addition, a high case for passenger (cruise) ships where the 75% percentile is used for fuel consumption to account for the a few cruise ships with significant fuel consumption in the GMA has been made.

The hardware and retrofit installation costs for scrubbers are taken from DNVGL's internal sources. There has been no accounting for costs necessary to convert HFO to LSF fuel in any ships, if needed. The NPV model is not broken down to analyse each port, but the main ship categories have their typical main target port.

Table 7-22: General input parameters to the NPV model

	Value:
Discount rate	8%
Investment horizon	15 years
OPEX, scrubber	Equivalent to 2.5% of fuel consumption, catering for fuel penalties, maintenance, consumables
OPEX for fuel switching	Only accounted for LSF price penalty
Fuel prices next 15 yrs. AUD	HFO: 462 AUD/t (500 USD/t), Low sulphur distillates: 792 AUD/t (620 USD/t) Assuming fixed fuel prices during investment period; similar price for 0.1% and 0.5% low sulphur distillates. (Novel heavy low sulphur 'hybrid' fuels are not considered)
Enforcement of IMO's 0.5% limit	1 January 2020 (possibly delayed to 2025)
First possible new local regulation	1 July 2016

Table 7-23: Specific input parameters to the NPV model

Type	Fuel cons. in GMA (tonnes/ yr)	% of year in GMA	Fuel cons. (tonnes/ yr)	% of annual fuel cons. in GMA	Engine Power (kW)	Scrubber cost (AUD/ kW)	Est. scrubber cost (mAUD)
Cruise, medium case	135	2%	14,830	0.9%	15,000	310	4.65
Cruise, high case	1,500	5%	36,916	4.1%	40,000	210	8.40
Tanker	135	3%	17,925	0.8%	18,000	310	5.58
Bulker	42	3%	14,132	0.3%	16,000	310	4.96
Gen Cargo	62	2%	6,472	1.0%	13,000	310	4.03
Container ship	162	4%	28,005	0.6%	36,000	210	7.56

7.7.2 Financial cases and results

In 2013, 273,000 tonnes of fuel, mainly HFO, was consumed in the GMA. If all this fuel should be substituted by low sulphur distillates (MGO) purchased in Singapore, the fuel would cost about 40-80%[76] more. The additional cost today for 273,000 tonnes of MGO instead of HFO is approximately $75 m AUD.

The results from the NPV analyses are presented below. The analyses are repeated for cruise ships, tankers, bulkers, general cargo and container ships. Here we say all LSF qualities have the same price.

NPV analyses, BAU case 1: HFO until 2020 and Scrubber from 2020 onwards

In the 'BAU case 1' HFO+scrubbers is in use from 1 January 2020 to comply with IMO regulations. As a consequence of potential new, local low sulphur regulations in the GMA the following is calculated for the 'typical ship' to estimate added NPV for the following two alternatives:

1. The added NPV for installing scrubber by July 2016, run HFO+scrubber in the GMA from July 2016, continue with HFO+scrubber globally after 2020

[76] See footnotes 6 & 7 above

2. The added NPV for using low sulphur distillates in the GMA from July 2016, and continue with distillates globally after 1 January 2020 (instead of HFO+scrubber)

Table 7-24: Results, added NPV for local initiatives as compared to BAU-1, GMA traffic.

BAU-1: HFO until 2020 and Scrubber from 2020 onwards	#1: Installing scrubber by July 2016, run HFO+scrubberin GMA from July 2016, run HFO+scrubber globally after 2020. Added NPV (AUD)	#2: Use LSF in GMA from July 2016, and LSF globally after 1 January 2020 (instead of scrubber). Added NPV (AUD)
Cruise, med. case	1,097,174	13,896,520
Cruise, high case	2,027,550	37,950,020
Tanker, med. case	1,316,019	16,815,748
Bulker, med. case	1,166,818	12,699,566
Gen Cargo, med. case	949,116	4,295,921
Container, med. case	1,782,075	26,812,215

Table 7-24 demonstrates that for ships that initially plan on using HFO+scrubber after 2020, an advancement of the scrubber installation to 2016 will cause limited extra costs. The greatest penalty for early adoption of a low sulphur regime affects the vessels using (relatively speaking) a lot of fuel. The table also shows that ships that plan for LSF also after 2020 instead of scrubbers, will be heavily penalized.

Due to the relatively low granularity of data we can only calculate added NVP for the entire GMA, not broken down to individual ports. However, with reference to dominant ship type in each of the ports, the cruise ship data is mainly associated with Port Jackson, the bulkers with Port of Newcastle and the container data is mainly for Port of Botany.

<u>NPV analyses, BAU case 2: HFO until 2020 and low sulphur fuel from 2020 onwards</u>

In the 'BAU case 2' low sulphur distillates has replaced HFO from 1 January 2020. As a consequence of potential new, local low sulphur regulations in the GMA the following is calculated for the 'typical ship' to estimate added NPV for the following two alternatives:

1. The added NPV for installing scrubber by July 2016, run HFO+scrubber in the GMA from July 2016, run HFO+scrubber globally after 2020 instead of LSF
2. The added NPV for using LSF in the GMA from July 2016, and LSF globally after 1 January 2020

Table 7-25: Results, added NPV for local initiatives as compared to BAU-2 GMA traffic

BAU-2: HFO until 2020 and low sulphur fuel from 2020 onwards	#3: Installing scrubber by July 2016, run HFO+scrubber in GMA from July 2016, run HFO+scrubber globally after 2020 instead of LSF Added NPV (AUD)	#4: Use LSF in GMA from July 2016, and LSF globally after 1 January 2020. Added NPV (AUD)
Cruise, med. case	-9,808,513	73,930
Cruise, high case	-49,033,369	1,151,017
Tanker, med. case	-22,315,339	109,046
Bulker, med. case	-16,960,183	32,241
Gen Cargo, med. case	-5,797,942	49,218
Container, med. case	-35,721,267	127,778

Table 7-25 demonstrates also that running on HFO+scrubber already from 2016 and continue beyond 2020 is less expensive than starting using low sulphur distillates from 2020. The table also shows that the added cost of using low sulphur distillates in the GMA for the period from July 2016 to 2020 is minimal. By comparing Table 7-24 to 7-25, we see that merely advancing scrubber operation from 2020 to 2016 (#1) is more costly than advancing LSF operation to 2016 (#4). But still the operation of low sulphur distillates gets more costly over time.

It is foreseen that a potential low sulphur regulation in the GMA from mid-2016 will give mixed reactions among ship owners. Many will probably switch to low sulphur distillates for a couple of years to get experience with that low-investment solution, while others will start planning for scrubber installations either from the start or after a few years.

Table 7-26 refers to maritime industry's understanding and DNVGL's best knowledge through work for the NOx Fund, assessment of scrubbers etc. Different engine configurations, operational profile, external operating conditions and varying fuel qualities complicate such studies.

Table 7-26: Typical abatement technologies.

		CAPEX[77]				OPEX	Emissions effect			
	Main components removed	**Passenger (40-100k kW)**	**Container (25-50k kW)**	**Bulker (30k kW)**	**Tanker (30k kW)**	(over HFO)	**NOx reduction**	**SOx reduction[78]**	**CO2 reduction**	**PM reduction**
Scrubber (ship installation)[79]	SOx, some PM	200-420 AUD per kW installed power				Variable	-	90-95%	1.5-2% increase	80-85%
LNG fuel (ship installation)	SOx, NOx, PM	700-1200 AUD per kW installed power				~30% higher than HFO but lower than low sulphur distillate	Low pressure engine: 90% High pressure engine: 40%	90-100%	Approx. 15%	More than 90%
Low-sulphur distillates	SOx, some PM	Variable depending on piping, storage, systems, training requirements				40-80% higher than HFO	-	80% (0.5%S) 96% (0.1%S)	-	About 90%[80]
SCR (Selective catalyst)	NOx	90-250 AUD per kW installed power					65- 90%		Slight increase	20-40%
EGR (exhaust gas recirculation)	NOx	80-250 AUD per kW installed power					35-40%		Slight increase	Slight increase
Shore-side power (at berth)	SOx, NOx, PM, CO2	Infrastructure shore-side: ca. $80m AUD				$375k- $2m AUD p.a.	Unknown, dependent on how electricity is generated and resultant power plant emissions.			
		Vessel refit: $320k - $1.8m AUD				Infrastructure costs passed on in fees	Up to 100% emission reduction from the connected ships			

77 Exclusive of installation costs.

78 Based on average sulphur content (2.7%) currently in GMA

79 Since the operational experience from dry scrubbers is minimal and wet scrubbers by far are the dominant scrubber solution, in this work wet scrubbers are referred to when addressing scrubbers unless dry scrubbers are specifically mentioned.

80 Extensive PM data series from large series of ships and engines have not been reported; we use same reduction rates for PM2.5 and SOx: 80% and 96% reduction when switching from HFO to distillates with 0.5% and 0.1% sulphur, respectively.

8 STAKEHOLDER CONSULTATION

An important part of the analysis of the various emission abatement measures applicable to the shipping sector was the consultation with stakeholders along the whole value chain. Whilst the key focus area of the Report is the technical feasibility of the various 'measures', it was important to also seek input from the industry on the subject of emissions – generally and specifically – including their perspective on compliance and implementation.

From the outset, as presented and communicated at the Stakeholder Workshop in Sydney on November 14, 2014, a number of avenues were open for DNV GL to receive input from organisations and individuals. This included the following:

- Open invitation for unsolicited feedback from interested parties on any aspect of the topics covered by this Report
- Electronic questionnaire sent to stakeholders from lists compiled by DNV GL and NSW EPA
- Face to Face meetings
- Telephone meetings
- Email correspondence
- Document review

By the close of the analysis period (January 29th 2015) the following summary depicts the extent of input received.

Table 8-1: Organisations contacted (listed in random order):

Wallenius Wilhelmsen Logistics	Royal Caribbean International	MSC
Maersk Line	Carnival Australia	Australian Institute of Petroleum
Australian Shipowners Association	Port of Newcastle	RightShip
Shipping Australian	Port Kembla	White Bay Residents
NSW Ports	Port Botany	Endeavour Energy
Caltex Australia	Rio Tinto	ASP Ship Management Group
Viva Energy	LBH Group	Ports Australia
AusGrid	AMSA	Port Authority NSW
Wartsila	NSW Ports	V Ships
CSL Australia	Hamburg Sud	Australian Marine Fuels
OW Bunkers	Baileys Marine Fuels	BP Marine ANZ
Trinity Petroleum Services	United Petroleum	

Meetings and Phone

A total of 25 face to face meetings or in-depth phone meetings were held with 27 different entities.

Electronic Questionnaire

A total of 114 email invitations to complete an on-line survey were sent out with a response from 12 different entities. Please note that there were some organisations on the distribution list with multiple contact names (to which the questionnaire was sent). As such the real response rate (Nr. responses /Nr. Invitations to unique organisations) is about 23%.

Details from all stakeholder contact remain confidential; however, a summary of the key areas covered during meetings, conversations, etc. appears as below. A copy of the survey questions appears in Appendix B.

Regulations and compliance

Consensus globally – and reflected in feedback from stakeholders consulted as a part of this Study – is that regulations are there to be complied with and that the costs associated with compliance are 'normal'. With reference to NSW in particular, there was no significant deviation from this opinion.

However, one aspect mentioned by several stakeholders was the 'burden of compliance' and the (lack of) resources to ensure ships meet the regulated requirements.

Business impacts of increase in regulation and compliance

Generally speaking, ship owners and operators will do whatever is required to ensure their compliance with the regulations of a region in which they wish to operate. The costs of compliance will in most cases be passed onto customers through increases in charter rates. An exception to this is when the increase in costs of compliance coincides with a drop in charter rates in the market; in this case, whilst costs of transporting goods may decrease for the cargo owner, the costs of compliance for the ship owner/operator will increase, thereby affecting the profit margin achievable of doing business. If this situation (falling margins) persists, then one scenario will be that the ship owner/operator may cease trading altogether in areas where the costs of compliance outweigh the income earned.

> *STAKEHOLDER QUOTE: 'Ship owners and operators only adopt significant environmental improvement initiatives … if regulation requires it or there is an economic payback. Their resistance to these measures, often for valid financial reasons, are also not conducive to a positive green image.'*

Current state of preparedness to address emissions

The average age of vessels globally is dropping. This correlates with the uptake of new and emerging emission abatement measures. World shipping standards, as directed by the International Maritime Organisation (IMO) are progressively tightening the requirements of ships with respect to emissions both for those already in operation and those planned.

International trends in emission reduction methodologies translate to vessels operating in the NSW GMA. This includes – in some cases – 5-10 year corporate plans to install emission abatement technology (e.g. exhaust scrubbers, modifications to fuel systems to accommodate low sulphur fuel or even modifying fleet to use LNG as fuel). Technical and operational measures initiated to reduce fuel consumption (e.g. better underwater hull shape, advanced antifouling paint, programmes for intermittent hull cleaning, improved maintenance, cargo planning, hybrid diesel-battery power systems and slow steaming) will proportionally also reduce emissions.

For example, with respect to the use of LSF (low sulphur fuel), the majority of stakeholders consulted on the current viability of this option, nominate a medium term time frame (+/- 3 years) in order to be able to use this. This is affected by the lack of LSF supplies in SE Asia which in many cases will be the last bunker port for shipping before visiting NSW GMA.

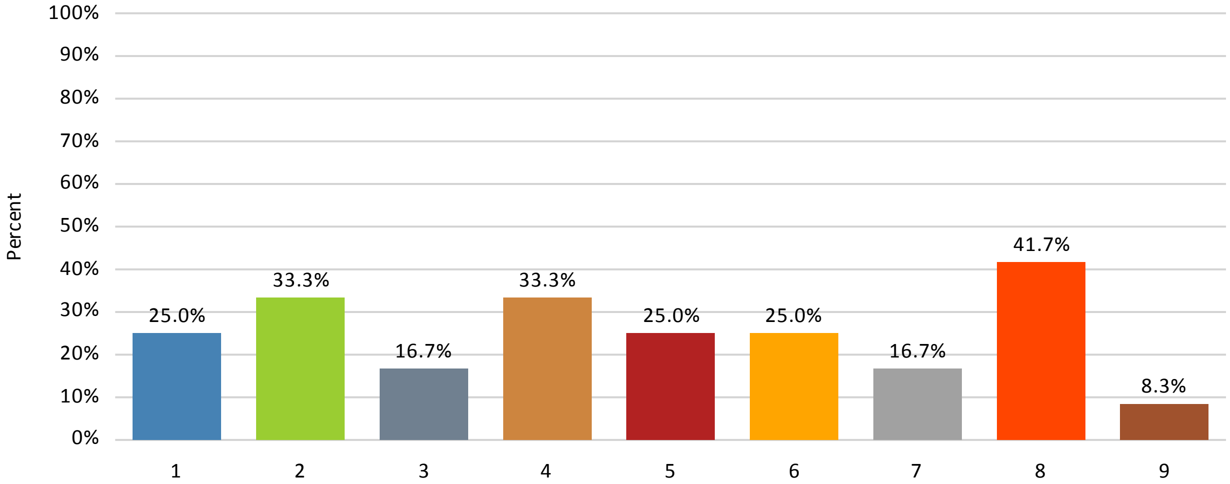
In addition, the majority of owners/operators have taken an active stance on their (internal) environmental policies and in reporting emissions not only for compliance purposes but also to external stakeholders.

STAKEHOLDER QUOTE: We concentrate very closely on itinerary planning to reduce distance and speed. Our fuel consumption continues to reduce year on year. We constantly strive with technological innovation which has reduced our in port fuel consumption year on year.

Planned (future state) state of preparedness to address emissions

In terms of SOx and PM emission abatements, these will be partly achieved by the introduction of a global sulphur limit for fuel of 0.5% by 2020 (possibly pushed back to 2025). There are no announced international NOx regulations which will apply directly to Australia, however as more newbuilds in the international fleet are built to the stringent Tier II standard of 2011 and the very strict North American ECA Tier III standard of 2016, visiting ships will gradually emit less NOx in NSW waters. CO_2 emissions will gradually also come down per ship as the EEDI requirements for newbuilds are gradually tightened.

As above, all shipping industry stakeholders have indicated advanced planning to meet the new SOx regulations. For example, the passenger segment, however, is already undergoing the installation of exhaust scrubbers / engine modifications to a planned maintenance schedule in the lead up to 2020[81]. Whilst other segments are expecting new-build vessels with significantly lower 'emission profiles' to be used in NSW GMA.



1 - LNG fuelled vessels
2 - Scrubbers
3 - Selective Catalytic Reduction
4 - Engine modifications
5 - Distillate fuels (MGO)
6 - Cold ironing (Shore side power)
7 - Other
8 - Not applicable
9 - I don't know

Figure 8-1: Future emissions abatement measures planned

[81] Stakeholder information received

Miscellaneous

Incentives to emit less were general absent at state and local level. At a federal level the 'Emissions Reduction Fund'[82] was perceived to be too vague and broad in its application to be considered a practical means to incentivize ship owners/operators to invest in emission reduction measures.

Further anecdotal evidence gathered through the project of a (perceived) level of complexity between regulators in NSW GMA in designing, launching and administering any such (incentive) program with the objective of reducing emissions in Port or at sea. No party consulted discounted the value of such an 'incentive program' if one were available however there was a degree of scepticism as to the efficacy of such a measure when compared to other more tangible options available to reduce emissions.

Further, customers of shipping services are generally accepting that transporting (their cargos) by sea is the most fuel efficient and that this is underlined by the reality that there is no real alternative in most cases (that is, rail, road and air).

However, Shipping is often targeted by the public due in part to the general proximity of shipping activity to the population (at work, rest and play).

> *STAKEHOLDER QUOTE: '...Public awareness of the sustainability of shipping is probably much less and it is a challenge for industry and government to communicate this message more effectively.'*
>
> *STAKEHOLDER QUOTE: 'Our customers understand shipping is the most sustainable, low emission transport method for bulk cargoes.'*

[82] See http://www.environment.gov.au/climate-change/emissions-reduction-fund

9 CONCLUSIONS

Ship emissions are quite significant in the GMA and the analysed ports; quite high emission loads of CO_2, SOx, NOx and PM 2.5 were found. However, annual ship emissions account for only approximately 5% of the total anthropogenic emissions in the GMA when comparing the AIS emission estimates with reported figures for NSW (32). However there are emission hot spots in the inner city with high emission rates.

The expected financial growth in the region will likely cause more ship traffic and emissions – the latter can be assumed unless specific measures are taken. IMO's global sulphur limit of 0.5% sulphur in fuel being phased in between 2020 and 2025 will reduce SOx and PM significantly but not CO_2 and NOx. Of all 2013 GMA ship CO_2 emissions, Port Jackson, Port Botany, Port of Newcastle and Port Kembla account for approximately 3.9%, 10%, 4.5% and 2.0% respectively. The percentages for the other emission components are comparable.

Based on experience with ECAs worldwide, in deciding how to move forward, there are some principal issues to consider:

1. Timing for implementing local regulations and how to establish a fair system giving a robust, non-manipulative emission reduction regime if deemed necessary?
2. Should the ports prepare for removing emissions only for ships that are stationary at berth? Or should the potential measure give effect also off the coast, in GMA waters?
3. Should an emission reducing regime focus on fewer but more dominant emitters, or all ships trafficking in the GMA?
4. How can the abatement strategy be cost-effective for ship owners, charterers, fuel or technology providers, and at the same time effectively reduce emissions?
5. How will potential measures be scrutinized and at what penalty levels?
6. Many of the emission abatement options are novel technologies not proven through decades of operation. For instance, fuel switching between HFO and distillates has shown difficulties, with several ships recently having lost all engine power and thus causing safety hazards off the coasts of the UK and California. Scrubber and LNG retrofits have also proved difficult. Thus, these pose a potential technical and financial risk to the ship owner. How can such risks be mitigated?

Measures for removing emissions from berthed ships, like shore-side power or land/barge based exhaust gas treatment systems rely on investments done only to curb emissions at berth not while moving in the GMA. Many such systems typically require investment both from port operators and ship owners, which can be challenging to coordinate. Some of the necessary support systems like shore-side power outlets must in many ports cover huge distances, questioning the financial feasibility of such systems.

On the other hand, on-board abatement systems such as scrubbers remove SOx effectively in port and while sailing, but not CO_2 or NOx. LNG fuel removes both SOx and NOx, but is space-demanding and investment intensive. Ship owners understand now that sooner or later they need SOx abatement systems that work both at berth and while sailing due to IMO's 2020 (or 2025) global regulation of 0.5% sulphur in fuels. This will trigger a need for systems that work while sailing, thus investing in shore-side power connectors etc. may seem less relevant.

High power demand on vessels in port requires handling of high voltage systems by dedicated competent on-board personnel. The requirement of shore-side power connection can be demanding for large oceangoing vessels operating worldwide if such investments shall be justified for operating at one local harbour. There is still little standardisation of shore power systems, which can cause confusion for ships in worldwide operation. When considering shore-side power, vessels operating on fixed routes should be targeted.

For larger ships a switching regime to low sulphur fuels is cost-effective to reduce SOx and PM emissions.

In this work it was found that ship emissions in all ports only account for 10-20% of the overall ship emissions in the GMA. This may be explained by a large number of ships moving around in, and through, the GMA, while many vessels are waiting at anchorage for cargo operations. It was also observed that emissions from the merchant fleet are approximately 10 times higher than the emission levels from passenger ships.

Ship emissions towards 2040 have been predicted based on IMO's 2nd GHG study forecasts; predominant emission reducing regulation for GMA is IMO's global limit of 0.5% sulphur in fuel coming into force sometime from 2020-25.

Merchant ships in the GMA will emit more than a million tonnes of CO_2 per year by 2040. Due to IMO's sulphur regulation the SOx emissions will drop from current level of 11,000 annual tonnes to about 2,400 tonnes by 2020 (2025), thereafter rise to above 4,300 tonnes by 2040. The NOx emissions will remain relatively steady at 12,000 tonnes/year and PM2.5 is also expected to drop from 1,200 to approximately 300 tonnes/year in 2020 (2025).

CO_2 emissions for passenger vessels in the GMA will climb towards 124,000 tonnes annually by 2040. The IMO regulations will cause a drop in SOx emissions from 1,200 to 260 tonnes/year by 2020 (2025), while NOx emissions remain relatively steady towards 2040 at about 1,600 tonnes/year. PM2.5 is also expected to drop from 140 to 30 tonnes/year when the sulphur cap is enforced.

SO2 emissions from passenger ships in Port Jackson will drop from 140 tonnes/year to 30 tonnes/year as a result of the upcoming IMO regulation by 2020, along with a reduction of PM2.5 from 14 tonnes/year to 3 tonnes/year.

If NSW authorities go beyond MARPOL's 0.5% sulphur cap on fuel with low sulphur regulations starting July 2016, forecasted emission reductions have been calculated for the following scenarios:

a) 0.5% low sulphur limit (or equivalent treatment) in the entire GMA / in Port Jackson only
b) 0.1% low sulphur limit (or equivalent treatment) in the entire GMA / in Port Jackson only

With a local 0.5% fuel sulphur limit SO2 and PM2.5 emissions from all ships in GMA will be reduced by more than 10,000 and 1,100 tonnes/year in 2017 respectively, compared to the Business As Usual scenario with IMO's 0.5% limit coming in by 2020 (2025).

A potential 0.5% or 0.1% sulphur limit for passenger ships calling Port Jackson without any other GMA emission regulations will remove 113 and 138 tonnes/year of SO2 respectively in 2017; and 11 and 14 tonnes/ year of PM2.5, respectively, compared to the BAU regime based on IMO's 0.5% sulphur limit.

Related to these scenarios, the local demand may become sufficient to justify shore-side power installations at a number of berths providing electricity to a selected fleet of regular visitors. Alternatively or in addition, on-site/barge mounted SOx treatment could be explored.

However, since most of the emissions occur at sea, and the global sulphur cap comes in a few years, other solutions such as low sulphur fuels, scrubber or even LNG need to be considered. Having a fair and transparent enforcement regime and dialogue with the maritime industry, are also key requirements here.

In 2013, 273,000 tonnes of fuel, mainly HFO, was consumed in the GMA. If all this fuel should be substituted by low sulphur distillates (MGO) purchased in Singapore, the fuel would cost about 40-80%[83] more. The additional cost for 273,000 tonnes of MGO instead of HFO is now approximately $70 m AUD.

The investment analysis demonstrates that the added NPV for a large cruise ship that starts using a scrubber in the GMA in 2016 instead of in 2020, adds up to $2 mAUD. It is also evident that the added costs for using low sulphur distillates over time instead of HFO+scrubber is significant.

Looking ahead, there will probably be a few ECA-equipped ships also coming to NSW that can run scrubbers and possibly also EGR for NOx reduction when in the GMA. Regimes for reduced port dues have proven effective in some ports.

For smaller ships, battery and LNG fuel should be considered phased in on a few ships during the coming years. Such solutions bring stakeholder awareness, build capabilities and reduce local pollution.

[83] See footnotes 6 & 7 above

10 DISCLAIMER

All emission data provided in the report originate from AIS ship movements and best assumptions for specific fuel consumption and engine configuration on-board a given ship. The same methods were applied as have successfully been used in numerous other AIS-based emission studies, but it is still recommended that the results are compared to emission inventories derived from in-situ measured data from specified emitters.

DNV GL takes no responsibility for the difference between ‘estimated’ emission data presented herein and ‘actual’ data obtained by on-board measurements.

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APPENDIX A
Ship types and sub categories

Ship type and sub categories
1 Oil tankers
Asphalt/Bitumen Tanker
Bunkering Tanker
Crude Oil Tanker
Crude/Oil Products Tanker
Products Tanker
2 Chemical/Prod tankers
Chemical Tanker
Chemical/Products Tanker
Molten Sulphur Tanker
3 Gas tankers
LNG Tanker
LPG Tanker
4 Bulk carriers
Bulk Carrier
Bulk Carrier, Self-discharging
Cement Carrier
Ore Carrier
Wood Chips Carrier
5 General cargo vessels
General Cargo Ship
General Cargo Ship (with Ro-Ro facility)
General Cargo Ship, Self-discharging
Heavy Load Carrier
Heavy Load Carrier, semi submersible
Livestock Carrier
Open Hatch Cargo Ship
6 Container vessels
Container Ship (Fully Cellular)
7 RoRo vessels
Ro-Ro Cargo Ship
Vehicles Carrier
8 Reefers
Refrigerated Cargo Ship
9 Passenger vessels
Passenger Ship
Passenger/Cruise
Passenger/Ro-Ro Ship (Vehicles)
10 Offshore supply vessels
Anchor Handling Tug Supply
Crew/Supply Vessel
Platform Supply Ship
11 Other offshore service vessels
FPSO, Oil
Offshore Support Vessel
Well Stimulation Vessel
12 Other activities

APPENDIX B
Stakeholder questionnaire

1. Relevant Segment
- All main types represented

2. Ports of Operation
- Stakeholders representing all Ports in GMA responded

3. Main ship types
- Bulk carriers most represented

4. Average Age (of vessels)
- No clear dominance

5. Extent of bunkering activities in port
- Small proportion heavily reliant on Sydney to source bunkers. Most 'rarely' bunker in GMA.

6. Comments on port's or ship owners' green profile
Selection of quotes received:

- Shipping has a relatively negative environmental image to most stakeholders. Despite being more environmentally friendly than alternatives … because a ship is a lot more of visual impact and the environmental effects being more obvious … Our customers understand shipping is the most sustainable, low emission transport method for bulk cargoes.
- The government has an increasing understanding of the environmental challenges of the shipping industry and also has a vested interest in continuing to balance the public good (pollution/CO2 emissions) and creating a cost efficient environment for the shipping companies to do business.

7. Environmental drivers from Port
Selection of quotes received:
- Lack of national standards in line with world best practice - NSW, in areas of high population exposure, should match requirements of US and EU ports and should reflect the availability and feasibility of emission reduction technologies in its requirements on shipping. Closely related … increasing evidence of the serious health impacts of particle pollution and community expectations of pollution control are key drivers
- Key drivers for environmental performance at ports include: compliance with statutory obligations and approval conditions; maintaining good community relations and acceptance of existing port operations and potential future development.

8. Environmental Policies from State
- No consistent themes

9. Environmental Incentives from State
Selection of quotes received:
- No incentive programs for reducing shipping emissions to date. We would be supportive of any initiatives that would assist vessels in reducing their emissions
- We are unaware of any incentive programs from NSW State Government that support our efforts to reduce the environmental impact of our operations.

10. National Environmental Incentives
Selection of quotes received:
- Federal Government should follow international schemes in operation
- The Emissions Reduction Fund is too broad and vague and the lack of certainty around the auction bidding process makes it difficult to build any credits into CAPEX for projects

11. Stakeholder groups

Selection of quotes received:

- Stakeholder groups generally seem to be vested interests (e.g. landowners near a port) who, if taken seriously by the authorities, may make far-reaching and changes that is of detriment to wider society.
- Traditionally, we had a solid relationship with stakeholders regarding our environmental performance and our reporting protocols. This took a different path once the White Bay terminal opened where the relationship changed and we now being challenged on our operating methods which are within the acceptable guidelines set by the State.
- We are continually engaging multiple stakeholders in relation to shipping and the environment. We do this through our interactions with customers, NGO's, our suppliers, governments, international industry groups amongst others. … This interaction is key for us to refine our view on the most material impacts our business has in the eyes of these various stakeholders and therefore target our actions to reduce our impact on these identified issues.

12. Preparedness for shore-side power

- Most (relevant) respondents indicted this would require 'significant modifications' in the medium to long term

13. Ships' likelihood to use low emission fuel

- Plans for use were generally set for the period 2018-2020

14. Bunker supplier's situation and your viewpoints

- Not my area of expertise. I understand Caltex has indicated no problems in supply for NSW with either MARPOL implementation or accelerated implementation of low-sulphur fuels.
- Cannot comment on general bunker supplies. But LNG bunker facilities are non-existent and will likely need state intervention to make LNG vessels a possibility. Traction is being made in VIC and WA but I am not aware of such developments in NSW.
- Bunker suppliers will always find a way to provide fuel if they are to make a profit from their efforts. The question comes as to how financially viable their supply is. The bunker supplier plays no part in driving any form of emissions reductions.

15. Environmental policy, KPIs

- A high degree of engagement was reported including policy and KPIs achieved

16. Emissions abatement measures in-place

- Current measures are predominantly operational in nature

17. Future options being actively considered

- A wide range of options were being considered by respondees including scrubbers, 'fuel type' and engine modifications

18. Any operational procedures aimed at reducing emissions

- Generally focused on voyage planning (speed, port turnaround)

19. Experience with policy and/or regulations outside of Sydney GMA
Selection of quotes received:

- Very minor example and not sure if it impacts economically on cruise lines but noted that Friends of the Earth maintains a website that grades cruise ships environmentally, encouraging consumers to consider this in choosing a cruise, http://www.foe.org/cruise-report-card
- NSW EPA Lower Hunter Air Quality Emissions Network - This network is funded by a cost on EPL holders in Newcastle. There is no equivalent network in other NSW ports despite a lack of evidence that air quality in those ports is superior to the lower Hunter. This is a cost on EPL holders in Newcastle Port that their equivalent operators in other Ports do not have.
- The following is a list of the programmes (both emissions focused and other) that we have participated in over the last 5-10 years. The list is not exhaustive:
    - Mandatory
        - USA - Vessel General Permit – vessels must have in place by 19 DEC 2013
        - ECA North Europe and North America – 1.0% sulphur limit from 2012 – 2015 and now 0.1% sulphur limit from Jan 1, 2015
        - EU in ports sulphur limit – 0.1% Sulphur from 2010
        - US Atlantic – Mandatory speed reduction enforced by radar (<10kts Apr-Oct)
        - California - Fuel Switch to MGO/MDO max sulphur 0.1% within 24 NM
          At berth emissions – Shore Power rule to reduce emissions at berth by 50% using Shore Power or other equivalent methods
          Water discharge – Beyond Vessel General Permit
          Wales – new lanes for SF approach and SB channel
    - Voluntary incentivised programs
        - Canada – Voluntary speed reduction/caution zone (< 10kts June 1 to Oct 31)
        - California POLA and POLB Speed reduction – 20 and 40 NM programs
        - California Santa Barbara channel speed reduction trial
        - Seattle – fuel switch at berth to use fuels max 0.1% sulphur
        - Vancouver – fuel switch at berth to use fuels max 0.1 % sulphur
        - Prince Rupert, British Columbia – Environmental Shipping Index (ESI) program
        - Norfolk, Virginia – fuel switch at-berth to use fuels max 0.1% sulphur
          NY/NJ – Air emissions through ESI and speed control on one transit
        - Houston, Texas – program completed 2011
        - Gothenburg, Sweden – fuel switch to fuels max 0.1% sulphur whilst in port limits
        - Hong Kong – fuel switch to fuels max 0.5% sulphur at-berth
        - Singapore – fuel switch to fuels max 1.0% sulphur (in port limits and at-berth program)
        - New Zealand – fuel switch program completed in 2012
- Participating in the above programmes is something that we do as a company both as it ensures our license to operate (mandatory programmes) and because we strive to be industry leaders in terms of managing our environmental impacts and engaging our stakeholders openly to address these issues.

20. Average sulphur content for bunkers
- All reported figures (of respondents actual fuel samples tested) were below the 3.5% required by AMSA

21. Emissions reporting
- Large majority of respondents are required to report emissions externally
- 0% respondents reported a worsening emissions trend in their operations
- 63% respondents reported an improving emissions trend in their operations

22. If there is an area that was not covered in the questions please provide any comments and/or feedback that you believe should be highlighted
Selection of quotes received:
- The survey has not considered planning policy options to reduce the future exposure of residents and other sensitive receptors to shipping emissions.
- Leakage of trade to interstate ports and associated increase in interstate road transport is a significant risk of unilateral action in NSW.

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