POTENTIAL MEASURES FOR AIR EMISSIONS FROM NSW PORTS

PRELIMINARY STUDY

PREPARED FOR THE

NSW OFFICE OF ENVIRONMENT & HERITAGE

23 June 2011

A PEL Company

ACKNOWLEDGMENT

PAEHolmes would like to thank Mr Nick Agapides, Mr Kelsey Bawden and Mr Gareth Jones, from the NSW Office of Environment and Heritage, for providing the air emissions inventory data for shipping, cargo handling, rail freight and road freight for the 2008 calendar year. The underlying emissions inventory activity data and estimation techniques were gathered and developed by the NSW Office of Environment and Heritage.

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Abbreviations Acronym	 Definition
AB	Auxiliary Boiler
AE	Auxiliary Engine
ABC	At-Berth Clean Fuels Vessel Incentive
AMC	Australian Maritime College
ARB	Air Resources Board (California)
CARB	California Air Resources Board
CEMS	Continuous Emissions Monitoring System
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
DWT	Deadweight tonnage
ECA	Emissions Control Area
E-diesel	Ethanol Diesel
EEV	Environmentally Enhanced Vehicle
EGR	Exhaust Gas Recirculation
ESI	Environmental Ship Index
EU	European Union
FBC	Fuel Borne Catalyst
GMR	Greater Metropolitan Region
GT	Gross Tonnage
HAM	Humid Air Motor
HSD	High Sulfur Diesel
IAPH	International Association of Ports and Harbours
IFO	Intermediate Fuel Oil
IMO	International Maritime Organisation
LGA	Local Government Area
LNC	Lean NO_x Catalyst
LNG	Liquefied Natural Gas
LS180	Low Sulfur IFO180
LS380	Low Sulfur IFO380
LTEC	Land Transport Environment Committee
MDO	Marine Diesel Oil
ME	Main Engine

Abbreviations	
Acronym	Definition
MGO	Marine Gas Oil
MSD	Medium Sulfur Diesel
MW	Megawatts
MWh	Megawatt Hour
NAC	NOx Adsorber Catalyst
NEPM	National Environment Protection Measure
NH_3	Ammonia
nm	Nautical Mile
NMVOC	Nonmethane Volatile Organic Compounds
NOK	Norwegian Kroner
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
NSW GMR	New South Wales Greater Metropolitan Region
NTC	National Transport Commission
OEH	NSW Office of Environment and Heritage
OGV	Ocean Going Vessel
PAH	Polycyclic Aromatic Hydrocarbon
PCDF	Polychlorinated Dibenzofurans
PM	Particulate Matter
PM_{10}	Particulate Matter with diameter less than 10 µm
$PM_{2.5}$	Particulate Matter with diameter less than 2.5 µm
PSCAA	Puget Sound Clean Air Agency
RO	Residual Oil (Heavy Fuel Oil, Intermediate Fuel Oil)
RSZ	Reduced Speed Zone
RTA	NSW Road and Traffic Authority
RTG	
RoRo	Roll-on/Roll-off
S	Sulfur
SCR	Selective Catalytic Reduction
SCR	Selective Catalytic Reduction
SEK	Swedish Kronor
SNCR	Selective Non Catalytic Reduction
SO_2	Sulfur Dioxide
SO_x	Oxides of Sulfur (primarily SO_2)
SSD	

Abbreviations	
Acronym	Definition
TEU	Twenty-foot Equivalent Unit, based on the volume of a 20-foot-long (6.1 m) intermodal container
ULSD	Ultra Low Sulfur Diesel
UNCLOS	United Nations Convention on the Law of the Sea
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds (Hydrocarbons)
VSR	Vessel Speed Reduction
WPCI	World Port Climate Initiative
wt%	Weight percent

EXECUTIVE SUMMARY

In NSW, Ports Botany, Jackson, Newcastle and Kembla are located within the Greater Metropolitan Region (GMR). These ports provide berthing and loading/unloading facilities for international shipping and are supported by a network of transport infrastructure for the movement of goods. The port precincts generate significant volumes of freight-related traffic with commensurate environmental impacts. The principal air pollution emissions from ports and related activities include fine particles (PM_{10}, and $PM_{2.5}$) and oxides of nitrogen (NO_x) from fuel combustion, sulfur dioxide (SO_2) from the combustion of high-sulfur heavy fuel oil used in ships, and volatile organic compounds (VOCs) from a variety of fuel-related sources. These pollutants have known adverse health effects in humans and are subject to ambient air concentration limits.

Emissions from port-related activities in the GMR are summarised in the tables below.

Source of Emissions	Emissions (tonnes/annum)				
	PM_{10}	$PM_{2.5}$	NO_x	VOC	SO_2
Shipping	892	820	9,688	198	7,187
Cargo handling	59	58	1,082	97	0.5
Associated diesel rail freight	156	151	8,154	317	9
Diesel road freight#	0.5	0.5	19	1	0.1
Total emissions from ports in GMR*	1,108	1,030	18,943	516	7,197
Total emissions in GMR*	75,128	30,499	292,054	171,067	301,863

* Total emissions are sourced from NSW DEC 2003 Air Emissions Inventory, based on year 2000 data. Port emission estimates are based on 2008 data supplied by OEH (2011).

Percent of Port Emissions	Emissions (% / annum)				
	PM_{10}	$PM_{2.5}$	NO_x	VOC	SO_2
Shipping	80.51%	79.61%	51.14%	38.37%	99.86%
Cargo handling	5.32%	5.63%	5.71%	18.80%	0.01%
Associated diesel rail freight	14.08%	14.66%	43.04%	61.43%	0.13%
Diesel road freight#	0.05%	0.05%	0.10%	0.19%	0.00%
Port contribution to emissions in the GMR	1.47%	3.38%	6.49%	0.30%	2.38%

* Total emissions are sourced from NSW DEC 2003 Air Emissions Inventory, based on year 2000 data. Port emission estimates are based on 2008 data supplied by OEH (2011).

Diesel road vehicles contribute only a small proportion of emissions from GMR ports but their wider airshed impacts are significant, particularly the health impacts of diesel particulate emissions.

In the Botany Local Government Area, emissions associated with Port Botany form the following proportion of total emissions: PM_{10} 49.3%, NOx 26.3% and VOC 6.5%. Valuing the particle emissions alone (\$165,450/tonne PM_{10}), emissions from NSW ports are estimated to result in health costs of approximately \$183 million.

Emissions growth from NSW port freight movements, in the absence of improved management, is projected to be high, due largely to a forecast increase in throughput of twenty foot containers (TEUs) from 1.62 million in 2007 to 3 million in 2020. Air pollutant and greenhouse gas emissions from commercial vehicles in the GMR are forecast to grow significantly, at nearly four times the rate of passenger car emissions. The projected growth in road freight is especially pronounced.

It is important to note that emissions impacts may not relate only to the quantities released. Timing of emissions and characteristics such as the locations and effective heights of release also play a role. Identifying the relationships between emissions and their impacts in terms of off-site ground level concentrations and associated health risks will enable more focused and cost-effective planning of emissions reduction strategies.

Port stakeholders were consulted on a variety of potential measures to reduce emissions from shipping, cargo handling and rail and road freight. These options were based on a survey of measures both in place and proposed in various jurisdictions within Australia and internationally.

A number of broad issues and themes emerged from the consultation process:

- What are the needs and benefits of targeted emissions reductions for the shipping and ports sector?
- Industry does not support a 'go it alone' approach by NSW in imposing regulations or programs, such as emission taxes or stringent fuel standards, that would incur greater costs compared to other ports that compete for the same business.
- Any pricing mechanisms to change emissions behaviour should be considered and developed nationally.
- The cost effectiveness of any capital-intensive changes in NSW and other Australian ports needs careful consideration in relation to port throughput and consequent ability to cover the costs.
- Industry regards financial incentives favourably when considering the implementation of capital-intensive programs such as retrofitting or technology upgrades. Non-financial incentives are generally not considered to be beneficial.
- Industry is willing to engage in voluntary initiatives and partnerships, particularly where there are benefits in efficiency as well as environmental dividends.

Emission Reduction Strategy

The "Clean Air Action Plan" developed by the Ports of Los Angeles and Long Beach in California can usefully inform a general strategy for emissions improvements at NSW ports. This plan established a strategy for reducing port-related health risks while allowing port development and the job creation and economic activity associated with that development to continue. The plan introduced anti-air pollution strategies including the ports' Clean Trucks program, vessel pollution reduction programs and new technologies. Importantly, all port stakeholders contributed to the plan's development. Applying a similar coordinated approach for NSW ports would help to establish priorities in terms of port-wide contributions to off-site impacts. Specific measures could then be developed through understanding the potential benefits, costs, opportunities and barriers.

As a first step, it is proposed that the Office of Environment and Heritage (OEH) meet with relevant agencies and authorities to discuss the issue of air pollution in ports. The scope for extending operational improvements under the Port Botany Landside Improvement Strategy should be discussed.

As a further step, agencies and port authorities could meet with private sector organisations involved with port operations, including stevedores, truck fleet operators, shipping companies and other participants in the logistics chain, to discuss potential emission reduction strategies.

The following issues for specific port-related emissions should be considered further in the preliminary scoping of a broader strategy:

Ships

- Voluntary reduced vessel speeds in the vicinity of NSW ports, governed by a Memorandum of Understanding. A 10% speed reduction can reduce emissions by 20% and provides the most immediate option for reducing emissions from shipping. An industry agreement, governed by a Memorandum of Understanding, could be negotiated and would provide industry the opportunity to determine the most cost effective speed for them to operate at and the extent of the reduced speed zone. Reduced vessel speeds require no capital upgrades and can be adjusted to suit the specific port circumstances. Negotiation of a Memorandum of Understanding would need to include the relevant Port Authority, Maritime NSW and the Australian Shipping Association. Ports' contributions to total air shed emissions and the human health impacts would need to be clearly demonstrated.

- The impact in NSW of planned international controls on ship emissions, i.e. International Maritime Organisation (IMO) MARPOL VI (the International Convention for Prevention of Air Pollution by Ships) global maximum fuel sulfur limit of 0.5wt%, expected to come into effect in 2020.

- Evaluation of the impacts of an Emission Control Area (ECA) enacted through IMO MARPOL Annexe VI, with requirements to meet fuel standard limits. To present the case for an ECA to the IMO, NSW would first need to demonstrate that ship emissions are harmful to human health in the GMR. This work would be required to establish the merits of any next steps.

- Assessment of the costs and benefits for introducing shore power for new and major redevelopments of port berths under Environmental Protection Licenses. Such an option would need to clearly demonstrate it does not impact the commercial operation of affected businesses and consider emissions reductions achievable.

Cargo handling

Cargo handling emissions, while relatively small compared to shipping (Table 3-1), do have a noticeable impact on overall port emissions. Current equipment replacement, retrofit and other programs identified by industry in the consultation process appear to have emissions improvement potential, particularly over the medium to longer terms, e.g.

- progressive replacement of rubber tyred gantry cranes (RTGs) by new low-emission equipment
- retrofitting diesel particulate filters to older RTGs
- extending anti-idling to all major items
- extending the NSW Clean Machines program

Emission standards for non-road diesel engines are currently being evaluated nationally and would provide additional emission management options.

Extension of the Clean Machines Program

Extension of the ports component in the NSW Clean Machines program could assist uptake of cleaner equipment. In addition to encouraging retrofits, the program could provide guidance for on-site operational measures that reduce emissions and fuel use, such as anti-idling. A broader framework could be developed with industry through a Memorandum of Understanding that defines an agreed plan for achieving plant and equipment improvement milestones.

Improved Operational Efficiency

Industry's ability to reduce emissions is tied to the productivity and profitability of port operations. The Port Botany Landside Improvement Strategy aims to improve productivity and reduce emissions. Its current focus is vehicles; however there may be additional scope to extend it to diesel powered cargo equipment to achieve greater overall port emissions reductions.

Rail

Diesel rail freight emissions of NOx and VOC are a significant proportion of total port-related emissions in the GMR (Figure 2-1) although their contribution to total emissions from Port Botany is small (Figure 2-2).

Locomotives and rail infrastructure are highly capital intensive. Industry consultation indicates significant barriers to 'big ticket' rail emission reduction actions such as line electrification or a move to lower emitting LNG powered locomotives. However, assessing the scope to expand the Clean Machines program to include locomotives could deliver some emission reductions. The program could also provide a framework for improving locomotive engine maintenance.

Moving goods with locomotives generates less pollution than truck equivalent freight movements and specific measures that increase rail's mode share should be considered as part of a possible package of measures. These include:

- Engaging with port corporations, the Roads and Traffic Authority (RTA), RailCorp and industry to encourage greater modal shift from road to rail freight to and from GMR ports. Although net changes in port emissions may be small, wider airshed benefits would be realised from reduced road network diesel traffic and congestion. Without intervention, a large increase in truck movements is expected in the next 20 years.
- Managing truck and rail servicing charges under the Port Botany Landside Improvement Program, in support of Port Botany's 40% rail target.

Road

Diesel road vehicles contribute only a small proportion of emissions from GMR ports but their wider airshed impacts are significant, particularly health impacts of diesel particulate matter. A broad based mitigation strategy that includes and extends upon existing programs appears to be most beneficial for addressing diesel road vehicle emissions.

Measures that could be considered include:

- Extending or improving the Port Botany Landside Improvement Strategy (PBLIS) measures to reduce congestion and improve truck turnaround times at Port Botany, which in turn reduce idling emissions. Additional measures could include:
  - Engaging with port corporations and industry on the feasibility of differentiated fees for trucks of different emissions performance standard with the aim of encouraging cleaner vehicles at GMR ports. Sensitivity to pricing would need to be investigated with industry.
  - Assessing whether all or part of the PBLIS could be extended to other NSW ports (i.e. Kembla, Jackson, Newcastle). This will depend on how significantly these ports are affected by truck queuing.
- In liaison with RTA and industry, encourage further driver education to help reduce truck idling and the adoption of retrofit technologies through the NSW Diesel Retrofit Program, targeting older vehicles.

1 INTRODUCTION

1.1 Study Background

Substantial growth in world trade and the relative efficiency of shipping for bulk transport has led to increased port activity worldwide over recent decades, with a consequent increase in port emissions. This in turn has led to increased efforts to manage emissions (Saxe, 2004; Bailey & Solomon, 2004; Giuliano & O'Brien, 2007; Corbett et al, 2007; Dalsøren et al, 2009; Eyring et al, 2005; EPA, 2010). Emissions arise from ships, other vessels and landside activities within the ports. Port activity also contributes to wider urban air pollution through the heavy reliance on diesel trucks for freighting goods to and from ports. Diesel locomotives are an additional source of emissions.

The principal emissions from ports and related activities include oxides of nitrogen (NO_x) and fine particles (PM_{10}, $PM_{2.5}$) from fuel combustion, sulfur dioxide (SO_2) principally from the combustion of high-sulfur heavy fuel oil used in ships, and volatile organic compounds (VOCs) from a variety of fuel-related sources. All of these pollutants have known adverse human health effects. In Australia, and internationally, air quality standards set limits on ambient concentrations of these pollutants. NSW is committed to meeting the Australian air quality goals identified in the National Environment Protection Measure for Ambient Air Quality (AAQ NEPM).

Ports are also significant contributors to greenhouse gas emissions owing mainly to the fuel-combustion sources on ships and landside. Although greenhouse gas emissions are not the focus of this study, actions that reduce air pollution through reducing fuel use at ports would also have greenhouse emission reduction benefits.

In NSW the major ports are Ports Botany, Jackson, Newcastle and Kembla, all of which are located within the Greater Metropolitan Region (GMR). These ports provide berthing and loading/unloading facilities for international shipping and are supported by a network of transport infrastructure for the movement of goods. The port precincts generate significant volumes of freight-related traffic with commensurate environmental impacts. Figure 1-1 shows the defined NSW GMR area.

Figure 1-1: NSW Greater Metropolitan Region

In 2007, OEH released a comprehensive air emissions inventory for the NSW GMR. The analysis indicates that the key sectors responsible for emissions of ozone precursors (NO_x and some VOCs) and particles in Sydney are motor vehicles, industry and a range of products and equipment used in the domestic and commercial sectors. OEH is developing strategies and programs for these areas, incorporating initiatives that are already underway and proposed new actions. However, further measures are needed to meet the AAQ NEPM and protect human health.

The emissions inventory for the NSW GMR indicates that ships, heavy duty trucks and non-road diesel vehicles are the main port-related sources of emissions. For example, in the Botany Bay Local Government Area (LGA) ships, trucks and non-road industrial vehicles account for 26.3% of NO_x emissions, 49.3% of PM_{10} and 6.5% of VOCs. Total Botany Bay LGA emissions represent approximately 4% of NO_x, 2% of VOC, and 2% of PM_{10} and $PM_{2.5}$ for the entire Sydney airshed. The majority of emissions arise from fuel combustion aboard ships and in road vehicles, freight trains and cargo handling equipment. Port-related emissions are expected to grow as port activity increases in the future.

OEH is assessing emissions from ports so as to develop a possible framework for managing these emissions, in line with international trends. Work is being informed by consultation with organisations representing the commercial and regulatory interests of shipping, ports management and cargo handling in the NSW GMR.

1.2 Study Aims and Objectives

This study aims to identify controls and strategies to reduce air emissions from NSW ports, resulting in environmental and public health benefits. Objectives include to:

- Scope and summarise the regulatory environment for controlling emissions to air from shipping in NSW territorial waters and ports, including current Australian legislation, international agreements and departmental roles at state and federal levels.
- Scope and summarise NSW, Australian and international strategies and programs in place or under consideration to control emissions to air from ships in port zones.
- Update the estimates of key sources of air emissions at GMR ports using information from OEH inventory and other sources, including identifying any additional sources.
- Analyse the applicability of identified external strategies to NSW.
- Suggest innovative strategies that could offer potential air emission reductions in NSW.
- In particular, scope and summarise the barriers to, implementation issues and legislative or other changes required to implement:
  - low sulfur zones in GMR ports
  - shore-side power for ships at berth in GMR ports, including technical and infrastructure requirements both on-shore and on ships
  - options for controls on incinerators
  - reduced emissions from diesel locomotives.
- Scope the potential for local cogeneration facilities in association with shore-side power and identify likely viable locations.
- Estimate the potential air emission reductions through:
  - retro-fitting of pollution traps on diesel non-road and on-road machinery at ports
  - mandating USEPA Tier 1 to 4 off-road diesel standards or similar.
- Identify major stakeholders and summarise their positions in relation to items 3-12 above.
- Detail key implementation issues/ critical steps for implementation for items 3-12 above. This will include identifying partners for cooperative actions and likely costs and benefits of proposed measures.

1.3 Study Methodology and Document Outline

The following research and assessment tasks were undertaken:

- Quantification of the amount and type of emissions of particles, sulfur oxides, nitrogen oxides and volatile organic compounds to air from ships, off-road equipment and on road mobile equipment at each port in the GMR using data provided from OEH's air emissions inventory and other available sources.
- Identification of and consultation with major stakeholders on possible policy options. Stakeholder positions and their level of support for policy options are included in this report.
- Estimation of broad emission reductions and preliminary costs and benefits for each policy option along with strategies and possible implementation issues.
- Discussion, in this report, of the potential scope for reducing emissions from shipping and other sources of air emissions in NSW ports through implementing emission control strategies, including:
    - emission control regulations and strategies in place in NSW ports and other state and international jurisdictions
    - relevant technological or operational changes that could deliver emission reductions in GMR ports
    - the range of policy options suitable for NSW ports, ranked according to feasibility, abatement and cost benefit potential
    - stakeholder positions on the primary strategies identified
    - potential emission reductions and preliminary costs and benefits of identified strategies
    - implementation issues and timeframes indicated in evaluations of regulatory, technological and other controls used in other jurisdictions.

This report then recommends a package of strategies likely to be most effective in NSW.

2 REGULATORY ENVIRONMENT AND PORT EMISSION SOURCES

2.1 Legal Jurisdictions

Under the United Nations Convention on the Law of the Sea (UNCLOS), port and coastal States have jurisdiction over ships entering their waters and can implement emissions mitigation strategies (Hildreth and Torbitt, 2010). However, signatories to UNCLOS must enact enabling legislation for the International Maritime Organisation’s (IMO) Convention MARPOL (short for Marine Pollution) Annex VI.

Under MARPOL Annex VI, ships over 400 gross tonnes under the flag of a party to MARPOL Annex VI must carry an International Air Pollution Prevention (IAPP) certificate. A port or coast State may block access to any vessel not complying with the IAPP requirement.

According to Hildreth and Torbitt, UNCLOS effectively allows port States to establish standards that exceed the IMO conventions and to prohibit ships from entering their waters if they do not comply (Hildreth and Torbitt, 2010). Hildreth and Torbitt cite examples such as California’s low sulfur fuel standards for ocean going vessels within 24 nautical miles of the coast and a Swedish port city’s law requiring NOx control systems on new and existing vessels. Note that UNCLOS Article 26 places restrictions on charges that can be levied on ships, requiring that a service is provided to the ship in return for any payment.

The International Council on Clean Transportation (ICCT, 2007 p40) states that MARPOL 73/78 does not prevent a country from setting standards for its ships. They assert that Annex VI specifically allows a country to set alternative standards that would apply to engines on ships that operate solely in waters under its jurisdiction and that the United States and several European nations have begun to address shipping emissions in their waters based on this authority.

2.2 Regulations Applying to Ports

Under traditional law of the sea, ships have the right of ‘innocent passage’ when transiting territorial and international water. For this reason, the regulatory environment concerning ports and coastal waters is governed by both domestic and international maritime law. The regulatory environment includes key environmental and other legislation in NSW and Australian as well as international maritime legislation. The following sections outline relevant legislation that relate to the regulatory environment at and around ports within the NSW GMR. Further details on the regulatory environment are provided in Appendix A.

2.2.1 IMO MARPOL Annex VI 2008 and Emission Control Areas

The IMO enacted MARPOL Annex VI, also known as the ‘International Convention for Prevention of Air Pollution by Ships’, to control exhaust emissions from international ships. Annex VI limits SO_2 and NO_x emissions from ships. SO_2 emissions are regulated by prescribing limits on fuel sulfur content. Reduced sulfur content significantly reduces particle emissions so MARPOL Annex VI effectively regulates particle emissions but without prescribing limits. VOC and CO emissions from ships engines are not presently regulated.

MARPOL Annex VI also designates Emission Control Areas (ECAs) where lower sulfur fuels and/or lower NOx emissions are required. At present, fuel of sulfur content not greater than 1% must be used in ECAs. This decreases to 0.1% sulfur from 2015. Low sulfur fuel must be used in main engines, auxiliary engines and auxiliary boilers. An ECA can cover NOx, SO_2 or particles, or all three types of emissions.

The provisions of MARPOL Annex VI (as revised in 2008) are:

- 2005 – global IMO Tier 1 NOx limits for new engines post 2000
- 2010 - ECA fuel sulfur 1%
- 2011 – global IMO Tier 2 NOx limits for new engines (IMO Tier 1 less 15 to 20%) (engine tuning)
- 2012 – global maximum fuel sulfur 3.5% (currently 4.5%)
- 2015 - ECA fuel sulfur 0.1%
- 2016 - ECA Tier 3 NOx for new engines (IMO Tier 1 less 80%) (exhaust gas after treatment)
- 2020 - global fuel sulfur 0.5%, if refineries can produce it. To be reviewed in 2018.
- Retrofit of NOx controls to engines greater than 5 MW and cylinder displacement at or above 90 litres installed 1990 to 2000 so they meet IMO Tier 1. To be fitted within 12 months of an approved conversion kit becoming commercially available for any particular engine.
- Exhaust gas scrubbers can be used as an alternative to low sulfur fuel, if the exhaust SOx is shown to be equivalent to the use of low sulfur fuel.

The International Air Pollution Prevention (IAPP) and Engine International Air Pollution Prevention (EIAPP) certificates, which complying ships must carry, detail their control equipment for NOx, fuel sulfur, fugitive emissions of VOC and ozone depleting substances, and shipboard incineration.

2.2.1.1 Process for Designation of an IMO ECA

The Commonwealth Government can apply to the IMO to designate waters adjacent to the coast of NSW an ECA. The ECA proposal needs to be supported by an assessment showing how emissions from ships are contributing to ambient air pollution and a description of the resulting adverse impacts (human health and the environment). The proposal also needs to describe the land-based measures for addressing emissions and demonstrate the relative cost effectiveness of reducing emissions from ships compared with land based controls.

2.2.2 Protection of the Sea (Prevention from Pollution from Ships) Act 1983

The Protection of the Sea (Prevention from Pollution from Ships) Act 1983, administered by the Australian Maritime Safety Authority, implements the MARPOL Convention in Australian Commonwealth waters. It includes provisions enacting MARPOL Annex VI, which refers specifically to air pollution.

Jurisdiction under this Act extends from 3 nautical miles (nm) out to the Australia Exclusive Economic Zone (200 nm) and also applies within the 3nm limits where the State or Territory does not have complementary legislation.

2.2.3 NSW Marine Pollution Act 1987

The NSW *Marine Pollution Act* 1987 is administered by NSW Maritime and protects the NSW marine environment from pollution caused by commercial, recreational and trading vessels operating in NSW waters. The Marine Pollution Act currently enacts MARPOL Annex I and II regarding sewerage, garbage, oil and noxious liquids but does not specify limits on emissions to air. The NSW Government is currently amending the act to include MARPOL Annex III, IV and V but is not proposing to include Annex VI. NSW Maritime could seek to align the requirements in the Act with IMO MARPOL Annex VI, if a regulatory case was established.

2.2.4 NSW Protection of the Environment Operations Act (POEO) 2010

The *Protection of the Environment Operations Act* 1997 ("POEO Act") is the key piece of environment protection legislation administered by OEH. The Protection of the Environment Operations (Clean Air) Regulation 2010 ("Clean Air Regulation") limits the sulfur content of liquid fuel to 0.5% by weight. The prescribed limits are broadly in line with IMO standards for open seas, but much higher than those prescribed for ECAs.

The Protection of the Environment Operations (General) Regulation 2009 includes shipping facilities (bulk cargo handling) in Schedule 1. Under the Regulation, a vessel whilst berthed at premises licensed as shipping facilities is subject to conditions of an Environment Protection Licence (EPL) if vessels are described in the EPL as being part of the premises[a].

2.2.5 NSW Port Botany Landside Improvement Strategy

The Sydney Ports Corporation established the Port Botany Landside Improvement Strategy (PBLIS) to improve the competitive access and service arrangements for container movements between stevedores and transport carriers at Port Botany.

The Ports and Maritime Administration Amendment (Port Botany Landside Improvement Strategy) Regulation 2010 governs the PBLIS and associated Mandatory Standards which came into effect in December 2010.

The Regulation provides for:

- the setting of and compliance with performance standards relating to access by road carriers to the Port Botany Container Terminals, the performance of road carriers at those terminals and the performance of stevedores in providing services to road carriers at those terminals; and
- the regulation by the Portfolio Minister of charges imposed by stevedores and service providers for or in connection with the operation or provision of facilities or services of the port-related supply chain at Port Botany, including truck servicing and rail servicing charges.

The objective of the PBLIS program is to maximise the amount of trade passing through Port Botany by making the landside supply chain more efficient, transparent and consistent, and with transitioning to 24/7 operations. Stage 1 in 2011 implements an Operational Performance Management framework for road, regulates rail pricing and monitors activity to determine if the desired change in industry performance has been achieved. If the desired performance has not been achieved, stage 2 from 2012 onwards may include a Demand Management System, a review of Empty Container Parks and/or the introduction of rail regulated performance standards.

At present, only truck services are governed by the PBLIS but the Sydney Port Authority remains committed to the target of 40% carriage of freight by rail. The PBLIS rail program is considering specific mode share targets for stevedores, setting a maximum cap on rail pricing at the port interface and ensuring there is price equity between rail and road.

[a] Section 56 of the POEO Act. "Premises" may include a vessel as defined in the Act. For example of this application, see condition A2 of EPL 12095.

2.3 Examples of Regulatory Actions taken in other Jurisdictions

2.3.1 EU Directive on fuel sulfur in EU Ports

The European Union (EU) has enacted a fuel sulfur directive that requires 0.1% sulfur or less in ships at berth from January 1, 2010. The sulfur limit applies to all fuel used in any machinery on ships alongside berth, at buoys or anchored whether or not they are working cargo, but allows higher sulfur fuels while ships are manoeuvring. Passenger vessels must use fuel of sulfur content not greater than 1% while moving between EU ports.

2.3.2 Californian Fuel Sulfur Requirements for Ships within 24 nm of the Coast and the North American ECA

The State of California has imposed controls on fuel type and sulfur content for all ship diesel engines and auxiliary boilers used within 24 nautical miles of the coast. Propulsion boilers are excluded from the requirement. From July 2009 marine gas oil (MGO) and marine diesel oil (MDO) is required. MGO is limited to 1.5% sulfur and MDO is limited to 0.5% sulfur. From January 2012, the fuel must contain no more than 0.1% sulfur. Shipowners have unsuccessfully challenged California's legal right to impose these restrictions.

From August, 2011, a North American ECA established under IMO MARPOL VI comes into effect. It applies out to 200nm from the east and west coasts of USA and Canada and covers NOx, SO_2 and particles. From August 2012 to January 2015, a 1% sulfur limit applies to all fuel used within the ECA (0.1% from 2015). The exception is California, where the lower fuel sulfur limits described above will be applicable. As suitable heavy fuel oil is increasingly less available, ships will need to use distillate fuel and/or scrubbers. California has not indicated whether it intends to permit scrubbers as alternatives to low sulfur fuel as occurs in the EU under MARPOL Annex VI.

2.4 Summary of Port Emission Sources

Emissions from NSW ports can be separated into four main source categories:

- shipping;
- cargo handling;
- associated diesel rail freight; and
- associated diesel road freight.

The emissions from these emission source categories are summarised in Table 2-1.

Table 2-1: Source of Port Emissions in NSW Ports within the GMR

Source of Emission	Emissions (tonnes/annum)				
	PM_{10}	$PM_{2.5}$	NO_x	VOC	SO_2
Shipping	892	820	9,688	198	7,187
Cargo handling	59	58	1,082	97	0.5
Associated diesel rail freight	156	151	8,154	317	9
Associated diesel road freight	0.5	0.5	19	1	0.1
Total emissions from ports in GMR	**1,108**	**1,030**	**18,943**	**516**	**7,197**
Total emissions in GMR [a]	75,128	30,499	292,054	171,067	301,863
Percent of GMR emissions	1.5	3.4	6.5	0.3	2.4

[a] Total anthropogenic emissions for the GMR, Technical Report No. 1 (DECC, 2007). Port emission estimates are based on 2008 data supplied by OEH (2011).

The significance of each emission category is also illustrated in Figure 2-1. As all the assessed $PM_{2.5}$ emissions were from uncontrolled combustion sources the $PM_{2.5}$ figure is identical to the PM_{10} figure and is not depicted graphically. Shipping is the dominant source of SO_2, PM_{10} and $PM_{2.5}$ from GMR ports. It also emits over half of the NO_x and a third of VOCs. Rail freight accounts for over half of the VOC emissions and over a third of NO_x emissions.

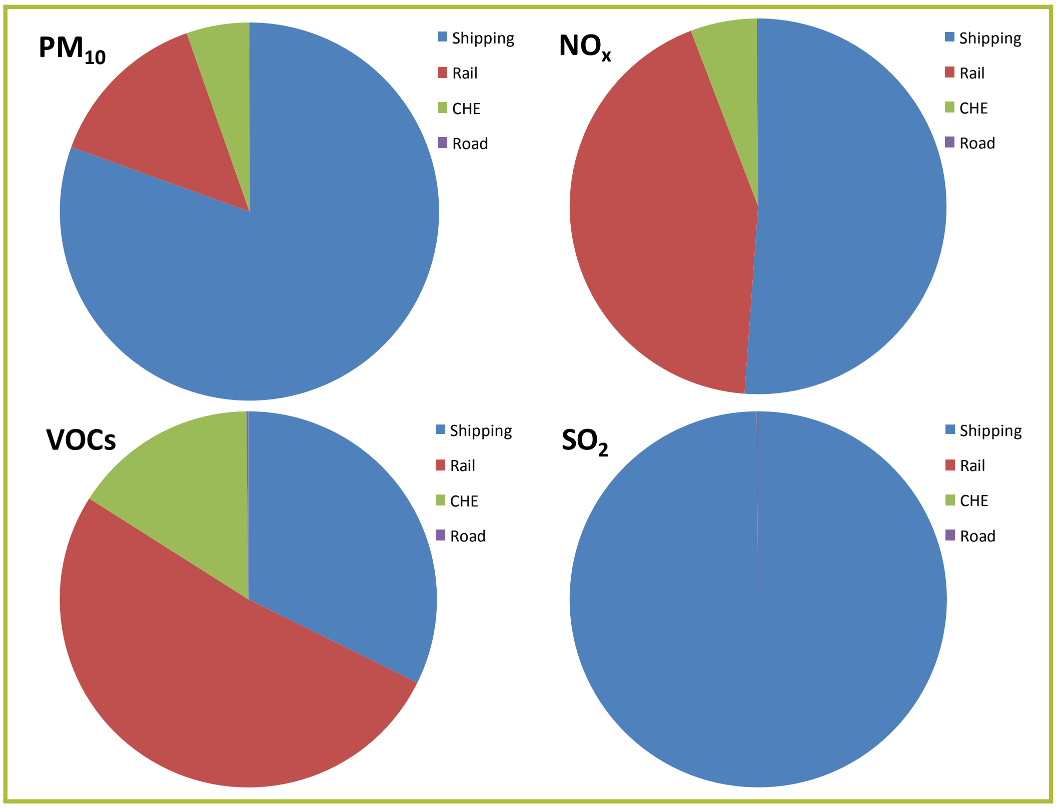

Figure 2-1: Total GMR Port Emissions Summary

For Port Botany, emissions form the following proportion of total emissions for the Botany Bay LGA: PM_{10} 49.3%, NO_x 26.3% and VOCs 6.5%. Figure 2-2 shows the four emission source categories for Port Botany only. Rail freight activity is significantly lower at Port Botany than at other GMR ports while cargo handling activities are higher. This suggests different emission reduction strategies may be warranted for different ports.

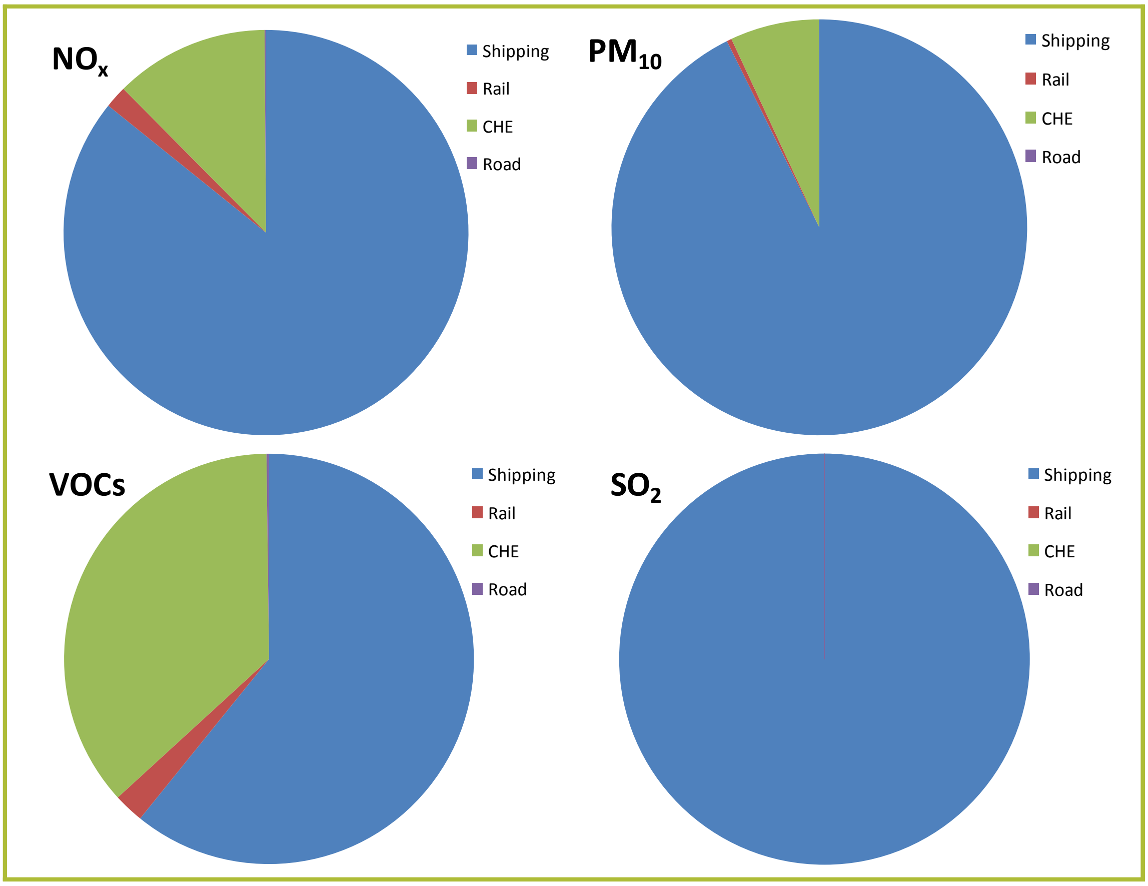

Figure 2-2: Port Botany Emissions Summary

Each year particle emissions from NSW ports are estimated to result in health costs of approximately $183 million[b] (DEC, 2005). Emissions growth from NSW port freight movements, in the absence of improved management, is projected to be high. Air pollution and greenhouse gas emissions from commercial vehicles in the GMR are forecast to grow nearly four times faster than from passenger cars with projected growth in road freight especially pronounced. Growth in emissions is due largely to a forecast increase in throughput of twenty foot containers (TEUs) from 1.62 million in 2007 to 3 million in 2020.

[b] The NSW Office of Environment and Heritage valued PM_{10} emissions at $136,000/tonne in 2003 dollars, which is $165,450 in AUD 2010 (DEC 2005).

3 SHIPS

3.1 Ship Emissions

Ships are generally powered by large diesel engines operating on low quality fuel oil of relatively high sulfur content (average around 2.7% sulfur by mass). These large slow revving diesel engines produce more NO_x and particle emissions per unit of power output than smaller automotive diesel engines. The sulfur content of marine fuels is emitted as SO_2, leading to secondary formation of very fine aqueous sulfate particles. The shipping industry provides a market for low quality residual oil produced during oil refining and so contributes to the overall economics of oil as a fuel source.

Ships use diesel powered electrical generators on board for lighting, air conditioning, control systems, fuel and water systems, bow thrusters and cargo handling. Ships also use oil fired boilers for fuel heating, cargo heating and to produce steam to supply turbines for cargo and ballast pumping. Cruise ships have relatively high electrical loads to supply the needs of passengers. Container vessels also use electricity to run refrigerated containers. Oil tankers tend to use fairly inefficient steam driven pumps to deliver cargo, driven by oil fired boilers.

OEH estimates that in 2008, ships emitted 9,688 tonnes of NOx, 7,187 tonnes of SO_2 and 892 tonnes of PM_{10} in the NSW GMR. Main propulsion engines in cruise mode at sea between the boundary of the NSW GMR and the port entrances were the greatest source of emissions, followed by auxiliary engines at berth and auxiliary boilers at berth. While the berth emissions were less than the cruise emissions, the proximity of berth emissions to population centres causes greater adverse health effects. More details on the methodology are provided in Appendix B.

Ship emissions in the NSW GMR were estimated for calendar year 2008. The estimates involved tracking individual ships and estimating emissions from the main propulsion engines, auxiliary generator engines and auxiliary boilers. Operating modes include anchorage, berth, cruise, movement in the Restricted Speed Zone and manoeuvring. Fuel consumption and emissions by port, operating mode and machinery type are listed in Table 3-1.

Table 3-1: Fuel Consumption and Emissions from Ships at Major NSW Ports

Port	tonnes/annum							
	Fuel	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	CO	CO_2
Overall total	146,005	9,688.4	7,187.3	891.8	820.4	200.7	459.4	463,698
Botany total	66,782	4,413.3	3,416.9	421.6	387.9	91.7	200.2	212,084
Newcastle total	30,468	2,171.4	1,379.0	177.0	162.8	43.4	89.8	96,772
Kembla total	17,365	1,266.5	835.8	107.3	98.7	24.9	55.1	55,152
Jackson total	31,389	1,837.2	1,555.5	185.9	171.1	40.6	114.4	99,690
Main Engine total	74,146	6,554.4	3,870.4	530.0	487.6	109.2	216.9	235,465
Auxiliary Engine total	46,056	2,956.4	1,969.9	239.1	220.0	82.8	225.6	146,291
Auxiliary Boiler total	25,803	177.7	1,346.9	122.7	112.9	8.7	16.9	81,942

Note that these figures are for ocean going vessels, and do not include commercial boats. Relative emission contributions by port for NOx and PM_{10} are illustrated in Figure 3-1

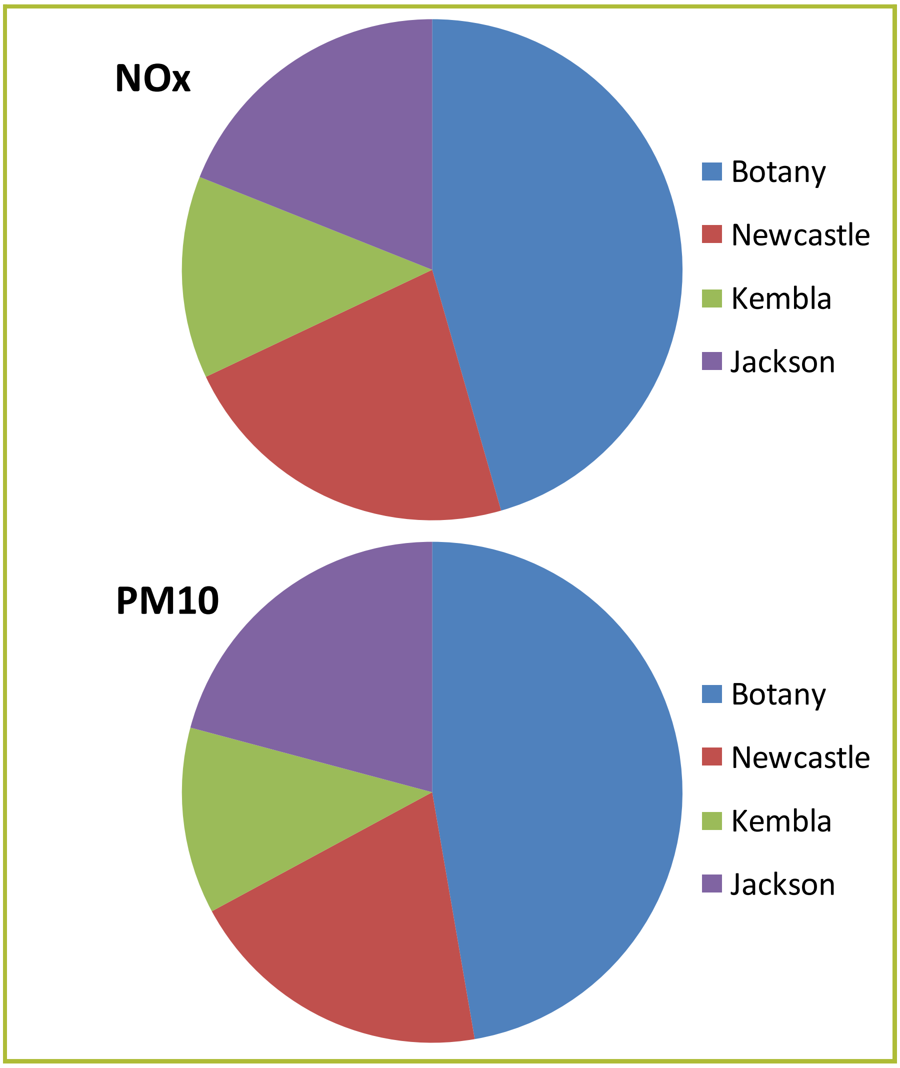

Figure 3-1: NO_x and PM_{10} Emissions by Port (tonnes/annum)

3.1.1 Port Boundaries and Restricted Speed Zone

Port boundaries at sea are defined by an arc centred on a defined point at the harbour entrance. For Botany and Jackson, the radius of the arc is 4 nautical miles. For Newcastle it is 3 nautical miles and for Kembla it is 2.5 nautical miles. The Restricted Speed Zones are administered by the Maritime Safety (General) Regulation 2009 and begin at the harbour entrance. They exist for operational safety within the confined harbour waters. Ships generally approach and depart the ports at ocean cruise speed.

3.2 Emission Mitigation Measures

3.2.1 Summary of Mitigation Measures

The two potentially most effective options to reduce emissions from ships are the use of low sulfur fuel and shore power. For low sulfur fuel, there is a range of options for the level of fuel sulfur and the extent of the area in which the fuel sulfur is controlled. Reducing fuel sulfur significantly reduces particles as well as sulfur dioxide emissions. Further control measures include use of exhaust gas scrubbers for sulfur emissions, vessel speed reduction, emissions capture and treatment, and restrictions on use of incinerators. Various technologies are available for reducing NO_x emissions. A summary of each identified measure is provided below and ship emission mitigation measures are described in more detail in Appendix C.

Globally, implementation of ship emission reduction measures has been driven largely by either regulation or the provision of incentives to reward changed practices. Some emission reductions have been achieved with voluntary initiatives. The international regulatory regime was presented in Section 2.1. Case studies of emission reduction incentives such as differentiated fees and direct levies are presented in Appendix C.

Identified ship emission mitigation options include:

1. Mandatory low sulfur fuel at berth: The use of low (0.1% by mass or less) sulfur fuel in ship auxiliary engines and auxiliary boilers if berthed for more than 2 hours, or the use of exhaust gas scrubbers to achieve equivalent results. The use of fuel of sulfur content 0.1% or less by mass is mandatory for ships at berth in EU ports, or equivalent reductions in SO_2 emissions by use of exhaust gas scrubbers.
2. Mandatory low sulfur fuel within a given distance from the coast: Required use of low sulfur fuel in ship main engines, auxiliary engines and auxiliary boilers within a given distance of the coast. This approach is applied in California where low sulfur distillate fuel is required within a 24 nm regulatory zone. From 2012, the required sulfur content will drop to 0.1%.
3. Sulfur Emission Control Areas (ECAs) under IMO MARPOL Annex VI: Ship main engines, auxiliary engines and auxiliary boilers must use fuel of sulfur content 1% or less in ECA waters (0.1% from 2015). ECAs currently exist in the Baltic Sea, North Sea, English Channel and North American east and west coasts. The North American ECA extends to 200 nm from the coast. The Mediterranean is likely to be declared an ECA in the near future and an ECA around Singapore is mooted. An Australian ECA in the near future is unlikely. However, it would have the advantage of creating an even playing field for all ports encompassed by the ECA.
4. Sulfur Reduction Incentives: Port fees have been differentiated according to the sulfur content of fuel used by the ship while at berth. The Vancouver model involves a direct rebate for use of low sulfur fuel. The World Ports Climate Initiative (WPCI) model involves a graduated fee according to environmental performance relative to international norms, measured by the Environmental Ship Index (ESI).
5. Shore power (Cold Ironing): Some ports are mandating the use of shore power where facilities are provided by the ports. In a number of cases capital grants have been offered to frequent users of ports to assist in the installation of suitable infrastructure on visiting ships.
6. Voluntary use of low sulfur fuel: Some shipping companies are voluntarily choosing to use low sulfur fuel. The Fair Winds Charter involves a number of shipping lines who are voluntarily using fuel of sulfur content 0.5% or less in Hong Kong Port. Closer to home, Maersk recently announced that it will voluntarily use low sulfur fuel in New Zealand ports.
7. Vessel Speed Reduction (VSR): Reducing vessel speed within a specified geographical limit reduces fuel consumption and emissions. The Ports of Los Angeles and Long Beach in California offer reduced port fees for voluntary speed reduction to 12 knots within 20 or 40 nautical miles of the coast.
8. IMO ECA that limits NOx emissions: From 2016 in IMO ECAs ships built in 2016 or later will need to reduce NO_x emissions to around 80% of current levels (IMO Tier 3). The impact on total NO_x emissions will be limited however as only new engines will need to meet the ECA standards.
9. NO_x Incentives: Swedish ports offer differentiated port fees according to NO_x emissions. This encourages retrofitting of emissions abatement measures to existing engines. In a number of cases capital grants have been offered to frequent users of ports to assist in the cost of fitting emission control technologies.

10. LNG bunkering facilities: Planning for LNG bunkering facilities at ports to supply fuel to LNG powered vessels would encourage uptake of LNG fuelling. This is a growing international trend offering large reductions in emissions of SO_2, NOx and PM_{10} emissions at relatively low cost compared with other control measures, although LNG fuelling is really only an option for new ships. There is potential to share production and distribution infrastructure with local LNG production for road transport.

3.2.2 Reduced Ship Queuing times

A review of options to reduce ship times at port or a regular audit of actual practices and times could help to reduce the numbers of queued ships around ports. Reduced queuing would have significant economic drivers.

3.2.3 Low Sulfur Fuel

A straightforward method of reducing emissions is to reduce the fuel sulfur content. Ships generally use low quality fuel oil (Residual Oil, RO) which has a relatively high sulfur content. The global average is around 2.7% sulfur by mass. There is a limit to how far the sulfur content of RO can cost-effectively be reduced. Low sulfur RO down to 1% sulfur content is available. Higher quality marine diesel fuels with sulfur content as low as 0.1% (i.e. distillates such as MDO and MGO) are produced, at a greater cost, but are not generally available in Australia. If ships were required to use fuel other than heavy fuel oil in or near port, they would have to either bring MDO or MGO with them or use Australian Ultra Low Sulfur Diesel (ULSD), which has very low sulfur content. Natural gas is another alternative fuel but is not as easy to implement as low sulfur distillate.

Internationally, where significant fuel sulfur reductions are sought in areas of high shipping activity close to land, fuel with less than 0.1% sulfur content (MGO) is the ultimate aim. It is currently required in EU ports, will be required in IMO ECAs in 2015 and will be required on the Californian coast in 2012. Transitional arrangements could involve a period during which fuel of higher sulfur content is allowed, as applied in California.

For any given engine, using MGO fuel with sulfur content of 0.1% may reduce particles by 80-90%, SO_2 by 80-90% and NO_x by 5-6%. Alternatively, using RO with 1% sulfur content may only reduce particles by 20% and SO_2 by 50-60%.

Low sulfur MGO costs at least 50% more than conventional RO. There would also be capital costs for shipowners to modify on-board systems to allow use of low sulfur fuel in auxiliary engines and auxiliary boilers of $6,800-$34,000 per boiler. More details are provided in Appendix C.

This is a significant cost impost on the shipping industry. RO at relatively low sulfur content around 1% is currently available at marginally higher cost than conventional RO. These price differences could increase with greater demand for low sulfur fuel.

It is important to note that there are operational and safety concerns associated with making the switch to low sulfur fuels. Many ships are built to operate on RO and they may have problems burning distillate unless design modifications are made. This applies to main engines, auxiliary engines and auxiliary boilers. These issues are further detailed in Appendix C.

Using low sulfur RO (available at around 1% sulfur content) would avoid many of the operational or safety concerns associated with using low sulfur distillate (MGO 0.1% sulfur content). However, the emissions reductions would not be as significant and experience shows that switching to low sulfur distillate can only be done safely if the appropriate measures are put in place.

As is the international norm, the use of exhaust gas scrubbers to achieve equivalent reduction in SO_2 emissions should be allowed. Scrubbers are described in more detail in Appendix C.

3.3 Assessment of Ship Emission Control Methods

3.3.1 Low Sulfur Fuel at Berth

The effect on emissions of using MGO with 0.1% sulfur content for auxiliary engines and auxiliary boilers on all ships at berth in Ports Kembla, Botany, Jackson and Newcastle are shown in Table 3-2.

Yearly emissions avoided are estimated to be more than 200 tonnes of particles and more than 2,000 tonnes of SO_2. Reductions in NOx emissions are relatively small. Emission reduction estimates were calculated using OEH's ship emissions inventory model (Appendix B).

Table 3-2: Reduction in emissions with low sulfur fuel option (0.1%S MGO) for auxiliary engines and auxiliary boilers for all vessels while at berth

	Mass of fuel and emissions reduced, tonnes/annum							
	Fuel	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	CO	CO_2
Total mass reduction (tonnes)	1,367	90.4	2,232	216.9	199.5	0	0	4,130
% reduction in total mass across all operating modes	0.9	0.9	31.0	24.3	24.3	0	0	0.9

3.3.1.1 Policy Considerations

Use of low sulfur distillate at berth could be required under Environment Protection Licences (EPLs) for any new port facilities, and renegotiated EPLs for existing premises, where vessels tied at berth are defined as part of those premises. This would subject vessels to the current 0.5% fuel sulfur limit.

In evaluating the potential costs and benefits of the mandatory use of low sulfur fuel, consideration needs to be given to the costs for administration and compliance, particularly the possible impacts on the commercial viability of affected businesses.

3.3.2 Low Sulfur Fuel in NSW GMR

In 2020, the global IMO MARPOL Annex VI fuel sulfur standards will require the use of fuel of sulfur content 0.5% or less for all shipping outside ECAs which is significantly less than the current average content of around 2.7% sulfur by mass. It should be noted that this requirement will be subject to review in 2018, based on the availability of sufficient quantities of such fuel globally.

However, 0.5% fuel sulfur content is still well in excess of the sulfur content of diesel fuels for land based transport (0.001%). If lower sulfur fuels are desirable, or interim measures needed prior to the lowering of sulfur in fuel in 2020, the use of low sulfur fuel by ships operating within the NSW GMR could be assessed.

Low sulfur fuel could be mandated for main propulsion engines as well as auxiliary engines and auxiliary boilers throughout all operating modes. Ships generate the most emissions when in cruise mode when their main engines consume large amounts of fuel (Table 3-1). Generally, it takes between 45 minutes and 4 hours for a cruising ship to completely change from heavy fuel to distillate for a typical slow speed marine diesel engine. Auxiliary engines can be switched over in less time.

The reduction in emissions through requiring use of MGO with 0.1% sulfur content for all machinery on all ships while operating in the NSW GMR, including at berth, are shown in Table 3-3. The use of the GMR boundaries for this analysis is roughly equivalent to a low sulfur fuel zone boundary at 20 to 30 nautical miles from the coast, as described in Appendix B Section 9B.13.

Yearly emissions avoided are estimated to be more than 700 tonnes of particulate matter, nearly 7,000 tonnes of SO_2 and more than 500 tonnes of NOx.

Table 3-3: Reduction in emissions of implementation of low sulfur fuel (0.1%S MGO) for main engines, auxiliary engines and auxiliary boilers for all vessels while in the NSW GMR

Operating Mode	Mass of fuel and emissions tonnes/annum							
	Fuel	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	CO	CO_2
Total mass reduction (tonnes)	5,714	528	6,913.0	769.9	708.3	0	0	17,507
% reduction in total mass across all modes	3.9	5.5	96.2	86.3	86.3	0	0	3.8

In terms of fuel costs and operational complexity, using low sulfur fuel in the main propulsion engines is a significantly greater impost on ship operators than requiring low sulfur fuel use at berth alone. There is a significant risk of problems with fuel changeover in main engines and thus loss of propulsion while underway. The international experience being developed (starting with California from 2012) regarding fuel changeover and operation on low sulfur fuels whilst cruising will provide more detailed information on this measure in the near future.

3.3.2.1 Policy Considerations

There are legal issues concerning jurisdiction at certain distances from the coast under the UNCLOS. In California, state law authorises the Air Resources Board (ARB) to regulate marine vessels to the extent such regulation is not pre-empted by Federal Law. ARB has established through extensive studies that atmospheric conditions transport air pollutants from that zone to the coastal communities and adversely affect the health, welfare and safety of people in those communities. As such, California requires the use of low sulfur fuel within 24 nautical miles of the coast. An existing legislative mechanism by which NSW could impose similar restrictions was not determined during this study.

The declaration of an IMO ECA for Australia would mandate low sulfur fuel of 0.1% or less from 2015 and provide a level playing field for all Australian ports. See Section 2.2.1.1 for the steps required to seek the establishment of an Australian or NSW GMR ECA under MARPOL Annex VI. Alternatively, an ECA could be sought only for Sydney or the NSW GMR. Operational considerations such as the distance from the coast at which the low sulfur fuel requirement would apply should be determined based on cost, analysis of the dispersion of the emissions and the resultant contribution to urban pollution and associated adverse human health impacts.

3.3.2.2 Stakeholder comment on the use of low sulfur fuel

There is some support for the use of cleaner fuel. It was noted that verifying compliance can be difficult. Generally it is felt that low sulfur fuel is best mandated through the IMO conventions. The existence of ECAs in other parts of the world will tend to normalise the use of low sulfur fuel. Installation of LNG facilities might be an option when new berths and landside facilities are developed.

3.3.3 Shore Power

Shore power, also referred to as cold ironing, involves switching off auxiliary engines at berth and supplying the ships with electricity from shore. Auxiliary boilers for steam and hot water remain in operation at berth. The rate of uptake of the shore power option is limited by the high capital cost required for both ports and shipowners. The emissions benefits at berth also depend on the contribution of auxiliary boilers to total emissions because auxiliary boilers are still burning fuel at berth. Use of shore power has the significant added benefit of protecting adjacent premises from the noise from the generators.

For NSW ports, the ship emissions inventory shows that the greatest auxiliary engine energy production is for container vessels at Botany, followed by cruise vessels in Port Jackson at Sydney Cove and Darling Harbour.

The feasibility of installation of shore power depends on the physical space on the wharves, the available electrical supplies and the number of relevant cruise vessels that have shore power capability or can be reasonably converted. The maximum auxiliary engine power generation indicates the peak electrical loading which would need to be supplied from the shore. The greatest peak loads occur for cruise vessels at Sydney Cove and Darling Harbour. The maximum electricity demand for any individual vessel at these berths is 11 MW, which would require a large substation. The greatest cost benefit for installing shore power at berths and connections on ships would be obtained for frequent visitors with high auxiliary engine energy production per visit.

If all container vessels visiting Botany for the inventory year used shore power for their total berth duration, emissions of more than 700 tonnes of NOx, nearly 600 tonnes of SO_2 and more than 70 tonnes of particles would be avoided. This would involve installing shore power on a number of berths and container vessels.

If all cruise ships visiting Port Jackson for the inventory year used shore power for their total berth duration, emissions of nearly 200 tonnes of NOx, nearly 160 tonnes of SO_2 and nearly 20 tonnes of particles would be avoided. Only three berths would need to install shore power and 34 cruise ships would need to be converted.

The cruise ship berths are the most realistic targets for implementation of shore power in the near future, given their proximity to the city centre and the global tendency for cruise ships to use shore power. Two ships and one berth accounted for 42% of the visits, and one of those ships, accounting for 12% of visits, already has a shore power connection.

Most existing berths in the NSW ports do not have sufficiently sized substations to provide shore power to ships. Some recently developed berths have been required under planning approvals to make spatial provision for shore power, should it be used in future. The cost of installation of the shore power facility may be $4 million or more per berth if new substations need to be installed. The cost of installation of the facility per ship is of the order of $0.5 million. The high capital investment for ports and ship owners is a barrier and reduces the overall cost-effectiveness of this option when considered against the emissions savings. However, the current purchase cost of electricity is less than the cost of fuel to run ship auxiliary generators, depending on the means used to generate the shore power and the required fuel sulfur content. Also, there will be reduced auxiliary engine maintenance costs.

3.3.3.1 Cogeneration

This electrical supply can be achieved by one of the following methods:

- using electricity supplied from land grids;
- using low emission diesel or gas turbine cogeneration systems located near the port, with the waste heat used to supply an industrial heating task.

Use of cogeneration will increase the efficiency of diesel generators, which already exceeds the efficiency of coal electricity generation. The benefits depend on emissions produced in the alternative electrical generation systems and the savings in emissions from supply of waste heat to industry with the cogeneration option. It is not feasible to supply steam or hot water from the cogeneration facility to the ships to replace their use of auxiliary boilers. The fitting of suitable supply lines would be difficult. There are no suitable industries near the Port Jackson cruise ship berths that could use the heat from cogeneration. There are suitable industries at Ports Botany, Newcastle and Kembla. However, there is generally not enough space available on the wharves for the cogeneration plant, so it would need to be located near the industries using the heat, with the electricity reticulated to the ships. A specific investigation would be required to identify industries, their heat requirements and an evaluation of how those heat requirements match the potential electricity requirements estimated, as well as an evaluation of the likely running time of the generator and any impacts on industry of switching it off when ships are unable to use the power.

There does not appear to be widespread use of cogeneration specific to ports. A cogeneration facility has been operating at Long Beach within the Port of Los Angeles since 1989 and some ports such as Singapore appear to have some associated activities that benefit from energy or steam from nearby cogeneration facilities.

3.3.3.2 Policy Considerations

Negotiated inclusion of a requirement for provision of shore side power as a condition on the Environmental Protection Licence (EPL) is a feasible means for implementation. Additionally, if the vessels are described in the EPL as being part of the premises, the licence may assist in compelling use of shore power, where it is available. As noted previously, the use of an EPL requirement for premises to require action of a third party vessel is has not been fully tested. However, the provisions exist and can be considered when negotiating or renegotiating licence conditions for new or significant redevelopment of port berths.

In evaluating the potential costs and benefits of shore side power, consideration needs to be given to the impacts on industry and costs for administration and compliance, particularly possible impacts on the commercial viability of affected businesses.

3.3.3.3 Stakeholder Comment on Shore Power

There was generally poor support for the introduction of shore power for a number of reasons. These include the high cost for the installations on the berths and on ships, insufficient repeat visits from individual vessels, the limited capacity of the local electricity network, the small number of ships already equipped, the variety of connection standards, limited available space at berth and that no existing berths are immediately suitable.

The nature of the bulk carrier trade means that there are many different ships calling in NSW ports. Stakeholders felt that only some car carriers were likely to visit the ports often enough to make shore power a cost effective emission reduction option. Cruise vessels and container vessels were considered to visit too infrequently to make the necessary investment in shore power worthwhile. Financial incentives for shore power infrastructure would be desirable from the industry perspective.

3.3.4 Vessel Speed Reduction

Slowing the speed of ships as they approach or depart the ports results in overall less fuel use and reduced overall emissions. Reduced vessel speeds demand less power from the main engine, which in turn reduces emissions and fuel consumption. A 10% speed reduction may reduce emissions by approximately 20%. A 20% speed reduction may reduce emissions by approximately 35%.

The impacts of reducing speed by 10% and 20% were estimated using the inventory model for all visits within the NSW GMR for the inventory year. The use of the GMR boundaries for this analysis is roughly equivalent to a Reduced Speed Zone boundary at 20 to 30 nautical miles from the coast, as described in Appendix B.

For a 10% speed reduction the estimated annual emissions avoided are 1280 tonnes of NOx, 755 tonnes of SO_2 and 103 tonnes of PM_{10}. For a 20% speed reduction scenario the estimated annual emissions avoided are 2240 tonnes of NOx, 1322 tonnes of SO_2 and 181 tonnes of PM_{10}. Reducing vessel speed also reduces greenhouse gas emissions.

Note that ships already operate at reduced speeds within the harbours (the Restricted Speed Zone) for operational safety (see Section 3.1.1). The vessel speed reduction described here applies to the ocean transits to and from the harbours, where ships routinely travel at normal cruise speed.

Further, to avoid congestion ports have instigated Vessel Arrival Systems that schedule ‘just in time’ ship arrivals to reduce transition times and the number of ships at anchor. This can involves reduced speeds for much longer distances from port than the 20-30 nm zone.

Costs of reduced vessel speed include the cost to shippers for operating their vessels for a longer period due to the reduced speed. Increased costs will be offset by reduced fuel costs within the reduced speed zones due to reduced fuel consumption. Alternatively, shippers may choose to cruise at higher speeds outside the vessel speed reduction zones to make up for lost time. Current global deliberations[c] around greenhouse gas emissions from shipping are also considering the use of slow steaming and optimised schedules for reduction of greenhouse gas emissions.

Los Angeles and Long Beach launched a voluntary program in May 2001 that requests vessels to reduce their speed to 12 knots at a distance of 20 nautical miles from the ports. Ship owners that achieve a 90 percent compliance rate with the speed reduction program, called the Green Flag program, are eligible for a 15 percent reduction in dockage fees.

3.3.4.1 Policy Considerations

An industry agreement, governed by a Memorandum of Understanding could be negotiated and would provide industry the opportunity to determine the most cost effective speed for them to operate at and would allow negotiation over the extent of the reduced speed zone. Reduced vessel speeds require no capital upgrades and can be adjusted to suit the specific port circumstances.

Negotiation of a Memorandum of Understanding would need to include the relevant Port Authorities, Maritime NSW, and the Australian Shipping Association. The case for reduction in emissions would need to be made both in terms of establishing the levels of emissions that contribute to the relevant air shed and demonstrating the human health impacts of those

[c] Crist, P. “Greenhouse Gas Emissions Reduction Potential from International Shipping” Joint Transport Research Centre of the OECD and the International Transport Forum, Discussion Paper No. 2009-11 May 2009. Accessed 6 June 2011 http://www.mlit.go.jp/kokusai/MEET/documents/MEETFUM/S2-ITF-sup6.pdf

emissions.

3.3.4.2 Stakeholder Comment on Reduced Vessel Speeds

Shipowners report that many ships are operated at reduced speed due to the recent economic downturn due to the increased cost of fuel. Stakeholders provided little comment on the concept of vessel speed reduction near the coast, but the impression was generally favourable.

3.3.5 Ship on-board incineration

California is currently amending it's *Airborne Toxic Control Measure for Cruise Ship Onboard Incineration*, which prohibits cruise ships from conducting onboard incineration of any material with in three nautical miles of the California coast, to include ocean-going ships. *

3.3.6 Summary of Stakeholder Feedback

3.3.6.1 Overall

Generally there is a strong preference for any emission control regimes for ships to be introduced on a national basis and to be in line with IMO MARPOL Annex VI. Respondents did not favour any jurisdiction, such as an individual state or port, attempting to introduce independent emission reduction measures.

Most respondents questioned whether OEH had established the necessity for controls on ship emissions. There is considered to be a need to thoroughly assess the impact of ship emissions on ambient air quality before looking at controls. This would be required under any proposal for an ECA.

For Australian owned ships, the imposition of emission controls would be a heavy impost. The Australian flagged shipping industry is already struggling financially. There is hope that this will change with reforms being considered by the Commonwealth including a second register, a revised taxation regime and changes to licensing arrangements for foreign flagged vessels. These reforms are crucial to the survival of the Australian owned shipping industry. If the reforms are favourable to the industry, there may be increased investment in new ships, which would facilitate reduced emissions including possibly uptake of LNG.

Commercial impacts have to be in the forefront of all considerations. The key to successful development of any programs is to get everyone on side, and this will require sensitivity to commercial considerations.

Port Authorities want any emission reduction measures in ports to be mandated by government and to cover the whole of the supply chain including shipping, trucks, rail and cargo handling. Any ports emissions reduction strategy should include road and rail, including more cargo on rail and truck retrofits.

The global IMO MARPOL Annex VI regulations tend to be seen as sufficient for control of ship emissions in Australia.

For shipowners, incentive based systems are preferred, especially if supported by funding. Ports are willing to consider fees that favour environmentally better performing vessels. The Authorities would need a revenue neutral system based on internationally recognised certification. A common national model would increase the incentive for ships to use the system. There would be a need for discussion and analysis of how it would affect ports' competitive position if the system was structured so that non-compliant ships had to pay more than they did before the fees were differentiated.

3.3.6.2 Legal Considerations

The Commonwealth Government has not requested that the NSW Government amend the *Maritime Pollution Act 1987* to include MARPOL Annex VI. NSW Maritime has no jurisdiction to regulate fuel sulfur content. However, an IMO ECA could be sought under IMO conventions. The case for an ECA needs to demonstrate significant environmental impact from ship emissions.

3.3.7 Potential Ship Emission Reductions

Potential Emissions Reductions

The estimated potential emissions reductions for the various options discussed above are summarised in Figure 3-2 and Table 3-4.

These estimates are based on a number of simplifying assumptions, as described in : Ship Emissions Inventory and Modelling of Mitigation Measures. They should be considered as upper estimates of the potential emission reductions available from each measure.

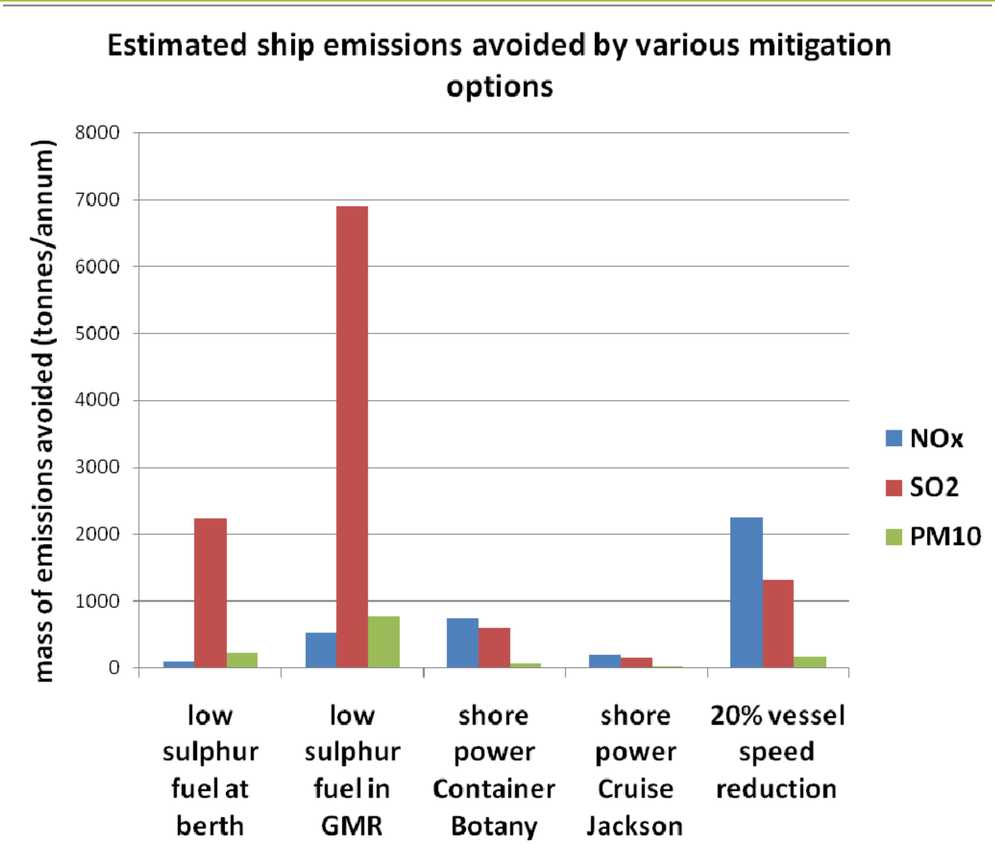

Figure 3-2: Estimated emissions avoided per annum for mitigation options

Table 3-4: Estimated emissions avoided per annum for mitigation options

Measure	tonnes of emissions/annum		
	NOx	SO_2	PM_{10}
low sulfur fuel at berth	90	2232	217
low sulfur fuel in GMR	528	6913	770
shore power Port Botany	745	597	72
shore power Port Jackson	194	156	19
20% vessel speed reduction at sea	2240	1322	181

The greatest reductions in SO_2 and particle emissions would occur with the low sulfur fuel options. Vessel speed reduction on approach or departure from the ports would achieve the greatest NOx reduction in terms of quantities. To achieve further significant reductions in NOx emissions, ports would require widespread implementation of shore power and/or provision of significant incentives for adoption of NOx reducing technologies on ship auxiliary engines.

3.4 Options for Ship Emission Reduction Measures

Specific measures that could be considered further as part of a broader package of measures include:

- Voluntary reduced vessel speeds in the vicinity of NSW ports, governed by a Memorandum of Understanding. A 10% speed reduction can reduce emissions by 20% and provides the most immediate option for reducing emissions from shipping. An industry agreement, governed by a Memorandum of Understanding, could be negotiated and would provide industry the opportunity to determine the most cost effective speed for them to operate at and the extent of the reduced speed zone. Reduced vessel speeds require no capital upgrades and can be adjusted to suit the specific port circumstances. Negotiation of a Memorandum of Understanding would need to include the relevant Port Authority, Maritime NSW and the Australian Shipping Association. Ports' contributions to total air shed emissions and the human health impacts would need to be clearly demonstrated.

- The impact in NSW of planned international controls on ship emissions, i.e. International Maritime Organisation (IMO) MARPOL VI (the International Convention for Prevention of Air Pollution by Ships) global maximum fuel sulfur limit of 0.5wt%, expected to come into effect in 2020.

- Evaluation of the impacts of an Emission Control Area (ECA) enacted through IMO MARPOL Annexe VI, with requirements to meet fuel standard limits. To present the case for an ECA to the IMO, NSW would first need to demonstrate that ship emissions are harmful to human health in the GMR. This work would be required to establish the merits of any next steps.

- Assessment of the costs and benefits for introducing shore power for new and major redevelopments of port berths under Environmental Protection Licenses. Such an option would need to clearly demonstrate it does not impact the commercial operation of affected businesses and consider emissions reductions achievable.

4 DIESEL POWERED EQUIPMENT

Ports use a wide range to diesel powered equipment to move cargo and the locomotives and trucks that visit ports are also powered by diesel engines. There are a range of technologies that have been developed to reduce emissions from diesel engines, and which are applicable to landside freight handling.

4.1 Retrofitting Technologies

Several available technologies aim to reduce particulate, VOC and NO_x emissions through chemical and physical processes to change the composition of the exhaust from cargo handling equipment. Stakeholder consultation is required to gauge the usefulness of each technology in the NSW port setting. Several of these technologies reduce the operating cost of the vehicle, however the capital cost of installation is high. Almost all retrofitting technologies are exhaust attachments. This means that most retrofitting technologies are incompatible with each other (ICF Consulting, 2005).

Financial incentive programs can be introduced to encourage the implementation of retrofit technology. An example of such a program is Boston's Clean Air Vehicles Program which offers grants to pay for half the cost (up to $10,000 USD) of any verified diesel retrofit device, while the owner pays the remaining half. The diesel vehicle must be a 2007 model or earlier.

Retrofitting is a proven implementation strategy that the NSW OEH and RTA have used to encourage fitting of emission control devices to diesel trucks.

The NSW Diesel Retrofit program has now been incorporated in the 'Clean Machines' pilot program. Clean Machines promotes the voluntary purchasing and use of non-road diesel engines manufactured to meet emission standards Tier 2 or higher, as well as encouraging other on-site emissions reduction techniques. A component of the program supports retrofits of existing diesel equipment for Clean Machines partners. The Clean Machines program targets non-road diesel engines. The design of a retrofit component considers the owner's capacity to pay.

4.1.1 Diesel Particulate Filter (DPF)

A diesel particulate filter (DPF) is a device that is fitted to the exhaust of a diesel engine or diesel vehicle to physically capture particulate matter, reducing the particulate emissions as well as emissions of CO, VOCs and other pollutants. DPF technology is proven and installed in many locations throughout the world. Depending on the type of DPF installed, particulate emissions can be reduced by a minimum 50% with a standard DPF, filtering high sulfur exhaust at a lower exit temperature. At higher temperatures and lower sulfur content, electrically regenerated DPFs can remove up to 95% of particulate matter. Catalytic DPFs are able to reduce particulate emissions by 50-90%, and VOCs and CO emissions by 60-90%. Catalytic DPFs require use of 10ppm sulfur fuel, which is the current standard for diesel.

The cost of installing a DPF is dependent upon the potential particulate emissions reduction. DPFs cost around to $14,000 AUD for heavy vehicles. The cost of the device depends on the size of the engine and the configuration of the exhaust. There are no operability issues with this technology because back pressure can be mitigated through professional installation. DPFs are relatively easy to install and maintain, therefore few barriers exist to its establishment within the port environment. The additional cost of installing DPFs has been estimated to be >25% of the cost of the original engine so, scrapping as a part of an accelerated fleet turnover (Section 4.2) program should be evaluated for engines nearing the end of their economic life (AEATE, 2005).

4.1.2 Partial Particulate Filter

Partial particle traps reduce particle matter (particularly PM_{10}) by around 50% but also contains a catalyst that reduces CO and VOC emissions. Partial traps can be fitted to most engines, and are virtually maintenance free. They have been used extensively in the NSW Diesel Retrofit Program due to excellent operability.

4.1.3 Diesel Oxidation Catalyst (DOC)

A diesel oxidation catalyst (DOC) device can be connected to the exhaust of a diesel engine or vehicle to reduce the emissions of CO, VOCs and particulate matter by converting them to CO_2 and water. DOC technology is proven and installed in many locations throughout the world. The installation of a DOC is able to reduce CO and VOCs emissions by up to 90% by oxidising CO to CO_2 and combusting VOCs to CO_2 and water. Particulate emissions can be reduced by up to 30% using this technology.

DOCs are a cost effective method of emission reduction, costing around $4,000 AUD depending on the size of the engine and the configuration of the exhaust. They are relatively easy to install and are largely maintenance free. DOCs are suitable for use with the 10ppm sulfur diesel available in Australia (ICF Consulting, 2005).

4.1.4 Lean NOx Catalyst (LNC)

The lean NO_x catalyst (LNC) system ensures the chemical reduction of NO_x to inert nitrogen gas. This is done by injecting a small amount of reductant into the exhaust stream. LNC system reduces NO_x emissions only. The additional reductant required is equivalent to approximately a 4-7% increase in fuel cost.

A 25% reduction in NO_x emissions is expected after the installation of an LNC. This comes at a cost of $6,500 USD - $10,000 USD. LNCs work well with the 10ppm sulfur diesel available in Australia (ICF International, 2008 & 2005; Bailey and Solomon, 2004; NRDC, 2004).

4.1.5 Selective Catalytic Reduction (SCR)

The Selective Catalytic Reduction (SCR) system is specifically designed to reduce NO_x emissions by chemically reducing NO_x to inert nitrogen gas. SCRs remove more NOx than LNC and also remove particulate matter and CO, amongst others. To reduce operational costs, the SCR is designed to use urea, a cheaper alternative reductant, as the exhaust additive. As a result, SCR-urea systems cost more than LNC systems to install. SCR may be chosen over an LNC where capital is available for installation in order to reduce long term costs. Financial incentives can aid uptake of SCR.

SCR systems are able to reduce NO_x emissions by up to 90%; this alone is significant. Also, some types can also oxidise 50-90% of exhaust CO to CO_2 and reduce particulate matter by 30-50%, through collection and deposition. Despite its benefits, the SCR system is uncommon due to the high initial cost which ranges from $15,000 USD to $27,500 USD. Operational costs can also be quite high with the input urea adding a further 4% on top of fuel costs. The additional cost of installing SCR technology has been estimated to be >25% of the cost of the original engine, so if an engine is nearing the end of its useful life, scrapping as a part of an accelerated fleet turnover program (Section 4.2) may be the more economic decision (ICF International, 2005 & 2008, Bailey and Solomon; 2004, NRDC, 2004).

4.1.6 NOx Adsorber Catalyst (NAC)

NO_x adsorbing catalyst (NAC) systems are another method of NO_x emission reductions. Rather than reducing the NO_x to nitrogen, a solid catalyst bank is installed and NO_x emissions are physically removed through adsorption onto the catalyst surface. The NAC system is not as efficient as the SCR in reducing NO_x emissions: a 70% reduction is possible with this system. However, NAC is less expensive. Also, the NAC system does not have the added benefits of reducing CO and particulate emissions. The cost of installation includes the catalyst and therefore the equivalent fuel cost does not increase. Very low sulfur-content diesel is required for the NAC system - around 10-15 ppm is recommended. Current Australian standard diesel sulfur content falls within this range, therefore currently available diesel is compatible with the NAC system (Bailey and Solomon, 2004, NRDC, 2004).

4.2 Accelerated Fleet Turnover

An option for emission reductions in the cargo handling equipment and vehicle fleets is to implement a program aimed at accelerating the fleet turnover (AFT), or reducing the average age of vehicles used in a particular area.

This can be implemented a number of ways. Incentives or subsidies can be supplied to owners of ageing vehicles to purchase new vehicles, or a ban can be placed on vehicles greater than a defined threshold age. Further, the extra step of making scrapping of old vehicles mandatory can stop emissions from these inefficient vehicles from occurring elsewhere. Scrappage, however, will increase the cost of the scheme further for both the governing body and participants, since the trade-in value of ageing vehicles, as received by operators, will be lower than their actual value.

Accelerated fleet turnover is effective when emissions from newer vehicles are less than those from ageing vehicles, as is usually the case due to increased engine efficiency as well as more complete combustion and exhaust technology installed as standard. It is also assumed that emission reduction systems on ageing vehicles lose efficiency over time and retrofit technology is more expensive or not possible on older vehicles.

The cost of implementing this type of program can be significant for governing bodies or authorities, but less so for operators and consumers. On top of the cost of enforcing the standards and assessment of vehicles for emissions standards is the cost of funding the subsidy for scrapping older vehicles (Facanha and Ang-Olson, 2008).

AFT programs currently exist at several ports around the world including Los Angeles and Oakland in the United States. In these cases the port authority provides grants to scrap and replace older road vehicles. These programs, however, do not apply to cargo handling equipment.

4.3 Idle Reduction Programs

An idle reduction program is a set of strategies implemented to change the behaviour of port operators, in order to reduce emissions from idling (stationary) cargo handling equipment. Several options are available, including the use of automatic engine shut-off devices and electric plug-in technology.

Shutting down the engine at the beginning of extended periods of inactivity can save fuel and reduce air emissions. Education can be provided to operators that identifies the benefits and the most useful applications.

Alternatively, automatic shut-off devices can be installed to shut off the engine after a specified period of idling, rather than relying on operators to turn off the engine. The definition of extended periods can be predetermined and linked to current idle times and goals for fuel and emissions savings. Automatic shut-off technology is now available to retrofit road vehicles and is standard in some cases. However, cargo handling equipment does not have automatic shut-off technology available. The technological barrier must be overcome before this can be achieved and funding or subsidy may be required.

In situations where shutting down the engine while the vehicle is stationary is not appropriate, for example refrigeration systems and other vital services, electric plug-in technology can be implemented to reduce emissions. Purchased electricity is produced under more efficient conditions, with lower emissions per kWh produced, and rarely contributes localised emissions of air pollutants. Plug-in power is used for ships while docked (cold-ironing or shore power) and for on-road heavy vehicles. A significant barrier to the implementation is the installation of hardware and systems within cargo handling equipment to accept power from both traditional diesel fuel and electricity (Port NY & NJ, 2009).

Where driver training, automatic engine shut-off devices or plug in technology are sought, an effective strategy for implementing an idle reduction program is likely to be similar to that used for retrofitting – an incentive-based approach.

4.4 Alternative Fuels

The use of alternative diesel fuels to replace traditional diesel can provide some reduction in air pollutant emissions. Assessment of the benefits of alternative fuels needs to be undertaken on a case by case basis considering the engine operability and emissions impacts. Alternative fuels currently available are listed and described in this section.

Diesel Emulsions

Diesel Emulsions and Emulsified Diesel are mixtures of diesel which contain water and other additives. Vehicles using this type of fuel will require more fuel – an increase in fuel consumption equal to the proportion of fuel additives – 15% increase for 85% diesel emulsion. Emissions can be reduced at a slightly greater rate, up to 20% for NO_x and 50% for particulate matter. Consequences of the increased fuel consumption include increased carbon dioxide emissions as well as the associated increased purchase price (ICF Consulting, 2005, Bailey and Solomon, 2004, NRDC, 2004).

In Australia there is no national standard for emulsified diesel fuels.

Biodiesel

Biodiesel is a generic name for ester-based oxygenated fuels made from vegetable oils and rendered animal fats (tallow). In Australia current biodiesel production is largely based on tallow, waste cooking oil and canola oil. Existing vehicles can readily use biodiesel or diesel-biodiesel mixes.

Reduced particle and greenhouse gas emissions are the most significant potential environmental advantages of biodiesel. A 2007 CSIRO study 'The Greenhouse and Air Quality Emissions of Biodiesel blends in Australia' reported reductions of 4% in particle emissions from B5 diesel blend. B20 produced reductions in particle emissions of 16%. The energy content of biodiesel is slightly less than diesel, which results in a small loss in fuel economy.

The implementation of a biodiesel fuel switch program is a very cost effective and relatively simple method of reducing emissions from cargo handling equipment. Biodiesel is produced from natural products, rather than crude oil refining, and the resulting fuel has reduced of emissions of CO by 50%, VOCs up to 90%, NO_x by 10-15%, particulate matter up to 70%, and sulfur up to 90%. Operators interested in corporate social responsibility often consider the use of biodiesel (Bailey and Solomon, 2004, NRDC, 2004).

The NSW Government currently requires at least 2% of diesel sold to be biodiesel and suppliers manage the requirement by blending biodiesel into current diesel supplied in NSW. The mandate is expected to increase to 5% when sufficient biodiesel supplies are available.

Fischer-Tropsch Diesel

Fischer-Tropsch diesel is usually made from coal and is compatible with existing diesel engines. Fischer-Tropsch diesel only increases fuel consumption by 2-3%, but it reduces NO_X emissions by 4-12%, CO by 18-36%, PM10 24-26% and VOCs by 20-40% (Bailey and Solomon, 2004; NRDC, 2004). Fischer-Tropsch diesel is not commercially available in Australia.

E-Diesel

Ethanol diesel (E-diesel or dieselhol) is a blend of conventional diesel and as much as 15 percent ethanol. E-diesel is expected to reduce PM10 by 20-40% and CO by 20-28%. However, the reduction in NO_x emission is relatively low in comparison to other fuel alternatives, reducing NO_X by approximately 1-6%. Unlike some of the other suggested fuel alternatives, E-diesel does not have a fuel penalty and hence there is no expected increase in fuel consumption, SO_2 or CO_2 emissions. Safety matters such as flammability remain an area of concern (NRDC, 2004). There are no Australian Standards for the supply and use of diesel ethanol blends in Australia.

Fuel Additives

Fuel additives are very small amounts of added chemicals which improve one or more properties of the base fuel. Some commonly used fuel additives include detergents, corrosion inhibitors and storage stability improvers (Emissions Advantage, 2005). While additive manufacturers aim to supply products that improve engine combustion and reduce emissions, in Australia there are no national standards for fuel additives and so the effectiveness and impact on operability are unknown.

Natural Gas Conversion

Natural gas is a hydrocarbon gas composed predominantly of methane, but also contains a number of heavier hydrocarbons including propane, butane and others. Natural gas is a readily available form of energy, currently used in many situations for transport, pumping and energy production. It is produced through direct extraction from fossil fuel deposits or coal seams and is sometimes found as coal seam gas. The purpose of replacing diesel engines and fuel tanks with that suited to natural gas is to achieve the emissions savings available, including 50-80% NO_x and 90-95% particulate matter. However, small increases in CO_2, CO and VOCs emissions occur (ICF International, 2008, NRDC, 2004).

Conversion to natural gas is an effective way of reducing air emissions but it can be very costly. Despite the large emissions savings available, high costs of conversion are incurred. Some engines will need only minor requirements to be converted to natural gas, but many will need replacing at a cost of $30,000 – $70 000 USD. Since cargo handling equipment will not leave the port site, a refuelling station would be required. The cost of installation can be between $500,000 and $1,000,000. Also, in comparison to diesel, natural gas can cost up to $0.65 USD per litre equivalent higher.

5 CARGO HANDLING EQUIPMENT

Cargo handling equipment includes all vehicles not classified as road or rail vehicles that transport cargo at a port. This includes cranes, generators, forklifts and similar vehicles and is almost exclusively diesel powered.

Cargo handling contributes approximately 5.7% of NO_x (1,082 tonnes), 5.3% of PM_{10} (59 tonnes), 5.6% of $PM_{2.5}$ (58 tonnes), 15.8% of VOCs (97 tonnes) and less than 1% of SO_2 (0.5 tonnes) total port emissions.

The reduction of emissions from cargo handling equipment is an important step to reducing general port emissions.

5.1 Emission Mitigation Methods

5.1.1 Emissions Standards for Cargo Handling Equipment

Current NSW and Australian Air Emission Standards

The NSW Protection of Environment Operations (Clean Air) Regulation 2010 (POEO) sets out emission concentration limits for various industrial activities. Ports and particularly cargo handling equipment are not regulated directly. However, other activities that may be carried out within ports, such as the storage of volatile liquids and the sulfur content of fuel used generally, are regulated. Schedule 4 of the POEO gives the maximum permitted emission concentrations of SO_2, NOx and PM_{10} at the point of emission from specified plant types. NSW is also subject to the requirements of national laws and regulations requiring vehicle standards and fuels standards.

At present, emission limits for diesel engines only apply to new diesel vehicles used on public roads. The emission limits are applied nationally through the Commonwealth *Motor Vehicle Standards Act 1989*. The quality of Australian diesel is also managed nationally through the Commonwealth *Fuel Quality Standards Act 2000*. National options to manage emissions from heavy non-road diesel equipment are currently being investigated by the Commonwealth and State/Territory Governments. The options under investigation include phased adoption of United States or European non-road emissions standards.

US EPA Cargo Handling Equipment Air Emission Standards

The US EPA 'Tier' system defines vehicles and engines based on power output and equipment model year, to give an estimate of emission rate. The tier guidelines are summarised in Table 5-1. Vehicles with a power rating between 25 and 750 horsepower (hp) (18.4 kW – 551.6 kW) come under the standard tier system. Smaller and larger engines are regulated by separate standards. Tier 1-3 standards are usually met by manufacturer standards, with little or no exhaust after-treatment needed (retrofitting technology, for example). Tier 4 emissions standards are being phased in from 2008 to 2015 depending on engine power rating. In comparison to preceding standards, Tier 4 standards are stringent: compliance with Tier 4 requires advanced emission control similar to those used in road vehicles. Standards such as these could over time close the gap in emissions standards between road vehicles and cargo handling equipment in ports.

Table 5-1: US EPA Emission Standards Tier 1-4

	First Year Model	Emission Standard (g/hp-hr)	
		NO_x + NMHC [a]	Particulate Matter
Tier 1	1999	7.1	0.6
Tier 2	2001-2006	4.8-5.6	0.15-0.45
Tier 3	2006-2008	3.0-3.5	0.15-0.45
Tier 4	2011-2013	0.3-0.35	0.01-0.02

a - NMHC: Non-Methane Hydrocarbons

Table 5-1 shows that emission standards are given for NO_x and particulate matter only. These substances are considered to contribute most significantly to the air quality problems as a result of cargo handling equipment.

5.1.2 Retrofitting Technologies and NSW 'Clean Machines' Program

Retrofitting technologies were described in detail in Section 4.1. Exhaust retrofit is a proven implementation strategy that the NSW OEH and RTA have used to encourage the fitting of emission control devices to on-road diesel trucks. As of February 2011, a total of 520 heavy diesel vehicles have been fitted with Diesel Oxidation Catalysts (DOCs), Diesel Particulate Filters (DPFs) or partial particle traps.

The NSW Diesel Retrofit program has now been incorporated in the 'Clean Machines' program. Clean Machines promotes the voluntary purchasing and use of non-road diesel engines manufactured to meet emission standards Tier 2 or higher, as well as encouraging other on-site emissions reduction techniques such as idle reduction. A component of the program supports retrofits of existing diesel equipment for Clean Machines partners. The Clean Machines program targets construction, mining and other non-road equipment.

5.1.2.1 Case Studies of Retrofitting Technology

Retrofitting technologies have successfully been installed as a part of grants provided by Port Authorities to operators at the Ports of Long Beach, Oakland and Los Angeles in California (ICF Consulting, 2005). For retrofit technology grant programs to be successful, incentives need to be balanced. High incentives deplete funding before emission reductions are achieved, and small incentives will result in low participation (ICF Consulting, 2005). A strategy that has been used in several programs is to mandate compulsory retrofit technology following the completion of the incentive period. This ensures a high level of participation with slightly lower cost than balanced incentives.

Oakland

Plans in 1997 for a large port expansion led to the Port of Oakland Authority being sued by community groups for impacts on the surrounding areas, including impacts of air emissions (ICF Consulting, 2005). As a result, the Air Quality Mitigation Program was established. The program included a detailed inventory of equipment in use, including age and hours of operation (ICF Consulting, 2005). The port authority provided information on available retrofit technology and reimbursement following the installation of a retrofit technology (ICF Consulting, 2005). During the period from 1997 to 2005, 151 DOCs and 159 DPFs were installed on cargo handling equipment at the Port of Oakland (ICF Consulting, 2005).

Long Beach

At the Port of Long Beach, DOCs have been installed on a large proportion of the stationary terminal equipment including yard hostlers, top picks, and side picks (ICF Consulting, 2005). This program was successful due to the high level of funding available and the support from DOC manufacturers (ICF Consulting, 2005). Variations to the DOC design were made to improve compatibility with cargo handling equipment, reducing costs for operators (ICF Consulting, 2005). The Long Beach program was very successful with over 600 DOCs installed (ICF Consulting, 2005). Contributing factors to this success have been identified as upcoming lease negotiations - operators hoping to establish good relations with the port authority - corporate social responsibility and the upcoming mandate for compulsory retrofitting technology (ICF Consulting, 2005).

Los Angeles

Similarly to Oakland, the Port of Los Angeles implemented an Air Quality Mitigation Program as a result of litigation by community groups over an expansion project (ICF Consulting, 2005). As a result of the 2003 settlement, $20 million USD was devoted to reducing particulate emissions over four years (ICF Consulting, 2005). Up until early 2005, the Port Authority received many more applications than there was funding available for (ICF Consulting, 2005). This very high level of participation is attributed to the success of nearby ports Air Quality Mitigation programs (ICF Consulting, 2005). Before the project concludes, it is expected that 600 DOCs will be installed on cargo handling equipment alone (ICF Consulting, 2005).

5.1.3 Accelerated Fleet Turnover (AFT)

An option for emission reductions in the cargo handling equipment vehicle fleet is to implement a program aimed at accelerating the fleet turnover, or reducing the average age of vehicles used in a particular area (Facanha and Ang-Olson, 2008).

5.1.4 Idle Reduction Programs

The Port Authority of New York and New Jersey has implemented a broad ranging Idle Reduction Program and has seen significant reductions in cargo handling equipment emissions, including a 25% reduction in NO_x, particulate matter, fuel consumption and carbon dioxide (Port NY&NJ, 2009). The cost of the NY/NJ program has not been publicised but it is not expected to be large in comparison to the emission reductions recorded. Also, a large proportion of funds invested in the program would be paid back in saved fuel costs.

5.1.5 Alternative Fuels

To reduce cargo handling activities’ emissions, a further option is to introduce the use of alternative fuels to replace traditional diesel. Alternative fuels currently available are listed and described in this section.

5.1.6 Operational Efficiency Measures

AUTOMATED CARGO HANDLING

An automated cargo handling system has the potential to remove the need for traditional cargo handling equipment. This means that diesel emissions from cargo handling activities in ports would be cut to zero in some cases and to significantly lower levels in other cases. There are currently two examples of this type of technology implemented at ports around the world, in Singapore and Rotterdam.

The implementation of an automated cargo handling system requires a very high capital cost, and relatively low operational costs (for purchased electricity) and likely requires significant funding (Ballis 2007). An alternative strategy for implementation of an automated cargo handling system is approaching a third party to develop and maintain the system, in a similar manner to bridge/tunnel building projects. Like those projects, the owner/operator of the system could charge fees for the use of their system. In this case, port stakeholders could opt to use the system and pay a fee instead of purchasing and operating their own equipment.

SINGAPORE

The Port of Singapore is outfitted with nine-story, freestanding concrete structures supporting automated bridge cranes. The remote controlled cranes are capable of very fast and flexible operations with a minimum number of operators. Artificial intelligence is used to semi-automate the stacking/unstacking process. This has reduced diesel emissions on site to zero, as well as cutting the amount of labour required for the port to remain operational and increase efficiency over time. As the cranes are controlled and powered electronically, they are subject to the cost of purchasing electricity and infrequent black-outs, but this is minimal in comparison to the costs saved and reduced emissions (NRDC, 2004).

ROTTERDAM

The Port of Rotterdam incorporates artificial intelligence with traditional labour as a part of its automated cargo handling system. Automated Stacking Cranes (ASC) as well as Automated Guided Vehicles (AGV) are used on site to both increase efficiency and reduce diesel emissions and associated costs of operation. ASC are electrically operated therefore the on-site emissions associated with loading are reduced to zero. However, AGV are operated on a diesel-hydraulic line drive. This means that with increased efficiency emissions are only reduced through the reduction in annual kilometres travelled. In addition, AGV has extremely high maintenance costs due to the semi-experimental nature of the technology. These costs are expected to decrease when the technology becomes more widespread (Ballis 2007 and Hopkins 2004).

LANDSIDE IMPROVEMENT STRATEGY

The Port Botany Landside Improvement Strategy (outlined in Section 2.2.5) is an example of a measure to improve operability and reduce emissions. Potentially the road transport focus of the strategy could be augmented in collaboration with industry to more explicitly incorporate cargo handling equipment to mitigate emissions.

5.2 Summary of Stakeholder Feedback on Cargo Handling

The key issues to emerge were as follows:

- Plans to <u>retrofit or upgrade</u> to lower emitting equipment are underway:
    - One company owns 20 Rubber Tyred Gantry Cranes (RTGs) at Port Botany and 16 of these have older style NTA855 14 litre engines: they are suitable for retrofitting technologies. A diesel particulate filter has been tested successfully on one and there is an active plan to retrofit DPFs to similar RTGs.
    - Key energy-using equipment is a fleet of 43 straddles. Of these, 15 have been acquired in the past 3-4 years and should have good emissions performance. The plan is to replace the other straddles within 24 months with diesel-electric units.
    - RTA was instrumental in retrofits to RTGs and on-site trucks at Port Botany.

- Retrofitting has significant cost: non-financial incentives would not likely be effective.
- In a large fleet with regular maintenance schedules for essential equipment, any retrofit scheme would need to be phased in to coincide with maintenance plans.
    - Average lifetimes for RTGs and Intra Terminal Vehicles (ITVs) are in the 15-20 year range. Engines are rebuilt or replaced is every 5-7 years. Straddles have major service every 4000 hours, with existing fleet mostly between 3 and 10 years old.
- Accelerated fleet turnover would be assisted by financial incentives, but they would need to be significant given high costs.
- Automated driverless straddles have been successfully installed at Brisbane. Automated cargo systems are seen by the industry as beneficial and applicable to NSW. Benefits include reduced emissions and fuel consumption as a result of automated anti-idling as well as route and task optimisation.
- Anti-idling straddle equipment is anti-idling equipped. RTGs have auto cut-off and despite difficulties, auto cut-off will be re-introduced at some time for ITVs and terminal vehicles.
- There is no cargo handling equipment in place that would require electric plug-in power to reduce idling.
    - Although plug-in power is not currently applicable, concern was expressed about the cost of electricity from coal-fired power stations.
- One company has successfully tested biodiesel but has deferred implementation until expiry of an existing fuel contract. Another company has investigated biofuels but has concluded that it is not worthwhile, for a number of reasons including lack of price incentive, potential price instability, technical constraints on blends >20%, supply and quality issues, questionable sustainability benefits, unknown long-term effects on engines and administrative issues with storage tanks.
- Natural gas has been investigated by one company but it is not regarded as commercially mature technology.
- Subsidies or incentives for using cleaner technologies or fuels were regarded favourably, but only if they made commercial sense after considering fuel cost, equipment maintenance issues, conversion cost and effects on equipment reliability. Even if funded, implementation is a distraction for operating companies.
- Diesel electric RTGs are available and one company will take delivery of four RTGs with low emission Cummins QTX engines later in 2011.

5.3 Options for Cargo Handling Equipment Emission Reduction Measures

Cargo handling emissions, while relatively small compared to shipping (Table 3-1), do have a noticeable impact on overall port emissions. Current equipment replacement, retrofit and other programs identified by industry in the consultation process appear to have emissions improvement potential, particularly over the medium to longer terms, e.g.

- progressive replacement of rubber tyred gantry cranes (RTGs) by new low-emission equipment
- retrofitting diesel particulate filters to older RTGs
- extending anti-idling to all major items
- extending the NSW Clean Machines program

Emission standards for non-road diesel engines are currently being evaluated nationally and would provide additional emission management options.

EXTENSION OF THE CLEAN MACHINES PROGRAM

Extension of the ports component in the NSW Clean Machines program could assist uptake of cleaner equipment. In addition to encouraging retrofits, the program could provide guidance for on-site operational measures that reduce emissions and fuel use, such as anti-idling. A broader framework could be developed with industry through a Memorandum of Understanding that defines an agreed plan for achieving plant and equipment improvement milestones.

IMPROVED OPERATIONAL EFFICIENCY

Industry's ability to reduce emissions is tied to the productivity and profitability of port operations. The Port Botany Landside Improvement Strategy aims to improve productivity and reduce emissions. Its current focus is vehicles, however there may be additional scope to extend it to diesel powered cargo equipment to achieve greater overall port emissions reductions.

6 RAIL

6.1 Rail Emissions

Rail activities contribute about 43% of NO_x (8,154 tonnes), 14% of PM_{10} (156 tonnes), 15% of $PM_{2.5}$ (151 tonnes), 52% of VOC (317 tonnes) and 0.1% of SO_2 (9 tonnes) to total port emissions.

Presently, moving goods with locomotives generates less pollution that with trucks per tonne of freight moved over the same distance. However, truck emissions are expected to reduce relative to locomotive emissions due to progressive implementation of more stringent heavy road vehicle standards.

6.2 Rail Emission Mitigation Methods

6.2.1 Encourage Mode Switching from Road to Rail

There are no standards for fuel or emissions from diesel locomotives in Australia. Measures currently undertaken to reduce emissions are largely voluntary. In this regard, the rail industry lags behind its competitors in the road sector. Locomotives have long working lives, hence rapid change in the fleet and associated emissions profile is not to be expected.

Further upgrades of the Port Botany to Enfield line and the southern Freight line are needed to take full advantage of intermodal terminal opportunities. Completion of the Maldon to Dombarton rail line would significantly increase the opportunity to shift freight by rail from Port Kembla, particularly the transport of new vehicles that are currently transported from Port Kembla to Sydney by truck.

In Sydney, Port Botany is committed to a 40% rail freight target. The Port Botany Rail Team (PBRT) was established to enhance rail operational performance and transport chain visibility, and to support modal shift to rail.

The PBRT comprises Sydney Ports Corporation, Australian Rail Track Corporation, RailCorp, Independent Rail, Patrick PortLink, POTA, SouthSpur, Freightliner, stevedores (DP World, Patrick), Australian Customs Service, Australian Logistics Council and Ministry of Transport.

The Port Botany Landside Improvement Strategy (PBLIS) regulation can assist in achieving mode share targets through its powers on truck and rail servicing charges. For example, in August 2010, Sydney Ports sought a maximum cap on the rail pricing at the port interface to promote greater equity between rail and road transport.

6.2.2 Accelerated Fleet Turnover (AFT)

An option for emission reductions in the rail sector of port operations is to implement a program aimed at accelerating the fleet turnover (AFT), or reducing the average age of engines used in a particular area (Facanha and Ang-Olson, 2008). This can be achieved through incentives for owners of ageing engines to update to new engines or modify existing engines to meet new emission standards.

Repowering of medium locomotive engines costs \$0.5 - \$1.5 million. Alternatively, use of locomotives older than a specified age or unable to meet an emission standard could be prohibited in urban areas (Facanha and Ang-Olson, 2008). The use of emission standards, rather than locomotive age, to define an engine is more effective since it incorporates build year, emission rates and other standards which can play a role in reducing emissions, creating an easy-to-use AFT system (Facanha and Ang-Olson, 2008).

The benefits of locomotive engine turnover depend upon emission rates of the new engines compared to the old engines. An effective AFT program is well served by tighter emission standards for new engines. A reduction of pollutant emissions could be achieved through the upgrade of NSW ports' locomotives to US EPA Tier 2 equivalent locomotives (post 2005 build). The Tier 2 standards for switching (shunting) and line haul (long distance) locomotives can be found in Table 6-1.

Table 6-1: Tier 2 Emissions Standards Locomotives (US EPA, 2011)

	Substances (g/kW-hr)							
	Build Year	HC	NO_x	PM_{10}	CO	Smoke %	Min. Useful Life	Warranty Period
Line Haul[a]	2005-2011	0.03	0.56	0.01	0.15	20/40/50	7.5 x power (hrs) or 10 years	1/3 of warranty life
Switch[b]	2005-2010	0.06	0.83	0.01	0.24	20/40/50	7.5 x power (hrs) or 10 years	1/3 of warranty life

a – Line Haul = Long Haul; b- Switch = Shunting

By adopting the US EPA Tier 2 emission standards and implementing an AFT program to update all locomotives in NSW ports to meet these standards, emission reductions approximately equal to those in Table 6-2 could be achieved.

Table 6-2: Emission Savings under Tier 2 AFT (SPBP, 2010)

	Emission Benefit (g/kW-hr)							
	CO	VOCs	NO_x	PM_{10}	$PM_{2.5}$	SO_2	FC	CO_2
Line Haul [a]	-	-	-38%	-35%	-	-	-	-
Switch [b]	-	-	-62%	-54%	-	-	-	-

a – Line Haul = Long Haul; b- Switch = Shunting

Since rail freight carriers are under contract to provide a service on state owned rail, an alternative to adopting locomotive emission standards would be to negotiate that engines undergoing rebuilds are rebuilt to a higher standard.

6.2.3 Retrofitting Technologies and Clean Machines program

Rather than replacing engines completely to reduce emissions from locomotives, retrofitting technology can be fitted to treat exhaust gas. Two retrofitting technologies are currently available for use on locomotives - Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF) systems. Section 4.1 provides details of the retrofitting technologies.

Financial incentive programs have been demonstrated to encourage the implementation of exhaust retrofit. Retrofitting is a proven implementation strategy that the NSW OEH and RTA have used to encourage fitting of emission control devices to diesel trucks.

The Clean Machines program supports retrofit of non-road diesel engines used in construction, mining and other non-road operations. An assessment could be made of the scope to expand the program to locomotives. The Clean Machines program could provide a framework for improving locomotive maintenance practices.

6.2.4 Track Electrification

To reduce emissions both within the port and on railways close to the port, rail and locomotives could be converted to electric power. Track electrification has occurred in many locations with high population density around the world to reduce the impact of rail emissions. The cost of constructing an electrified line far outweighs that of a diesel locomotive line due to the cost of extra infrastructure including overhead power, so typically short sections of track are electrified in highly sensitive, population dense areas.

For Port Botany, one option is to electrify the 18 km dedicated Botany-Enfield freight line and provide incentives for locomotives to upgrade. The predicted emissions benefits of this upgrade would be approximately equal to those applicable to any diesel-electric upgrade. It is reported that reductions of 71.6% CO, 99.9% VOCs, 81.4% NO_x, 76.8% particulate matter and 24% CO_2 could be achieved (AEATE, 2005). Further, the remaining emissions would be offsite at the relevant power station.

Rail operators would need to purchase new locomotives suitable for use with electric power or convert the existing diesel locomotives to electric power, with the option of accepting diesel. This would be especially useful for locomotives that travel long distances in areas where total track electrification is not necessary or feasible. Financial incentives may promote conversion, as well as higher charges for use of diesel locomotives on the line. However, there are substantial barriers to implementing any such change, primarily the large capital costs involved.

6.2.5 Alternative Fuels

Introduction of alternative fuels requires modifying existing locomotives to accept fuels which produce less harmful emissions. Two examples are currently available and proven for switching from diesel locomotives: hybrid natural gas conversion and hybrid diesel electric power.

Financial incentives are the most effective drivers for the uptake of alternative fuels. For locomotives, the use of an alternative fuel will require capital to convert engines to use a different fuel. Fuel subsidies for the use of natural gas may also be an appropriate driver for using a cleaner fuel. However, financial incentives would be needed and the required funding may not be feasible.

Diesel / Natural Gas Conversion

The use of natural gas as a diesel fuel alternative can be applied to existing locomotive fleets relatively cost-effectively. Emissions of NO_x can be reduced by up to 78%. A co-benefit of this dual fuel technology is having the flexibility to run entirely on diesel fuel if natural gas becomes unavailable. The current cost of replacing a diesel locomotive engine with a dual fuel diesel / natural gas engine can be between $400,000 and $800,000 USD per engine (EFEE, 1995, Bailey & Solomon, 2004).

Hybrid Diesel Electric

A diesel-electric hybrid conversion can also significantly reduce the emissions from a locomotive. Currently there are demonstration examples of clean locomotives such as the Green

Goat or Gen Set. These locomotives use a combination of a heavy duty battery rack and a small diesel generator. As well as a reduction in air emissions and fuel consumption, hybrid diesel electric locomotives also have the co-benefit of reducing noise levels at port facilities. The conversion to a diesel electric hybrid engine can reduce emissions of NO_x by 50-90%, particulate matter by 50-90%, SO_2 by 40-60% as well as reducing fuel consumption and associated CO_2 emissions by 40-60% each (ICF, 2008, AEATE, 2005 and EFEE, 1995).

Since this technology is not well proven in industry, current costs of hybrid diesel electric locomotives cannot be accurately estimated. The demonstration Green Goat hybrid locomotive cost $750,000 (USD) per engine to build, but this cost is expected to decrease if rail operator interest occurs.

6.2.6 Alternatives to Diesel Locomotives

This section looks at possible alternatives to diesel locomotives. The two alternatives examined are the Electromagnetic Cargo Conveyor (ECCO) and the Norfolk Southern 999 (NS 999). Both technologies are still in the early stages of research, development and deployment.

If a rail-replacement system such as an ECCO were to be introduced it would likely serve many port operators in a similar manner to an automated cargo handling system. While the significant costs involved with such a program would require state or federal government funding, introducing such a scheme can provide numerous benefits apart from the efficiencies and emissions reductions, such as positive publicity. Implementing a highly advanced system such as an ECCO in a port can have the effect of 'placing it on the map' – with so few of these systems in place, the port would gain international interest.

Another strategy for implementation of a rail-replacement system such as an ECCO is approaching a third party to develop and maintain the system, in a similar manner to bridge/tunnel building projects. Like those projects, the owner/operator of the system could charge fees for the use of their system. In this case, port stakeholders could opt to use the system and pay a fee instead of purchasing and operating their own equipment.

Electromagnetic Cargo Conveyor (ECCO)

An Electromagnetic Cargo Conveyor (ECCO) is an alternative to rail for the transportation of goods from ports to distribution centres. An ECCO transports containers without adding to road traffic or emitting harmful pollutants and greenhouse gases.

A demonstration ECCO system has been successfully tested in San Diego, California. The system uses electro-dynamic levitation to transport containers instead of using trains. Without wheels, the containers "float" above the conveyer and distribute their weight through large area magnets.

The introduction of an ECCO system would reduce emissions by reducing truck congestion. The ECCO emissions would be substantially lower than that from truck traffic. This reduced truck congestion would also benefit the community in terms of health and a reduction in truck noise. The ECCO corridor would also improve the speed and quantity of container distribution. As this technology is currently only demonstration-level, the cost of introducing ECCOs at NSW ports is unknown (EDF, 2010).

Norfolk Southern 999 (NS 999)

The NS 999 is a battery-powered locomotive unveiled in September 2009 by Norfolk Southern. The NS 999 is still in its early stages as only a prototype has been released. Used for railroad switching applications, the NS 999 is an electric locomotive that uses a lead-acid energy storage system (1,080 12-volt batteries) instead of a diesel engine. The battery life is monitored through an equipped battery management system to ensure safety.

The NS 999 alternative would result in zero on-site emissions and reduce port reliance on trucks and rail for transportation of goods. In comparison to traditional rail trains, the NS 999 is quieter, reduces health impacts and is comparable in terms of manufacturing cost. However as the NS 999 is still only a prototype, the cost is unknown. The prototype was developed by Norfolk Southern in partnership with the US Department of Energy, the Federal Railroad Administration and Pennsylvania University. Federal funding for the development of the NS 999 prototype was $1.3 million USD (EDF, 2010).

6.3 Summary of Stakeholder Feedback on Rail Emissions

The Australasian Rail Association (ARA) has developed the Draft Solutions for Freight Rail (http://www.ara.net.au/site/publications.php), a national program for emissions improvement based on a set of short-term and long-term proposed measures. The short-term proposal is for a government assisted 10-year program aimed at repowering or replacing the majority of highly utilised locomotives over 25 years old, costing in the order of $424-$721 million. The average locomotive age in Australia is over 35 years and it is envisaged that about 83 locomotives would be eligible nationally for replacement under this proposal.

This proposed replacement or repowering program would involve a combination of government and industry funding (dollar for dollar) and would be a significant step in modernising the aged components of Australia's locomotive fleet and improving their environmental performance. Analysis undertaken by the industry suggests that this type of program would have a high level of uptake and would result in considerable long term emissions savings. Clearly the public funding aspect of this proposal is a potentially significant barrier and would require engagement at a federal level.

The long-term part of the proposal is a jointly funded research and development program into the use of natural gas in Australia's locomotives. This program would focus on developing solutions to use natural gas as a primary alternative fuel in high powered and well utilised locomotives.

Specific to the consultation process for this study, key responses are summarised below:

- There is no experience with retrofitting exhaust treatment technologies
    - Generally locomotives used in terminal rail yard areas are not yard locomotives but instead operate in and out of port terminals as part of their overall trip. Therefore minimal fuel is used on site. There are some operations such as in Port Kembla where the locomotives are captive to a site.
    - It would be advisable to only retrofit the locomotives identified as having a high use in port terminal areas. This would be sensible from a cost benefit view.
    - It is likely that retrofit costs will be large and the ability to fund this retrofit is also determined by the profitability of the particular customer/industry the locomotive is servicing. For example locomotives dedicated to grain operations may be underutilised for long period of time due to drought and the cost of improving sunk cost equipment may affect the viability of the service.
    - Careful consideration and further consultation is required on financial assistance requirements on locomotive retrofit.
- There is no enthusiasm for trialling hybrid technology
    - Many of the locomotive types cited in the discussion paper have had limited success and are not yet proven technology.

- The modification of existing locomotives is cost prohibitive. To experiment on a $6 - $8 million asset requires significant funding for the locomotive, the modifications, lost asset utilisation time / productivity and risk of costly damage to the equipment.
- Such R&D is a costly time consuming business that risks expensive scarce locomotive assets and can also become a distraction for management. Full funding of any study to isolate and address these issues is required.

- One suitable locomotive option for short hauls and yard work where variable engine power is required is the use of <u>switching locomotives</u>. Essentially the locomotive has a number of truck engines instead of the standard one locomotive engine. This allows access to the latest in truck engine technology. Reduced energy use and cleaner air is achieved as engines switch on and off as horse power is needed.
- The whole business case for <u>reduction in fuel consumption</u>, cost of fuel, maintenance of equipment, capital purchase cost, etc, is evaluated when comparing locomotive options. It is rarely the case that fuel consumption reductions come at a zero cost to other factors that impact on overall purchase and operating cost.
- Preliminary investigations into the use of <u>natural gas</u> for locomotives have occurred.
  - The technology application in rail is still immature. There has not been a technology drive for key suppliers to develop natural gas technology for locomotives.
- A technology idea in Australia is for <u>dual fuel (natural gas/diesel)</u> that can also operate on just diesel if gas is not available. R&D on a dedicated locomotive would be required to fully prove this technology.
  - Systems currently available overseas are limited to only using gas or gas and diesel which means the equipment must have access to natural gas in all areas of operation. These technologies are also limited to certain types of locomotives.
  - An additional factor is that the Australian rail network has a small outline and lighter track than USA locomotives. This means that any locomotives designed for the USA must be redesigned smaller and lighter to fit on the Australian network. This adds complication for specialist hybrid locomotives or retrofit technologies.
  - Industry would require substantial further consultation on the issues around alternative fuels and technologies, particularly given the industry proposals flowing from the Australasian Railway Association study.
- For those locomotives that operate mainly in ports, the <u>average age</u> is 15 year plus.
  - The main driver for retiring a locomotive is when the maintenance costs and or operational reliability become so high that it is not effective to operate the equipment. With a high capital cost, locomotives that are debt free become valuable assets in providing service to profit margin vulnerable businesses such as grain haulage. As a general rule a locomotive undergoes a full component change out which involves an engine rebuild and full overhaul every 10 years. This varies depending on locomotive type and the profitability of the business unit.
- Any <u>non-monetary incentives</u> for a replace/repower program would only be complementary. Rail assets are too expensive for capital expenditure initiatives for non-financial reasons.
- The <u>electrification of the Botany-Enfield line</u> would create a number of challenges. The capital cost in providing new locomotives would be high. There are no standard gauge electric locomotives operational in Australia. New locomotives would need to be purchased and these would need to be adapted to fit on Australia's rail network.
  - The RailCorp electrified rail network uses an electric current supply that is non

standard to world design or technology produced. Electrification of the Port Botany – Enfield line would require the design and purchase of a dedicated fleet, at additional cost, for this network. These assets would be stranded assets unable to operate on any other rail network in Australia if they were to lose business on that track sector or suffer reduced demand. Therefore there would be significant business risks associated with responding to electrification by purchasing electrified locomotives. The service would also be expensive to provide and perhaps less competitive than diesel locomotives.

  - The locomotives used for this service would need to be dedicated solely for this operation. This may not adequately provide full asset utilisation of the locomotives and add to the cost. In addition, the change over from the electrified network to the diesel network would add to cost and time.
  - Generally rail operators try to avoid container handling where there is overhead wiring. There are significant risks in moving containers where there are live overhead wires.
  - The number of locomotives that operate on this line is not the same as the number of locomotives needed to dedicate locomotives solely to this line.
  - The operation of many locomotives on this line is seasonal. It is affected by Christmas periods as well as seasonal farming considerations. For example, for many years due to drought there was little traffic but recently there have been many train services to haul cotton.
  - Usage patterns, demand growth and infrastructure issues for this segment of rail network are important aspects that would require further detailed consideration and consultation with track network providers, ARTC and RailCorp.
  - Safe working consideration for containers under a live wire would also need to be dealt with.
  - Non-monetary incentives would not make switching to electric-ready engines more attractive.
- There is no experience with rail-replacement systems. The use of rail is an effective system and there is no known rail replacement system that would be adequate.

6.4 Options for Rail Emission Reduction Measures

Diesel rail freight emissions of NOx and VOC are a significant proportion of total port-related emissions in the GMR (Figure 2-1) although their contribution to total emissions from Port Botany is small (Figure 2-2).

Locomotives and rail infrastructure are highly capital intensive. Industry consultation indicates significant barriers to 'big ticket' rail emission reduction actions such as line electrification or a move to lower emitting LNG powered locomotives. However, assessing the scope to expand the Clean Machines program to include locomotives could deliver some emission reductions. The program could also provide a framework for improving locomotive engine maintenance.

Moving goods with locomotives generates less pollution than truck equivalent freight movements and specific measures that increase rail's mode share should be considered as part of a possible package of measures. These include:

- Engaging with port corporations, RTA, RailCorp and industry to encourage greater modal shift from road to rail freight to and from GMR ports. Although net changes in port emissions may be small, wider airshed benefits would be realised from reduced road network diesel traffic and congestion. Without intervention, a large increase in truck movements is expected in the next 20 years.

- Managing truck and rail servicing charges under the Port Botany Landside Improvement Program, in support of Port Botany's 40% rail target.

7 DIESEL ROAD VEHICLES

7.1 Road Emissions Related to Port Operations

Diesel road vehicles are estimated to contribute 0.1% of NO_x (19 tonnes), 0.2% of VOCs (1 tonne) and 0% of SO_2 (0.1 tonnes), PM_{10} (0.5 tonnes) and $PM_{2.5}$ (0.5 tonnes) to total port operation emissions.

Air emissions from new heavy vehicles are managed nationally through heavy vehicle emission standards. The current emission standards for heavy diesel vehicles are outlined in Table 7-1. These vehicle emission standards are the Australian Design Rules (ADRs) under the Commonwealth *Motor Vehicle Standards Act* 1989.

Table 7-1: ADR Emission Standards for Heavy Diesel Vehicles

Standard	Application Date	CO (g/kWh)	HC (g/kWh)	NOX (g/kWh)	PM10 (g/kWh)
ADR80/03	1/1/10 – 1/1/11	1.5	0.46	2.0	0.02

(http://www.infrastructure.gov.au/roads/environment/impact/Standards_for_Diesel_HDVs.doc)

National emission standards only apply to new vehicles. Diesel vehicles are long lived, often lasting more than thirty years, and older diesel vehicles are commonly used for freight transfer from ports. Measures that directly address emissions from existing vehicles, promote the use of cleaner vehicles or improve efficiency in use of vehicles can reduce associated port emissions.

7.2 Road Emission Mitigation Methods

7.2.1 NSW Clean Fleet Program and National Fuel Tax Rebate

The Commonwealth government offers an 18 cent per litre (c/l) credit to pre-1996 heavy vehicles that pass a DT80 emissions test, can demonstrate compliance with an endorsed maintenance schedule or that are part of an accredited audited maintenance program. The NSW Roads and Traffic Authority has developed the Clean Fleet audited maintenance program to assist fleet owners to utilise the 18 c/l credit.

7.2.2 Measures to Improve Operational Efficiencies

7.2.2.1 Idle reduction programs

Idle reduction programs aim to decrease the amount of time vehicles spend in idle mode as part of their overall operation. Idle reduction can be implemented through state and local anti-idling rules as well as educational programs. Anti-idling rules stipulate areas where idling is not permitted or regulate the duration of idling. Educational programs dispel myths relating to engine warming and advocate fuel cost savings associated with switching off an engine after a certain period of idling.

One hour of idling is estimated to produce 1-5 grams of PM_{10} and 140 grams of NOx, based on a post-1995 diesel truck. Idle Free BC, a program hosted by the BC Climate Exchange in British Columbia, Canada, has estimated that vehicle idling reduction programs have the potential to reduce approximately 20% of annual fuel budgets.

California adopted a rule in 2002 to prohibit trucks from idling within 100 feet of schools. In 2004, a further rule limited engine idling of heavy duty diesel trucks in California – at ports and elsewhere – to five minutes, and in 2005, to require trucks equipped with sleeper berths to meet the five-minute limit or use equipment with very low emissions in idle mode. Educational materials have also been produced for distribution to truck drivers and the general public.

7.2.2.2 Reduced truck trips involving empty containers

Only a small percentage of empty import containers are reloaded with outbound cargo at many ports. Part of the problem lies with container chasses which are typically owned by different terminal operators and are not permitted for use with containers from other carriers. Trucks therefore often need to switch chassis for each run, which can add up to an hour per trip. Due to these chassis logistics issues, the potential for expanded container reuse is low, but where large numbers of containers are involved, there may still be both operational and environmental benefits in better aligning the pickup and drop-off of cargo. Options to reduce truck trips involving empty containers include:

- using emptied import containers to transport export bound goods back to port
- common (container) chassis pools whereby shipping companies provide their own chassis so that trucks can serve multiple carriers, and so reduce the number of empty container movements as well as congestion and wait times at terminal gates
- off-dock container depots where incoming and outgoing containers are matched, or cargo stored until a full container truck load has been accumulated. Trucks are directed to this off-port depot rather than directly to the port. Such a system requires considerable coordination and agreement among truck operators, ocean carriers, leasing companies and other supply chain participants, and carries some risk that the benefits of reduced ‘empty container’ trips may be somewhat offset by the shift of truck traffic from the port to the off-port depot.

The Port of Virginia in the US requires all chasses stored on site to participate in its common chassis pool. Truck drivers who previously completed only two to three container moves per shift can now move up to 10 containers daily.

Coast 2000 is a private dock facility located an equal distance from all deep water container terminals in Vancouver. Since commencing operations in 2000, it has eliminated thousands of truck trips every year.

7.2.3 Port Botany Landside Improvement Strategy

The Ports and Maritime Administration Amendment (Port Botany Landside Improvement Strategy) Regulation 2010 and the associated Port Botany Landside Operations Mandatory Standards (under Part 2B of the Ports and Maritime Administration Regulation 2007) is an authoritative framework to support operational performance standards at Port Botany. It came into effect in February 2011.

Developed through the Port Road Taskforce, these performance standards will improve efficiency at Port Botany’s landside interface by encouraging the port supply chain’s stakeholders to be accountable to each other for their performance. Scheduling standards and penalties for non-compliance aim to ensure more efficient turnaround times for ships and trucks. This should reduce truck idling due to queuing and congestion.

The system includes tracking devices in the trucks to enable automated notification of arrival and departure. Nineteen hundred trucks have registered as Port Botany freight carriers. Fines for non-compliance are modest ($100 and loss of a booking time slot) but the measures should encourage smoother operations.

During the first three weeks of the Operational Performance Measures, 33,600 time slots were used (of 41,269) with average truck turnaround times of 25 minutes. Further updates on reductions in late arrivals, queuing and no-shows are expected periodically.

The applicability of all or part of the Port Botany Land Side Improvement Strategy to other NSW ports depends on how significantly the ports are affected by truck queuing. Evaluation of the extent of queuing at Ports Kembla, Jackson and Newcastle is recommended.

7.2.4 Low Emission Zones for Ports

A 'low emissions zone' is a geographically defined area which seeks to restrict or deter access by certain polluting vehicles with the aim of improving air quality.

Such a zone could be implemented for a port area so as to limit the operation of trucks and other vehicles according to their age and emission performance. Low emission zones are generally phased in over several years to allow time for compliance. Initially, a maximum age or minimum emission requirement for vehicles is set, and vehicles not meeting these requirements have to pay a fee to enter the zone. Each year, the level of the ban increases such that the average age of the vehicle fleet decreases over time.

Most of the costs of this type of program would be borne directly by trucking companies, to replace their older vehicles or equip them with emission controls (such as particle traps or oxidation catalysts). The different methods of reducing road vehicle emissions that will be discussed include:

- Application of retrofit technology
- Introduction of tolling programs
- Replacing road engines with diesel electric engines.

7.2.5 Accelerated Fleet Turnover (AFT)

Reductions of emissions from road vehicles entering and operating within the port may be achieved through implementing and accelerating the fleet turnover program (AFT), or reducing the average age of vehicles used. AFT would aid the implementation of a low emissions zone, allowing these schemes to be implemented together.

Implementation could occur in a number of ways: incentives for owners of ageing vehicles to purchase new vehicles, or prohibiting access to vehicles older than a threshold age. Further, mandatory scrapping of old vehicles would prevent emissions from inefficient vehicles from occurring elsewhere, but would increase the cost of the scheme (Facanha and Ang-Olson, 2008).

Table 7-2 shows that with the implementation of an AFT program with broad coverage across vehicle types and segments of the transport sector, emissions reductions can be significant.

Table 7-2: Modelled AFT Program and Expected Benefits

Vehicle Class	Scrapped Age	Replacement Age	Number of Vehicles Replaced	Annual VKT	Average Emission Reduction (tonnes/annum)	
					NO_x	$PM_{2.5}$
Medium trucks	1994-2006	2007+	2,262	58,541	925.3	16.3
Heavy trucks	1994-2006	2007+	1,204	109,676	3,436.5	175.1

The cost of implementing scrappage programs can be significant. The cost of enforcing the standards, assessing vehicles and the level of subsidy for scrapping older vehicles need to be carefully considered.

AFT programs currently exist at several ports around the world including Los Angeles and Oakland in the United States. In these cases the port authority provides grants to scrap and replace older road vehicles.

7.2.6 Retrofit Technologies

Several technologies are available that aim to reduce particulate, CO, VOCs and NO_x emissions through chemical and physical processes to change the composition of the exhaust from road vehicles. Available exhaust retrofit devices are described in Section 4.1.

The NSW Diesel Retrofit Program, jointly funded by the NSW OEH and RTA have encouraged the fitting of emission control devices to diesel trucks. As of February 2011, 520 heavy diesel vehicles have been fitted with exhaust treatment devices. The Diesel Retrofit Program is currently targeting road transport operators with a pre-2003 model diesel truck who regularly access Port Botany, Port Kembla, the Port of Newcastle and the Cooks River Rail Yard.

7.2.7 Tolling Programs

The introduction of a tolling program to reduce congestion and improve the access of trucks could improve the air quality at NSW ports in the GMR. Trucks produce 318% more particulate matter travelling at 8 km/h (5 miles/h) than at 88 km/h (55 miles/h). For every hour a truck idles, it produces 10 kg (22 pounds) of carbon dioxide (EDF, 2010). To increase travel speeds and reduce idling, a tolling program that eases congestion could be implemented. Tolling of heavy vehicles can provide incentive for shifting freight to rail.

At Port Botany differentiated charges for booking pick up time slots acts as a financial incentive to ease congestion by encouraging off-peak collection of freight from the port.

Case Studies for Tolling Programs

Two examples in which a toll program has been successfully implemented include the PierPASS in California and Germany’s Toll Collect. Both of these case studies are discussed below.

California’s PierPASS

In 2005, the West Coast Marine Terminal Operators Association created PierPASS to reduce congestion and improve air quality. PierPASS is a flagship program, providing financial incentives to move cargo during off-peak times of 6pm to 3am. The marine terminals charge a Traffic Mitigation Fee of $50/TEU during peak hours (3am to 6pm). This fee is not assessed for cargo movement in or out of the ports during off-peak hours (EDF, 2010).

Germany’s Toll Collect

Germany’s Toll Collect program is a distance-based toll for all trucks over 12 tons across the country to relieve congestion. Launched in 2005, Toll Collect aimed to shift freight from road to waterways and railways but it also penalises vehicles with poorer emissions. The revenue generated was used for transportation projects. Toll Collect uses a satellite-based GPS mobile system to collect tolls from heavy duty trucks based on the distance travelled, location and time. Germany’s Toll Collect program charges 14 eurocents per kilometre for Euro V or EEV (Environmentally Enhanced Vehicle) engines and 28 eurocents per kilometre for the Euro II or older engines (EDF, 2010).

Some of the benefits of introducing a tolling program in California and Germany are listed in Table 7-3.

Table 7-3: Benefits from the Introduction of Tolling Programs

	California PierPASS	Germany's Toll Collect
Environmental benefits	Truck traffic has shifted from day to night hours, reducing midday congestion and reducing emissions from idling vehicles	The number of Euro II engine trucks or worse fell from 50% to 20% Euro V engines increased from <1% in 2005 to almost 51% in 2008 Eliminated the need for toll booths, reducing idling
Co-benefits	Reduced traffic delays Reduced congestion for Los Angeles motorists	Reduced highway congestion with the number of empty truck trips decreasing by 20% Funding to infrastructure projects provided from toll revenue
Economic benefits	Improved company distribution as congestion can delay shipments for almost eight days at the port	Toll Collect has received 3.4 billion Euros in revenue since 2007

Implementing a Tolling Program

From the two tolling program case studies, it was found that each took on a different tolling system. The PierPASS encouraged off-peak travelling, whereas Toll Collect discouraged driving "dirty" trucks (i.e. Euro II engines or worse). Both tolling systems are possible options for NSW ports.

A tolling program such as the PierPASS may increase night time truck traffic and noise in local communities. The expense associated with implementing the tolling program depends on the design of the program. Toll revenue can be collected to recover the infrastructure and implementation costs (EDF, 2010, ICF International, 2008).

7.2.8 Diesel-Electric Engines

At present the majority of trucks have diesel engines. Diesel engines are durable and have a long life expectancy. These qualities suggest that it could take decades before diesel engines are replaced by cleaner engines . Hybrid diesel electric vehicles are much more fuel efficient and emit less pollution than even the cleanest diesel engine.

In recent years hybrid gasoline-electric passenger cars have become a popular alternative to conventional vehicles. Hybrid diesel-electric engines have recently started emerging in the market as an alternative for diesel trucks. A diesel-electric hybrid truck is powered by a diesel engine generating and storing electricity to power an electric motor. Replacing typical diesel trucks with diesel-electric hybrid trucks has many environmental and economic benefits such as:

- green house gas emission reductions of 30-50%
- diesel particulate matter reductions of 96%

- nitrogen oxide pollution reductions of 65%
- air quality and public health benefits to the community
- reduced noise and vibration of traditional diesel engines
- increased fuel efficiency of 30-57%.

These reductions using diesel-engine hybrid trucks are in comparison to the 1999 baseline vehicle (EDF, 2010).

Diesel-electric technology is most commonly used in medium and heavy-duty vehicles in urban stop-and-go settings such transit buses and local delivery trucks but not so much for long-haul trucks. Some companies which have purchased diesel-electric hybrid trucks include FedEx, Wal-Mart, Coca-Cola Enterprises and Ryder. Hybrid vehicle manufacturers include Honda, Volvo and Navistar. Market penetration of diesel-electric hybrids has been slow despite the technology being well-established.

Cost is one of the main contributing factors discouraging the widespread adoption of hybrids. A new typical diesel medium/heavy-duty delivery truck may cost around US$60,000 whereas a new diesel-electric hybrid truck might cost more than US$110,000 (EDF, 2010). Financial incentives help encourage the uptake of diesel-electric hybrid trucks.

7.3 Summary of Stakeholder Responses on Diesel Road Vehicle Emissions

- Low emission zones
    - No experience of low emission zones.
    - Low emission zones would have the potential to improve air quality not only in the ports but on all major metropolitan roads. Many of the trucks that travel to the ports are old and do not meet current emission standards.
    - Most trucks owned by large corporations that are used in NSW ports are Euro 3 emissions standard. Others that are lower than Euro 3 standard are owned by sub contractors and are between 1997 and 2002 vintage. Therefore a low emissions zone would have little impact on current behaviour as far as vehicle age and emissions standard.
    - Issues to be considered in scoping a low emission zone for NSW ports:
        - Technical: A standard would need to be developed and a means of certifying compliance with the standard established.
        - Compliance: Regulators would need to put in place cost effective systems to ensure that non-complying vehicles do not enter the port area.
        - Economic: Many of the trucks operating to the port are old and of low value. It is generally not viable to use newer vehicles because of the low freight rates for containers and the amount of non-productive time when trucks are caught in congestion or waiting to load or unload. If the trucks were to be up-graded or replaced operators would expect compensation and the conditions that make the operation of new trucks uneconomic would need to be addressed.
        - There would be an impact on small operators who may have difficulty in upgrading equipment and as such be penalised by the introduction of the zone.

- Further time for internal stakeholder investigation of this topic is required to provide a complete and considered response.

- Retrofitting
  - Retrofit technology is currently used in NSW ports.
  - Partial particle traps are the preferred technology. This technology removes around 50 percent of particles but does not have the operational problems that a full particle trap has. A full particle trap removes over 90 percent of particle emissions.
  - Catalytic converters have been retrofitted to some older trucks in the past as part of a RTA grant project. Equipment previously fitted provided the maximum amount of units at the least cost.
  - Access to the port area is the incentive most used in similar programs. Non-financial incentives, such as the operator being seen to be environmentally responsible, may not be sufficient for fleets operating in the very competitive container transport trade.
  - If vehicles that required retrofit technology were in a fleet, a cost benefit analysis would be required to ascertain what units to purchase to provide the maximum particulate reductions at the least cost. Subsidies in providing equipment through full grant payment of equipment would be a suitable incentive.
- Accelerated fleet turnover
  - Average age of vehicles currently in use is not known. RTA registration statistics can provide the age distribution of registered trucks but surveys would be necessary to establish the age of trucks using the ports.
  - The industry has a relatively young truck fleet. This is indicated by the fact that all vehicles owned by a large operator in NSW are Euro 3 emissions compliant.
  - An AFT program would not result in a significantly newer, cleaner fleet. Given the relatively young age of the current fleet, suitable incentives would only reward current behaviour, not drive or reward new behaviour of accelerated fleet turnover.
  - If the program resulted in all trucks meeting a standard equivalent to “Euro 4” it would significantly reduce fleet emissions.
- Tolling programs
  - No experience with tolling programs
  - Variable pricing has been considered and discussed in the past to encourage road users to access the ports out of key time periods to smooth demand and increase port productivity.
  - Consideration should be given to smoothing truck demand at ports with variable pricing and whether this is complementary to tolling for air quality reasons.
  - Further time is needed for internal investigation about the issues surrounding tolling programs.
- Diesel electric engines
  - No experience using diesel electric engines.
  - A trial is currently being conducted on the use of electric systems to facilitate the loading and unloading of trucks without using the engine at that time.
- Alternative fuels

- One company has investigated the use of biofuel but does not support its use for a wide range of reasons.

7.4 Options for Diesel Road Vehicle Emission Mitigation

Diesel road vehicles contribute only a small proportion of emissions from GMR ports but their wider airshed impacts are significant, particularly health impacts of diesel particulate matter. A broad based mitigation strategy that includes and extends upon existing programs appears to be most beneficial for addressing diesel road vehicle emissions.

Measures that could be considered include:

- Extending or improving the Port Botany Landside Improvement Strategy (PBLIS) measures to reduce congestion and improve truck turnaround times at Port Botany, which in turn reduce idling emissions. Additional measures could include:
    - Engaging with port corporations and industry on the feasibility of differentiated fees for trucks of different emissions performance standard with the aim of encouraging cleaner vehicles at GMR ports. Sensitivity to pricing would need to be investigated with industry.
    - Assessing whether all or part of the PBLIS could be extended to other NSW ports (i.e. Kembla, Jackson, Newcastle). This will depend on how significantly these ports are affected by truck queuing.
- In liaison with RTA and industry, encourage further driver education to help reduce truck idling and the adoption of retrofit technologies through the NSW Diesel Retrofit Program, targeting older vehicles.

8 CONSULTATION

8.1 Consultation Process

A component of this study was consultation with key stakeholders involved in NSW ports operations in the areas of shipping, stevedoring, freight and governance. The stakeholder organisations listed below were invited to participate:

- Australian Shipowners Association
- Sydney Ports Corporation
- Australian Maritime Safety Authority
- Newcastle Port Corporation
- Port Kembla Port Corporation
- Shipping Australia
- NSW Maritime
- Ports Australia
- Roads and Traffic Authority
- DP World
- Asciano Ltd:
    - Patrick
    - Pacific National

A Consultation Report was prepared for the stakeholders, setting out the key background issues and the technical issues and options associated with emissions management separated into the basic functional aspects of port operations: shipping, cargo handling and freight (road and rail).

The Consultation Report contained a questionnaire at the end of each technical section. Stakeholders were invited to respond to the questionnaires relevant to their activities. Telephone discussions were held with stakeholders and in some cases these discussions provided more detailed information to assist with responses, and also to elaborate on responses.

A copy of the Questionnaire is contained in Appendix D.

8.2 Key Issues

A number of broad issues and themes emerged from the consultation process:

- Some respondents questioned the needs and benefits of targeted emissions reductions for the shipping and ports sector.
- Competitive issues are important: industry generally would not support a ‘go it alone’ approach by NSW in imposing regulations or programs, such as emission taxes or stringent fuel standards, that would incur greater costs compared to other ports that compete for the same business. On the other hand, where pricing mechanisms are used, port operators acting in a co-ordinated fashion nationally could be considered to be acting collusively in breach of the *Trade Practices Act*. Hence, a nationally co-ordinated approach with government is broadly advocated in terms of initiatives for changing behaviour.

- Where the price of services is used as an incentive for changing emissions behaviour, initiatives should be implemented by national bodies. Unilateral actions in NSW may simply provide incentives to use other ports in Australia. Regulatory or pricing action that penalises certain behaviour may simply drive operators elsewhere, without significantly reducing emissions. However, action by Australian authorities in isolation may also be problematic due to the international nature of shipping and the relatively small volumes of specific vessels visiting NSW ports at a high frequency. Significant changes to shipping practices and/or technology should therefore be applied through IMO processes. Landside changes that would affect competitiveness of individual NSW ports, say through the application of local taxes or charges on pollution, are not broadly supported and therefore would need to be backed up by more detailed justifications or be integrated into broader-based programs.
- The nature of NSW and Australian port operations generally is that they do not have the economies of scale to implement significant changes in practice cost-effectively. Practices applied in NSW often differ from those in other States and internationally for practical reasons. Hence large scale changes to technology would not be cost-effective for the many operators that use the facilities occasionally (if different standards are applied elsewhere).
- Industry regards financial incentives from government favourably when considering the implementation of capital-intensive programs such as retrofitting or technology upgrades. On the other hand, the scope for government funding is limited and therefore such incentives may not be realisable. Non-financial incentives are generally not considered to be beneficial where intensive capital investments are concerned.
- Businesses and industry associations are willing to (and currently do) participate when voluntary initiatives are proposed and promoted to improve emissions performance. Those that see the benefit in terms of efficiency gains as well as environmental dividends will willingly adopt new practices and technologies.

More specific stakeholder feedback is contained within sections 3.3.2.2, 3.3.3.3, 3.3.4.2, 3.3.6, 5.2, 6.3 and 7.3 of this report.

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APPENDIX A: FURTHER DETAILS ON REGULATORY ENVIRONMENT

The regulatory environment concerning ports and coastal waters is complex. Many of the ships that berth at Australian ports are international vessels and subject to international maritime laws. The following sections outline relevant policies and conventions that relate to the regulatory environment at and around ports within the GMR.

A.1 Marine Pollution Act 1987

The Marine Pollution Act 1987 is administered by NSW Maritime, and protects the NSW marine environment from pollution caused by commercial, recreational and trading vessels operating in NSW waters through a set of requirements. NSW Maritime is seeking amendments to the Marine Pollution Act in order to make the current legislation more consistent with the International Maritime Organisation's MARPOL conventions (NSW Maritime, 2011).

A.2 IMO MARPOL Annex VI 2008

The International Maritime Organisation (IMO) enacted a revised convention in 2008 for control of exhaust emissions from ships. The convention is known as MARPOL Annex VI (IMO, 2008). MARPOL is the International Convention for Prevention of Pollution by Ships. Annex VI deals with air pollution. Globally, NO_x emissions from ships and fuel sulfur content are regulated by IMO MARPOL Annex VI. Regulating fuel sulfur levels effectively regulates SO_2 emissions because essentially all fuel sulfur is converted to SO_2. Particle emissions are also related to fuel sulfur content but the relationship is not so direct because there are other significant contributors to particle emissions. MARPOL Annex VI names particle emissions as regulated emissions, but does not prescribe limits. Exhaust emissions of VOC and CO from ships are not presently regulated. There is provision in MARPOL Annex VI for control of fugitive VOC emissions from cargo operations. The previous Annex VI was enacted in 2005 and is sometimes known as MARPOL Annex VI Tier1.

MARPOL Annex VI also designates Emission Control Areas (ECAs) where lower fuel sulfur levels and/or lower NOx emissions are required. At present, fuel of sulfur content not greater than 1% must be used in ECAs, with only 0.1% sulfur in fuel permitted from in 2015. In ECAs, low sulfur fuel must be used in main engines, auxiliary engines and auxiliary boilers. An ECA can cover NOx, SO_2 or particles, or all three types of emissions.

The provisions of MARPOL Annex VI are:

- 2005 - Tier 1 NOx for new engines post 2000
- 2010 - ECA fuel sulfur 1%
- 2011 - global Tier 2 NOx for new engines (IMO Tier 1 less 15 to 20%) (engine tuning)
- 2012 - global fuel sulfur 3.5% (currently 4.5%)
- 2015 - ECA fuel sulfur 0.1%
- 2016 - ECA Tier 3 NOx for new engines (IMO Tier 1 less 80%) (exhaust gas aftertreatment)
- 2020 - global fuel sulfur 0.5% - if refineries can produce it, review in 2018
- Tier 1 NOx for engines greater than 5 MW and cylinder displacement at or above 90 litres,

installed 1990 to 2000 (conversion kits). The cylinder displacement limit restricts this provision to the largest engines, on the basis that they produce the greatest NOx per unit of power. This conversion is only required where an approved conversion kit is available from the engine manufacturer and is subject to a cost limit. Generally all SSDs are 90 litres per cylinder or more, but only 35% of MSD propulsion engines are greater than 90 litres per cylinder (US EPA, 2009).

- Under Annex VI, exhaust gas scrubbers can be used as an alternative to low sulfur fuel, if the reduction in exhaust SOx can be shown to be equivalent to the use of low sulfur fuel. This option allows ships to operate on low cost high sulfur heavy fuel oil and meet relevant SOx limits.
- Reduced sulfur content will reduce fine particulate emissions significantly.

Under MARPOL Annex VI, all States that are parties to the convention may require any ship entering their waters to comply with these regulations. Ships must carry the International Air Pollution Prevention (IAPP) and Engine International Air Pollution Prevention (EIAPP) certificates.

The IAPP certifies that the equipment, systems, fittings, arrangements and materials fully comply with the requirements of Annex VI. It contains records of survey to determine if the ship maintains its compliance. It also contains details of the equipment related to NOx, SOx, management of VOC and ozone depleting substances, and shipboard incineration.

The EIAPP is detailed under the NOx Technical Code, which is a component of MARPOL Annex VI. The NOx Technical Code provides mandatory procedures for testing, survey and certification of marine diesel engines to ensure they comply with the NOx requirements of MARPOL Annex VI (Regulation 13). The EIAPP certifies each individual engine's NOx compliance and includes a technical file with detailed specifications of engine performance parameters. The level of detail is much greater than in the IAPP.

The North Sea (including the English Channel) and the Baltic Sea have been designated as sulfur Emission Control Areas (SECAs). The US/Canadian ECA is a combined SOx/PM10/NOx ECA along most of the coasts of the two countries and will extend 200 nautical miles (370 km) from the coast. The States surrounding the Baltic Sea are also expected to apply to the IMO for an ECA for NOx. The Helsinki Commission (HELCOM) is currently preparing a submission. (Kageson, 2009).

A.3 EU Directive on Fuel Sulfur in EU Ports

The EU has directed that from 2010 fuel of sulfur content 0.1% or less by mass must be used at berth in European Union ports from January 1, 2010. The sulfur limit is detailed in Article 4b, EU fuel sulfur directive 2005 (EU, 2005) and a subsequent amendment. The terminology "at berth" covers ships alongside, buoys or anchored and whether or not they are working cargo. The rule covers all grades of fuel oil and all types of combustion machinery including main and auxiliary boilers. Ships need not comply with this 0.10% limit while manoeuvring but must comply as soon as possible after arrival in port and comply till as late as possible before departure. Some named ships which stay less than two hours in port will be exempt from these regulations. The Bunker Delivery Note (BDN) from the fuel supplier must clearly indicate the actual sulfur content of the fuel. The requirement also applies to all vessels while operating on inland waterways.

As an alternative to using low sulfur marine fuels Member States may allow ships to use an approved emission abatement technology, provided that these ships:

- continuously achieve emission reductions which are at least equivalent to those which would be achieved through the limits on sulfur in fuel,

- are fitted with continuous emission monitoring equipment, and
- document thoroughly that any waste streams discharged into enclosed ports, harbours and estuaries have no impact on ecosystems, based on criteria communicated by the authorities of port States to the IMO.

With regard to passenger vessels, the directive requires that passenger ships operating on regular services to or from any Community port use fuel of sulfur content 1.0% by mass or less. Member States are responsible for the enforcement of this requirement at least in respect of vessels flying their flag and vessels of all flags while in their ports.

A.4 California Air Resources Board (CARB)

The State of California has imposed controls on fuel type and sulfur content for all ship diesel engines and auxiliary boilers, but not propulsion boilers, up to 24 nautical miles from the coast (Regulations 13 CCR §2299.2, and 17 CCR §93118.2) (CARB, 2009):

- From July 2009 sulfur in Marine Gas Oil (MGO) must be 1.5% or less, and Marine Diesel Oil (MDO) sulfur must be 0.5% or less.
- From Jan 2012 the maximum fuel sulfur in either MGO or MDO is 0.1% (ISO, 2010).

In August, 2011 the North American ECA comes into effect. The following August will see the start of enforcement. From August 2012 to January 2015, the 1% sulfur limit will apply except in California, where lower limits are applicable. Low sulfur heavy fuel oil (LSHFO) will be an option, except in California. After January, 2015, the sulfur limit for all marine fuels will be 0.1% and it is unlikely that suitable heavy fuel oil will be available. Thus, for ECA requirements from 2015, ships will need to use distillate fuel and/or scrubbers. There is no indication that CARB will allow scrubbers as alternatives to low sulfur fuel, unlike the EU.

Generally, it takes between 45 minutes and 4 hours to completely change from heavy fuel to MGO or MDO distillate fuels for a typical slow speed marine diesel engine. This process requires light fuel to gradually be mixed with heavy fuel in a mixing tank, or a mixing valve system, as the injection system temperature drops. The changeover process must be entirely completed prior to reaching the 24 nautical mile point. Conversely, the changeover process must not be initiated until the vessel departs the 24 nautical mile boundary.

A.5 Legal Jurisdictions

Hildreth and Torbitt explain that under the United Nations Convention on the Law of the Sea (UNCLOS, LOSC), port and coastal States have jurisdiction over ships entering their waters and can implement emissions mitigation strategies. Port States are States whose port, terminal or internal waters a vessel may enter. Coastal States are States adjacent to a body of water where they may have some jurisdiction. Flag States are States in which a vessel is registered. Under MARPOL Annex VI and its authority under UNCLOS, signatories to the conventions must enact enabling legislation. The primary obligation under UNCLOS is with flag States. However, port States generally provide the controlling regulations and their enforcement (Hildreth and Torbitt, 2010).

Under MARPOL Annex VI, ships must carry an International Air Pollution Prevention (IAPP) certificate. The IAPP certifies that the equipment, systems, fittings, arrangements and materials fully comply with the requirements of Annex VI. It contains records of survey to determine if the ship maintains its compliance. It also contains details of the equipment related to NOx, SOx, VOC management and shipboard incineration. All ships over 400 gross tonnes under the flag of a party to MARPOL Annex VI must obtain an IAPP. An IAPP cannot be issued to a ship which operates under the flag of a State which is not a party to MARPOL Annex VI. A port or coast State may block access to any vessel not complying with the IAPP requirement.

Further, according to Hildreth and Torbitt, UNCLOS effectively allows port States to establish standards that exceed the IMO conventions and to prohibit ships from entering their waters if they do not comply. Hildreth and Torbitt cite examples such as California's low sulfur fuel standards for ocean going vessels within 24 nautical miles of the coast and a Swedish port city's law requiring NOx control systems on new and existing vessels (Hildreth and Torbitt, 2010).

Hildreth and Torbitt state that the ECA designation allows the U.S. to enforce U.S. air quality NOx emission standards and fuel sulfur content limitations on vessels operating within 200 nautical miles off the U.S. coast, beginning in August 2012.

ICCT 2007 states that MARPOL 73/78 does not prevent a country from setting standards for its own ships. They assert that Annex VI specifically allows a country to set alternative standards that would apply to engines on ships that operate solely in waters under its jurisdiction. The United States and several European nations have begun to address shipping emissions in their waters based on this authority (ICCT, 2007 p40).

The following extract from Kageson explains the legal issues around charges levied on shipping according to pollution levels (Kageson, 2009):

> *According to UNCLOS Article 24, the coastal state shall not hamper the innocent passage of foreign ships through the territorial sea except in accordance with the Convention. However, 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"…*
>
> *…Port States have wide discretion under UNCLOS and are allowed to make voluntary port calls conditional on unilaterally enforced standards if they consider this necessary for the protection of their environment. However, the requirements must be proportional to the subject pursued and non-discriminatory. They can be enforced on all vessels regardless of flag. Examples of States having made use of this opportunity are the United States Oil Pollution Act, the European Union's ban on single hull tankers, the 1996 Stockholm agreement on roll-on-roll-off ferries, the US ballast water requirements, and a recent ruling by the Swedish Supreme Environment Court on the use of SCR in the case of the city of Helsingborg versus two ferry lines. Most of these unilaterally introduced requirements applied to domestic and foreign flagged ships for the right of entry to a port have also affected the vessels when travelling in the territorial sea and the Exclusive Economic Zone on their way to the ports…*
>
> *…However, Article 26 declares that no charge may be levied upon foreign ships by reason only of their passage through the territorial sea, and that charges may be levied upon a foreign ship passing through the territorial sea as payment only for specific services rendered to the ship and only in a non-discriminatory manner. This may be interpreted to rule out the use of distance-related charges.*
>
> *As shown above, it would in principle be possible to require all ships to be equipped with advanced technologies for the abatement of NOx, e.g. SCR, as a condition of entry into a port. However, from a cost-effectiveness point of view, it does not seem reasonable to require infrequent visitors or ships with few remaining years in operation to install technologies that would require 10 or more years to be written off. In such cases charging high emitters appears to be a more flexible and less costly solution. As this offers a greater flexibility to owners and operators of foreign*

flagged ships, it should in principle be regarded as less far-reaching than a fixed standard.

One way of limiting the risk of conflict over the interpretation of Article 26, may be to design the en-route scheme in a revenue-neutral way so as to avoid any net payment being levied on the average ship, though low-emitting ships would receive more than they pay, and owners of high-polluting ships would pay more than they get back. The latter would thus pay a net fee, which reflects higher than average damage to the environment. This is exactly what happens within the existing Swedish scheme for environmentally differentiated fairway dues, which however does not take distance into account. The risk of conflict with Article 26 would diminish even further if the scheme was designed as a baseline-and-credit system, where no charges would be involved at all.

The legal situation is evidently not entirely clear. Both UNCLOS and MARPOL were adopted at a time when air pollution from ships was not a major concern, and cap-and-trade systems and schemes for baseline-and-tradeable credits had not yet been invented. Therefore it is difficult to say how far a port state can go in introducing schemes that take account of emissions from ships in the territorial water and the economic zone on their way to a voluntary port of call. However, one may assume that what is not prohibited according to general principles or specifically forbidden, should be legitimate.

As baseline-and-credit schemes neither enforce mandatory standards that go beyond generally accepted international rules nor raise any charges, they seem to be more feasible from a legal perspective than en-route charges, even in a case where the latter are designed in a revenue-neutral manner.

The survival of a scheme that potentially operates under legal uncertainties depends to an extent on whether any flag state or any owner of a foreign flagged ship cares to complain. The risk of legal complaints is presumably small as long as the scheme is fair and efficient and the rules are transparent. The risk of conflict should be very small in a case where the objective is to incentivise ships to meet an agreed IMO regulation ahead of time.

The responsible entity

In maritime law, a ship has a distinct legal personality. It may be arrested and have legal proceedings brought against it separate from the legal owner or operator. Sweden's enforcement of its fairway dues requires all ships to submit electronically a declaration for fairway dues. According to the ordinance, "those who sign" declarations for fairway dues assume payment liability for these dues. The ordinance does not specifically place the liability with any legal entity. It is understood to be the ship that needs to comply with the regulation.

Making the ship responsible for submitting allowances or paying the tax or charge would make it possible to rule that a non-complying ship would be denied the right of calling voluntarily at participating ports until its debt was paid. To maintain the ship's right to call it would make no difference whether the charge or the credits were paid or submitted by the owner, the charterer, the operator or by someone else. Change of flag state or ownership would not alter the liability of the ship.

Making the owner or the charterer of the ship liable would potentially be less effective, as several different charters may be involved over time and as vessel ownership may change. It may be difficult to deny a ship the right of entrance in a case where a former charterer or owner was legally responsible and had not submitted enough NOx credits or paid the en-route charge.

> *A non-complying ship would be black-listed by the Authority and denied the right of calling voluntarily at participating ports until its deficit was balanced or the debt paid.*

The United Nations Convention on the Law of the Seas (UNCLOS) declares the region out to 3nm from a State's coast as the Territorial Sea. Governments can impose restrictions as long they do not interfere with innocent passage. The region out to 24nm from the coast is known as the Contiguous Zone. The region out to 200nm is the Exclusive Economic Zone where governments can only apply internationally agreed standards (AMSA, 2011).

APPENDIX B: SHIP EMISSIONS INVENTORY AND MODELLING OF MITIGATION MEASURES

B.1 OEH Model

The Office of Environment and Heritage supplied a preliminary emissions inventory for the four major NSW ports for the 2008 calendar year. The inventory was calculated in Microsoft Excel using a detailed methodology, whereby each individual ship movement was followed. Three separate spreadsheets were provided, one for each of three fuel types, RO, MDO and MGO.

The main data source for ship movements and ship characteristics was Lloyds Register. The ship movement data gave arrival and departure times at the ports and at individual berths. Some information on anchorage durations was also provided, but not for Newcastle, where anchorage time was derived from averages for the other ports. The proportion of each type of fuel used in all three categories of fuel burning machinery (main engines, auxiliary engines and auxiliary boiler) was assigned according to tank capacities defined in the Lloyds data for each fuel type. A comprehensive set of emissions factors was used, drawing on well recognised sources. The factors for PM_{10} are sensitive to fuel sulfur content.

The time from port arrival to berth was split between slow sailing at a restricted speed and manoeuvring. Manoeuvring typically involves the use of bow and stern thrusters, as well as tugs, to slow the ship to zero forward speed and to position the ship alongside. The movement data do not delineate this phase of operations, so the OEH model creates a notional manoeuvring time which is not necessarily representative. However, the approach is reasonable in the absence of more definitive data. Further refinement of the inventory could involve analysis of actual ship movement data from direct observation or historical AIS data. The analysis would provide guidance as to assignment of representative vessel speed and power profiles by vessel type and berth location. Fuel consumption during the combined manoeuvring and restricted speed zone operating modes represents only 1.5% to 4% of total fuel consumption (depending on the port), so the accurate representation of these phases is not crucial to the overall inventory accuracy. The use of default average cruise distances between the boundary of the NSW GMR and the ports is necessary given the form of the Lloyds movement data. However, given the large mass of emissions generated during this cruise segment, it may be worth using more detailed modelling of ship traffic patterns.

No emissions from tugs and dredges have been included in the inventory. These could be derived from actual fuel usage figures supplied by operators (Goldsworthy & Renilson, 2009).

B.2 Vessel Surveys

To resolve uncertainties in fuel type, fuel usage rates, fuel sulfur content, machinery type, etc, a program of surveying individual vessels is recommended. This could be by written survey form sent to ships by email or handed out by pilots, and/or by employment of a marine engineer to visit ships in port and interview chief engineers.

B.3 Revised Model

To facilitate scenario analysis, the OEH data were migrated across into AMC's existing ship inventory model in Microsoft Access. A number of assumptions in the OEH model were revised as detailed in the following sections.

B.4 Auxiliary Engine Type and Fuel Type

An analysis was made of auxiliary engine type and typical fuel type usage. This analysis drew on marine engineering and ship survey experience, a number of published sources and details of auxiliary engine type suppled with the Lloyds data. Accordingly, fuel usage was assigned by machinery type and typical fuel usage patterns rather than by tank capacity. Auxiliary engine type was assigned according to installed auxiliary power, rather than an assumed 42% HSD, 58% MSD across all vessels. In the revised model, all main engines and auxiliary boilers use RO, and smaller vessels use HSD auxiliary engines running on MGO. Larger vessels use MSD auxiliary engines running on RO. An intermediate range of vessel sizes use MSD auxiliary engines running on MDO. These assignments are to a degree arbitrary but have a rational basis, as explained in the supplementary document. The chosen settings resulted in 26% of the auxiliary engine fuel usage being MDO/MGO. As a result of these changes, total fuel consumption reduces by 1%, NO_x and PM_{10} reduces by 2% and SO_2 reduces by 3% compared with the OEH model.

B.5 Tanker Boiler Fuel Usage

Tanker boiler fuel usage is a dominant factor in berth emissions and its correct estimation is challenging. The OEH assumptions have been revised based on experience gained from previous inventory work, which included thermodynamic calculations of expected fuel consumption for the steam driven cargo pumps, personal communications with a number of ships engineers and published data from IMO. Thus, tanker discharge time is limited to 30 hours per visit, to avoid assigning high boiler fuel consumption to periods when tankers are alongside but not discharging. The 30 hour figure represents typical industry practice. Further, only tankers with dry weight greater than 80,000 tonnes were assumed to have steam turbine driven cargo pumps. Smaller tankers typically have hydraulically driven pumps which are much more energy efficient that the steam turbine pumps and are powered by the auxiliary generators (Buhaug et al, 2009). These assignments were partially verified by calculating the ratio of the total tanker boiler fuel usage at berth with total mass of oil delivered over the inventory period. Experience shows that this ratio should lie within the range 0.35 to 1 kg of boiler fuel per tonne of oil delivered. More recent Australian data from BP Shipping indicates that a value around 0.6 is typical. Using the revised methodology the resultant ratio for Sydney Ports is 0.7.

The revised methodology for assigning auxiliary engine type, fuel type usage and tanker boiler operation resulted in a 39% reduction in modelled auxiliary boiler fuel consumption and an 11% reduction in total fuel consumption for the inventory period. Emissions of NO_x remain essentially unchanged, while SO_2 decreases by 7% and PM10 decreases by 6%.

B.6 Cruise Ship Auxiliary Engine Power

Cruise ships are often powered by diesel/electric systems. In such cases, all the ship engines are coupled to electrical generators, to supply electric motors driving the propellers. Generally there are no auxiliary generators, because any electricity required for purposes other than propulsion is supplied from the main generating plant. In such cases, the Lloyds data for auxiliary engine power lists only the emergency generator. This is a small engine driven generator which is just large enough to provide emergency lighting, steering and compressed air in case of total blackout. For instance, for the QE2, main engine power is given in the Lloyds data as 9.6MW, and auxiliary engine power is given as around 768kW. This is far too small.

Thus, for cruise ships, auxiliary engine installed power needs to be defined as a fraction of main engine power. In the revised methodology, a value of 0.278 is used for this fraction (US EPA, 2009).

B.7 Final Changes in Estimated Values

Compared with the original OEH model, the revised methodology for assigning auxiliary engine type; fuel type usage; tanker boiler operation; and cruise ship auxiliary engine power results in a 39% reduction in modelled auxiliary boiler fuel consumption and a 9% reduction in total fuel consumption for the inventory period. Overall, emissions of NO_x increase by 3%, while SO_2 reduces by 5% and PM_{10} reduces by 3%. The emissions reported below and scenario analysis is based on the revised methodology.

B.8 Baseline Inventory Results for 2008

Table B-1 shows fuel consumption by machine type and fuel type, for each port. Also shown are aggregates by machine type, fuel type and port.

Table B-1: Fuel Consumption and Emissions by Port, Machine and Fuel Type

Port	Machine Type	Fuel Type	tonnes of fuel and emissions/annum												
			Fuel	NOx	N_2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	NMVOC	CH_4	CO	CO_2	PAH	PCDF
Botany	ME	RO	32,594	2,963.3	5.15	0.50	1,701.4	235.0	216.2	48.8	0.98	89.3	103,509	7.3E-01	1.7E-08
Botany	AE	MDO	1,674	107.2	0.24	0.02	21.3	2.9	2.6	3.1	0.03	8.5	5,320	1.9E-02	2.3E-10
Botany	AE	MGO	67	3.3	0.01	0.00	0.5	0.1	0.1	0.1	0.00	0.3	212	7.7E-04	9.2E-12
Botany	AE	RO	19,284	1,248.8	2.63	0.25	1,006.6	121.1	111.4	34.0	0.34	93.4	61,239	3.7E-01	8.5E-09
Botany	AB	RO	13,164	90.6	3.45	0.02	687.1	62.6	57.6	4.3	0.09	8.6	41,804	1.9E-01	4.3E-09
Newcastle	ME	RO	18,267	1,666.5	2.90	0.28	953.5	131.8	121.2	27.5	0.55	49.0	58,011	4.1E-01	9.3E-09
Newcastle	AE	MDO	4,400	281.8	0.63	0.06	55.9	7.5	6.9	8.1	0.08	22.3	13,985	5.1E-02	6.1E-10
Newcastle	AE	MGO	840	42.2	0.12	0.01	6.2	1.1	1.0	1.5	0.02	4.3	2,672	9.7E-03	1.2E-10
Newcastle	AE	RO	2,298	148.8	0.31	0.03	120.0	14.4	13.3	4.0	0.04	11.1	7,298	4.5E-02	1.0E-09
Newcastle	AB	RO	4,663	32.1	1.22	0.01	243.4	22.2	20.4	1.5	0.03	3.1	14,807	6.7E-02	1.5E-09
Kembla	ME	RO	10,764	959.6	1.69	0.16	561.9	77.2	71.0	15.7	0.31	31.2	34,184	2.4E-01	5.5E-09
Kembla	AE	MDO	1,717	110.0	0.25	0.02	21.8	2.9	2.7	3.2	0.03	8.7	5,458	2.0E-02	2.4E-10
Kembla	AE	MGO	64	3.2	0.01	0.00	0.5	0.1	0.1	0.1	0.00	0.3	205	7.4E-04	8.9E-12
Kembla	AE	RO	2,774	179.7	0.38	0.04	144.8	17.4	16.0	4.9	0.05	13.4	8,810	5.4E-02	1.2E-09
Kembla	AB	RO	2,046	14.1	0.54	0.00	106.8	9.7	9.0	0.7	0.01	1.3	6,496	3.0E-02	6.7E-10
Jackson	ME	RO	12,520	965.0	1.93	0.18	653.6	86.1	79.2	15.1	0.30	47.3	39,761	2.7E-01	6.1E-09
Jackson	AE	MDO	1,688	108.1	0.24	0.02	21.5	2.9	2.6	3.1	0.03	8.6	5,366	1.9E-02	2.3E-10
Jackson	AE	MGO	366	18.4	0.05	0.01	2.7	0.5	0.4	0.7	0.01	1.9	1,164	4.2E-03	5.1E-11
Jackson	AE	RO	10,884	704.8	1.49	0.14	568.1	68.3	62.9	19.2	0.19	52.7	34,564	2.1E-01	4.8E-09
Jackson	AB	RO	5,931	40.8	1.56	0.01	309.6	28.2	26.0	1.9	0.04	3.9	18,835	8.6E-02	1.9E-09
overall total			146,005	9,688.4	24.79	1.77	7,187.3	891.8	820.4	197.6	3.13	459.4	463,698	2.8	6.3E-08
ME total			74,146	6,554.4	11.66	1.12	3,870.4	530.0	487.6	107.1	2.14	216.9	235,465	1.6E+00	3.7E-08
AE total			46,056	2,956.4	6.36	0.62	1,969.9	239.1	220.0	82.0	0.82	225.6	146,291	8.1E-01	1.7E-08
AB total			25,803	177.7	6.77	0.03	1,346.9	122.7	112.9	8.5	0.17	16.9	81,942	3.7E-01	8.5E-09
Botany total			66,782	4,413.3	11.5	0.79	3,416.9	421.6	387.9	90.3	1.43	200.2	212,084	1.3E+00	3.0E-08
Newcastle total			30,468	2,171.4	5.2	0.39	1,379.0	177.0	162.8	42.7	0.72	89.8	96,772	5.8E-01	1.3E-08
Kembla total			17,365	1,266.5	2.9	0.23	835.8	107.3	98.7	24.5	0.41	55.1	55,152	3.4E-01	7.6E-09
Jackson total			31,389	1,837.2	5.3	0.36	1,555.5	185.9	171.1	40.0	0.57	114.4	99,690	5.9E-01	1.3E-08
RO total			135,189	9,014.1	23.2	1.95	7,056.9	873.9	804.0	177.6	2.93	404.6	429,318	2.7E+00	6.1E-08

MDO total	9,479	607.2	1.4	0.13	120.5	16.2	14.9	17.5	0.17	48.1	30,128	1.1E-01	1.3E-09
MGO total	1,337	67.2	0.2	0.02	9.9	1.7	1.6	2.5	0.02	6.8	4,252	1.5E-02	1.8E-10
AE RO	35,240												
AE MDO	9,479												
AE MGO	1,337												

The main engines dominate fuel use and emissions, followed by auxiliary engines then auxiliary boilers. The long cruise segments at service speed from the boundary of the NSW GMR to the port entrances produce almost all of the main engine consumption and emissions. Total fuel consumption and emissions by port are greatest for Botany, followed by Newcastle, Jackson then Kembla.

Table B-2 shows fuel consumption and emissions by port and operating mode. For convenience, the RSZ and manoeuvre modes have been combined. The manoeuvring time is not a true manoeuvring time as the movement data did not provide this level of detail.

The dominance of the cruise mode for fuel consumption and emissions overall is apparent. However, for Botany and Jackson, berth fuel consumption and emissions approach cruise mode quantities.

Fuel consumption at berth is greatest for Botany, followed by Jackson, Kembla then Newcastle. NO_x, SO_2 and PM_{10} emissions at berth are greatest for Botany, followed by Jackson, Newcastle then Kembla.

Table B-2: Fuel Consumption and Emissions by Port and Operating Mode

Port	Operating Mode	fuel consumption and emissions in tonnes/annum												
		Fuel	NOx	N_2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	NMVOC	CH_4	CO	CO_2	PAH	PCDF
Botany	Anchor	7,872	321	1.49	0.07	382	41.1	37.8	9.28	0.10	24.73	25,000	1.3E-01	2.9E-09
Botany	Berth	23,367	946	4.43	0.19	1,190	128.4	118.1	27.20	0.30	72.41	74,208	4.0E-01	9.0E-09
Botany	Cruise	33,729	3,019	5.29	0.51	1,753	240.6	221.3	50.97	0.99	96.24	107,113	7.5E-01	1.7E-08
Botany	RSZ/Man	1,815	127	0.28	0.02	92	11.5	10.6	2.83	0.04	6.81	5,763	3.6E-02	8.1E-10
Newcastle	Anchor	2,433	94	0.47	0.02	89	9.3	8.5	2.81	0.03	7.46	7,731	3.4E-02	6.6E-10
Newcastle	Berth	8,524	333	1.63	0.07	309	32.5	29.9	10.20	0.11	27.18	27,079	1.2E-01	2.3E-09
Newcastle	Cruise	18,688	1,682	2.95	0.28	950	131.1	120.6	28.38	0.55	52.09	59,350	4.1E-01	9.3E-09
Newcastle	RSZ/Man	822	62	0.13	0.01	31	4.2	3.8	1.33	0.02	3.04	2,612	1.5E-02	3.0E-10
Kembla	Anchor	1,048	41	0.20	0.01	40	4.2	3.9	1.21	0.01	3.23	3,329	1.5E-02	3.0E-10
Kembla	Berth	4,767	217	0.85	0.05	206	22.6	20.7	6.24	0.07	16.78	15,141	7.6E-02	1.6E-09
Kembla	Cruise	11,306	993	1.77	0.17	580	79.3	73.0	16.68	0.32	34.00	35,906	2.5E-01	5.6E-09
Kembla	RSZ/Man	244	16	0.04	0.00	10	1.2	1.1	0.40	0.00	1.06	776	4.2E-03	8.7E-11
Jackson	Anchor	3,629	149	0.69	0.03	160	17.1	15.8	4.34	0.05	11.56	11,526	5.7E-02	1.2E-09
Jackson	Berth	12,717	564	2.30	0.12	621	68.2	62.8	16.18	0.18	43.42	40,389	2.2E-01	4.8E-09
Jackson	Cruise	13,562	1,021	2.06	0.19	700	91.3	84.0	17.29	0.32	53.27	43,071	2.8E-01	6.4E-09
Jackson	RSZ/Man	1,481	103	0.22	0.02	74	9.3	8.6	2.21	0.03	6.11	4,704	2.9E-02	6.6E-10
total Anchorage		14,982	605	2.85	0.13	671	71.7	66.0	17.64	0.20	46.98	47,585	2.4E-01	5.0E-09
total Berth		49,374	2,060	9.21	0.43	2,325	251.6	231.5	59.83	0.66	159.79	156,816	8.1E-01	1.8E-08
total Cruise		77,286	6,715	12.07	1.16	3,983	542.2	498.9	113.32	2.18	235.61	245,440	1.7	3.8E-08

total RSZ/Manoeuvre	4,363	308	0.66	0.06	208	26.2	24.1	6.77	0.09	17.02	13,856	8.4E-02	1.9E-09
overall total	146,005	9,688	24.79	1.77	7,187	891.8	820.4	197.57	3.13	459.39	463,698	2.8	6.3E-08

Total emissions at anchorage are significant, equivalent to 30% of berth emissions. This percentage is fairly uniform across ports. Further analysis of anchorage emissions is warranted, in terms of the proximity of the anchorage areas to the coast, and the potential for reducing anchorage time by altering schedules. This is further discussed in a later section.

Table B-3 shows fuel consumption and emissions by machinery type and by location, where anchorage and cruise are combined as "Ocean" and RSZ, manoeuvre and berth are combined as "Port". Also shown are auxiliary engine and auxiliary boiler fuel consumption and emissions at berth. The berth values are also expressed as percentages of port totals.

Table B-3: Fuel Consumption and Emissions by Machine Type and Broad Location

Machine Type	Operating Mode	fuel consumption and emissions in tonnes/annum												
		Fuel	NOx	N_2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	NMVOC	CH_4	CO	CO_2	PAH	PCDF
ME	Ocean	72,362.6	6,398.8	11.39	1.09	3,777	517.27	475.88	104.54	2.09	211.46	229,801.	1.61E+00	3.65E-08
ME	Port	1,783.3	155.6	0.28	0.03	93	12.70	11.68	2.53	0.05	5.42	5,663	3.95E-02	8.97E-10
AE	Ocean	13,642.2	878.2	1.89	0.18	549	66.88	61.53	24.37	0.24	67.02	43,334	2.32E-01	4.77E-09
AE	Port	32,413.8	2,078.2	4.47	0.43	1,420	172.21	158.43	57.66	0.58	158.57	102,956	5.75E-01	1.22E-08
AB	Ocean	6,263.0	43.1	1.64	0.01	326	29.79	27.41	2.05	0.04	4.11	19,889	9.04E-02	2.05E-09
AB	Port	19,539.9	134.5	5.13	0.03	1,020	92.94	85.51	6.41	0.13	12.81	62,052	2.82E-01	6.41E-09
Ocean Total		92,267.8	7,320.2	14.92	1.28	4,654.	613.94	564.82	130.97	2.38	282.59	293,025.	1.93E+00	4.34E-08
Port Total		53,737.0	2,368.3	9.87	0.48	2,533.	277.85	255.62	66.60	0.76	176.80	170,672.	8.97E-01	1.95E-08
Overall Total		146,005	9,688.5	24.79	1.77	7,187.	891.79	820.44	197.57	3.13	459.39	463,698	2.83E+00	6.29E-08
Ocean as % of Total		63	76	60	73	65	69	69	66	76	62	63	68	69
Port as % of Total		37	24	40	27	35	31	31	34	24	38	37	32	31
AE	Berth	30,075.7	1,927.6	4.15	0.40	1,318	159.83	147.04	53.50	0.54	147.13	95,529.9	5.34E-01	1.14E-08
AB	Berth	19,298.6	132.9	5.06	0.03	1,007	91.79	84.45	6.33	0.13	12.65	61,286.5	2.78E-01	6.33E-09
AE at berth as % of port total		56	81	42	83	52	58	58	80	71	83	56	60	58
AB at berth as % of port total		36	6	51	5	40	33	33	10	17	7	36	31	32

NO_x, SO_2 and PM_{10} emissions outside the ports represent 76%, 65% and 69% respectively of total emissions. These emissions are primarily from the main engines while ships are cruising between the boundaries of the GMR and the port entrances.

NO_x, SO_2 and PM_{10} emissions from auxiliary engines at berth represent 81%, 20% and 58% respectively of total emissions in port. Auxiliary boiler NO_x emissions at berth represent only 6% of total NO_x emissions in port, but boiler SO_2 emissions at berth represent 40% of total SO_2 emissions in port. This is because boilers inherently produce low NO_x emissions for a given mass of fuel compared with diesel engines, but the mass of SO_2 emissions is simply related to the mass of fuel burnt.

These data serve to illustrate the gains to be made from switching to low sulfur fuel compared with the use of shore power for auxiliary engines. 100% uptake of shore power would eliminate

50% of SO_2 emissions in port, while switching to low sulfur fuel in auxiliary engines and auxiliary boilers at berth would eliminate around 92% of SO_2 emissions in port. However, the reduction in NOx emissions from the use of shore power would potentially be much greater than from the use of low sulfur fuel, depending on percentage uptake of shore power. These control scenarios are examined in more detail in the next section.

B.9 Control Boundaries for Modelling Port Emissions Reductions

The current inventory uses the same average cruise distance for all vessels visiting a given port. This average is determined by assuming three possible entry points into the GMR - north, south and east. A straight line is drawn from each of the entry points to the port entrance, and the average length of the three straight lines is taken as the cruise distance. Thus, with the present inventory methodology, it is not possible to accurately determine the emissions benefits for control measures in arbitrary zones at given distances from the coast. More accurate modelling of the emissions benefits for a particular measure would require more accurate modelling of ship traffic patterns. This is beyond the scope of the present project. Accordingly, the emissions benefits for measures within the GMR were calculated by modelling the reductions in emissions during the cruise mode for the whole of the GMR, as well as the relevant reductions in port, if any. This gives an upper estimate. Roughly, a boundary between 20nm and 30nm would take in most of the modelled cruise paths.

By comparison, the RSZ zone for the Ports of Los Angeles and Long Beach extends out to 40nm. Shippers obtain benefits by complying within 20nm. Extra benefits are available for complying between 20nm and 40nm. The CARB low sulfur fuel zone extends out to 24nm.

B.10 Low Sulfur Fuel at Berth

The impact of switching all vessels to distillate fuel of 0.1% sulfur content while at berth is shown in Table B-4. The low sulfur fuel would be used in all auxiliary engines and auxiliary boilers. SO_2 emissions at berth are reduced by around 96%, which is effectively the % reduction in fuel sulfur content of 0.1% MGO compared with 2.7% RO. The normal use of some quantities of MDO of average 0.65% sulfur or MGO of average 0.38% sulfur in auxiliary engines results in small differences between ports in the percentage reduction in SO_2.

According to this modelling, the measure would have avoided 2,232 tonnes of SO_2 emissions in the NSW GMR for the inventory year, or 31% of total ship SO_2 emissions. PM_{10} emissions from ships would have reduced by 217 tonnes or 24%. These reductions have added significance because the sources are located relatively close to population centres compared with emissions during the cruise and anchorage modes outside the ports.

A small reduction of about 1% in total fuel consumption and total NO_x and CO_2 emissions is apparent, due to the greater heating value, lower NO_x emissions factor and lower carbon to hydrogen ratio of MGO compared with RO. Similarly, PAH emissions reduce by 11% and PCDF emissions reduce by 19%.

Table B-4: MGO 0.1%S emissions from auxiliary engines/boilers for berthed vessels

Port	Scenario	mass of fuel and emissions in tonnes/annum												
		Fuel	NOx	N_2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	NMVOC	CH_4	CO	CO_2	PAH	PCDF
Botany	Berth 0.1%S	22,641	897.6	4.4	0.2	44.3	16.2	14.9	27.2	0.3	72.4	72,008	2.3E-01	2.8E-09
	Berth baseline	23,367	946.1	4.4	0.2	1,190	128.4	118.1	27.2	0.3	72.4	74,208	4.0E-01	9.0E-09
	% reduction at berth	3.1	5.1	0.0	0.0	96.3	87.4	87.4	0.0	0.0	0.0	3.0	42.3	69.2
Newcastle	Berth 0.1%S	8,394	326.5	1.6	0.1	16.4	6.0	5.5	10.2	0.1	27.2	26,696	8.6E-02	1.0E-09
	Berth baseline	8,524	333.4	1.6	0.1	308.5	32.5	29.9	10.2	0.1	27.2	27,079	1.2E-01	2.3E-09
	% reduction at berth	1.5	2.1	0.0	0.0	94.7	81.4	81.4	0.0	0.0	0.0	1.4	29.4	56.2
Kembla	Berth 0.1%S	4,648	208.6	0.9	0.0	9.1	3.5	3.2	6.2	0.1	16.8	14,783	4.9E-02	5.8E-10
	Berth baseline	4,767	216.6	0.9	0.0	205.7	22.6	20.7	6.2	0.1	16.8	15,141	7.6E-02	1.6E-09
	% reduction at berth	2.5	3.7	0.0	0.0	95.6	84.7	84.7	0.0	0.0	0.0	2.4	36.1	63.4
Jackson	Berth 0.1%S	12,325	537.3	2.3	0.1	24.1	9.1	8.4	16.2	0.2	43.4	39,199	1.3E-01	1.5E-09
	Berth baseline	12,717	564.4	2.3	0.1	620.9	68.2	62.8	16.2	0.2	43.4	40,389	2.2E-01	4.8E-09
	% reduction at berth	3.1	4.8	0.0	0.0	96.1	86.7	86.7	0.0	0.0	0.0	2.9	40.8	67.9
All ports	Berth 0.1%S	48,007	1,970	9.2	0.4	93.9	34.7	32.0	59.8	0.7	159.8	152,686	4.9E-01	5.9E-09
	Berth baseline	49,374	2,060	9.2	0.4	2,325	251.6	231.5	59.8	0.7	159.8	156,816	8.1E-01	1.8E-08
	% reduction at berth	2.8	4.4	0.0	0.0	96.0	86.2	86.2	0.0	0.0	0.0	2.6	39.4	66.6
total mass reduction (tonnes)		1,367	90.4	0.0	0.0	2,232	216.9	199.5	0.0	0.0	0.0	4,130	3.2E-01	1.2E-08
% reduction in total mass across all modes		0.9	0.9	0.0	0.0	31.0	24.3	24.3	0.0	0.0	0.0	0.9	11.3	18.7

B.11 Low sulfur fuel in NSW GMR (0.1%S MGO)

The impact of switching all vessels to distillate fuel of 0.1% sulfur content while in the NSW GMR is shown in Table B-5. The low sulfur fuel would be used in all main engines, auxiliary engines and auxiliary boilers. SO_2 emissions are reduced by around 96%, which is effectively the % reduction in fuel sulfur content of 0.1% MGO compared with 2.7% RO.

According to this modelling, the measure would have avoided 6,913 tonnes of SO_2 emissions in the NSW GMR for the inventory year, or 96% of total ship SO_2 emissions. PM_{10} emissions from ships would have reduced by 770 tonnes or 86%. As discussed in Appendix C, there is some uncertainty around the actual mass reduction in particles resulting from the use of low sulfur fuel.

Table B-5: MGO 0.1% S emissions for vessels engines while in the NSW GMR

Port	Operating Mode	mass of fuel and emissions tonnes/annum												
		Fuel	NOx	N2O	NH_3	SO_2	PM_{10}	$PM_{2.5}$	NMVOC	CH_4	CO	CO_2	PAH	PCDF
Botany	Anchorage	7,647	307	1.49	0.07	15.0	5.5	5.0	9.3	0.10	24.7	24,321	7.8E-02	9.4E-10
Botany	Berth	22,641	898	4.43	0.19	44.3	16.2	14.9	27.2	0.30	72.4	72,008	2.3E-01	2.8E-09

Botany	Cruise	32,032	2,838	5.29	0.51	62.6	32.2	29.6	51.0	0.99	96.2	101,875	4.3E-01	5.1E-09
Botany	RSZ/Man	1,737	120	0.28	0.02	3.4	1.5	1.4	2.8	0.04	6.8	5,524	2.1E-02	2.5E-10
Newcastle	Anchorage	2,398	92	0.47	0.02	4.7	1.7	1.6	2.8	0.03	7.5	7,628	2.4E-02	2.9E-10
Newcastle	Berth	8,394	327	1.63	0.07	16.4	6.0	5.5	10.2	0.11	27.2	26,696	8.6E-02	1.0E-09
Newcastle	Cruise	17,770	1,583	2.95	0.28	34.7	17.9	16.5	28.4	0.55	52.1	56,518	2.4E-01	2.8E-09
Newcastle	RSZ/Man	797	60	0.13	0.01	1.6	0.7	0.7	1.3	0.02	3.0	2,535	9.8E-03	1.2E-10
Kembla	Anchorage	1,031	40	0.20	0.01	2.0	0.7	0.7	1.2	0.01	3.2	3,278	1.0E-02	1.3E-10
Kembla	Berth	4,648	209	0.85	0.05	9.1	3.5	3.2	6.2	0.07	16.8	14,783	4.9E-02	5.8E-10
Kembla	Cruise	10,749	935	1.77	0.17	21.0	10.7	9.9	16.7	0.32	34.0	34,187	1.4E-01	1.7E-09
Kembla	RSZ/Man	237	15	0.04	0.00	0.5	0.2	0.2	0.4	0.00	1.1	754	2.7E-03	3.3E-11
Jackson	Anchorage	3,543	144	0.69	0.03	6.9	2.5	2.3	4.3	0.05	11.6	11,267	3.6E-02	4.3E-10
Jackson	Berth	12,325	537	2.30	0.12	24.1	9.1	8.4	16.2	0.18	43.4	39,199	1.3E-01	1.5E-09
Jackson	Cruise	12,926	961	2.06	0.19	25.3	12.1	11.1	17.3	0.32	53.3	41,111	1.6E-01	1.9E-09
Jackson	RSZ/Man	1,417	98	0.22	0.02	2.8	1.3	1.2	2.2	0.03	6.1	4,508	1.7E-02	2.0E-10
All ports	Anchorage	14,618	582	2.85	0.13	28.6	10.5	9.6	17.6	0.20	47.0	46,493	1.5E-01	1.8E-09
All ports	Berth	48,007	1,970	9.21	0.43	93.9	34.7	32.0	59.8	0.66	159.8	152,686	4.9E-01	5.9E-09
All ports	Cruise	73,477	6,316	12.07	1.16	143.7	72.9	67.1	113.3	2.18	235.6	233,691	9.7E-01	1.2E-08
All ports	RSZ/Man	4,188	292	0.66	0.06	8.2	3.7	3.4	6.8	0.09	17.0	13,320	5.0E-02	6.0E-10
total mass at 0.1% MGO		140,291	9,160	24.79	1.77	274.3	121.9	112.1	197.6	3.13	459.4	446,191	1.7E+00	2.0E-08
baseline mass		146,005	9,688	24.79	1.77	7,187.3	891.8	820.4	197.6	3.13	459.4	463,698	2.8E+00	6.3E-08
total mass reduction (tonnes)		5,714	528	0	0	6,913.0	769.9	708.3	0	0	0	17,507	1.2E+00	4.3E-08
% reduction in total mass across all modes		3.9	5.5	0.0	0.0	96.2	86.3	86.3	0.0	0.0	0.0	3.8	41.3	68.3

A reduction of about 4% in fuel consumption and NO_x and CO_2 emissions is apparent, due to the greater heating value, lower NO_x emissions factor and lower carbon to hydrogen ratio of MGO compared with RO. Similarly, PAH emissions reduce by 41% and PCDF emissions reduce by 68%.

B.12 Shore Power

The usage of individual berths by various ship types, and the auxiliary engine power generation totals for each berth are summarised in Table B-6. Total number of visits, number of unique vessels, total auxiliary engine energy output, and maximum auxiliary engine power output are shown. The data are filtered to include only the 32 berths where total AE energy production from any ship type exceeds 1,000 MWh. The number of berths examined here is limited in this way because only a small proportion of berths would ever have shore power facilities implemented.

Table B-6: Auxiliary engine power generation , > 1,000 MWh per year

Port	Berth	Long Name	Vessel Type	Visits	Unique Vessels	Total AE energy MWh	Max AE power kW
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	197	84	9910	2752
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	188	82	7205	4978
Botany	2BD	BROTHERSON DOCK 2	Container Ship (Fully Cellular)	160	82	6981	3329

Botany	2ABD	BROTHERSON DOCK 2A	Container Ship (Fully Cellular)	147	82	6518	2752
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	200	75	6308	1968
Botany	1BD	BROTHERSON DOCK 1	Container Ship (Fully Cellular)	140	77	5740	2643
Botany	1ABD	BROTHERSON DOCK 1A	Container Ship (Fully Cellular)	107	63	3995	2752
Botany	BLB1	BULK LIQUID BERTH 1	LPG Tanker	84	19	1471	1472
Botany	BLB1	BULK LIQUID BERTH 1	Chemical/Products Tanker	93	51	1211	933
Botany	3BD	BROTHERSON DOCK 3	Container Ship (Fully Cellular)	132	52	3327	2643
Botany	KUR3	KURNELL 3	Crude Oil Tanker	86	30	2239	761
Newcastle	E2	EASTERN BASIN NO.2	General Cargo Ship	54	24	1391	1544
Newcastle	SP		Weapons Trials Vessel	2	2	1407	776
Newcastle	K6	KOORAGANG NO.6	Bulk Carrier	228	165	1671	333
Newcastle	K5	KOORAGANG NO.5	Bulk Carrier	233	177	1551	333
Newcastle	K4	KOORAGANG NO.4	Bulk Carrier	252	186	1554	343
Newcastle	D5	DYKE NO.5	Bulk Carrier	169	134	1303	268
Newcastle	D4	DYKE NO.4	Bulk Carrier	170	133	1183	317
Kembla	107	AAT PORT KEMBLA TERMINAL	Vehicles Carrier	97	64	1888	2178
Kembla	110	BLUESCOPE RORO BERTH	Ro-Ro Cargo Ship	75	1	1686	733
Kembla	109	BLUESCOPE NO 2 PRODUCTS BERTH	General Cargo Ship	30	18	1543	1544
Kembla	111	BLUESCOPE NO 2 DISCHARGE BERTH	Bulk Carrier	47	34	1299	331
Kembla	113	BLUESCOPE NO 1 PRODUCTS BERTH	General Cargo Ship	21	12	1063	1544
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	41	24	6629	11273
Jackson	DH8	WHARF 8	Passenger/Cruise	61	13	5107	8199
Jackson	GOR1	GORE COVE 1	Products Tanker	44	23	1676	857
Jackson	GOR1	GORE COVE 1	Crude/Oil Products Tanker	41	18	1066	826
Jackson	GLB1	GLEBE ISLAND 1	Vehicles Carrier	153	91	2504	1140
Jackson	FB4	FLEET BASE 4	Weapons Trials Vessel	3	2	2262	776
Jackson	ICCD	CAPTAIN COOK DRY IN	Passenger/Ro-Ro Ship	1	1	1903	4137
Jackson	WHT4	WHITE BAY 4	Container Ship (Fully Cellular)	4	4	1523	1640
Jackson	FB3	FLEET BASE 3	Weapons Trials Vessel	10	4	1385	4729
Jackson	GLB2	GLEBE ISLAND 2	Vehicles Carrier	67	52	1350	1201
Jackson	FB2	FLEET BASE 2	Weapons Trials Vessel	5	4	1189	964
Jackson	WHT6	WHITE BAY 6	Fishery Research Vessel	3	1	1064	688

The greatest auxiliary engine energy production, and thus emissions, is for container vessels at Botany. The next largest values are for cruise vessels in Port Jackson at Sydney Cove and Darling Harbour. The maximum auxiliary engine power generation indicates the peak electrical loading which would need to be supplied from the shore. In Table B-6 the greatest values occur for cruise vessels at Sydney Cove and Darling Harbour. The maximum value is 11MW.

The individual vessels which generate the most auxiliary engine energy at any given berth are given in Table B-7.

There are some potential anomalies apparent in Table B-6 and Table B-7. The first concerns Naval Vessels (Weapons Trial Vessels). For a relatively small number of visits to their various berths, the total auxiliary engine energy generation is relatively high. A further possible anomaly concerns four container vessel visits to White Bay 4. This is not a container berth and it is possible that these vessels were laid up for considerable periods without running their auxiliary engines at normal power. For instance the container ship Nora Maersk berthed at White Bay 4 for 873 hours on its sole visit to Port Jackson. The Spirit of Tasmania II at the Captain Cook Dry Dock should not be showing significant auxiliary engine usage.

The cruise ships Pacific Dawn and Sun Princess, and the Ro-Ro Iron Monarch show as the most frequent visitors and the main generators of auxiliary engine energy and thus emissions. A number of container vessels at Botany show a significant number of visits and significant auxiliary engine energy generation.

Table B-7: Top 100 generators of auxiliary engine energy for the inventory year.

Port	Berth	Berth Name	Vessel Type	Vessel Name	Visits	Total AE energy MWh	Max AE power kW
Jackson	FB4	FLEET BASE 4	Weapons Trials Vessel	HMAS MANOORA	2	2182	776
Jackson	DH8	WHARF 8	Passenger/Cruise	PACIFIC DAWN	33	2169	6918
Jackson	ICCD	CAPTAIN COOK DRY IN	Passenger/Ro-Ro Ship (Vehicles)	SPIRIT OF TASMANIA II	1	1903	4137
Kembla	110	BLUESCOPE RORO BERTH	Ro-Ro Cargo Ship	IRON MONARCH	75	1686	733
Jackson	DH8	DARLING HARBOUR WHARF 8	Passenger/Cruise	SUN PRINCESS	13	1558	8199
Jackson	WHT4	WHITE BAY 4	Container Ship (Fully Cellular)	NORA MAERSK	1	1432	1640
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	RHAPSODY OF THE SEAS	8	1065	8967
Jackson	WHT6	WHITE BAY 6	Fishery Research Vessel	SOUTHERN SURVEYOR	3	1064	688
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	OOCL YOKOHAMA	11	962	1956
Jackson	WHT3	WHITE BAY 3	Fishery Research Vessel	SOUTHERN SURVEYOR	3	909	688
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	MILLENNIUM	2	813	8896
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	SAPPHIRE PRINCESS	5	811	10800
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	AMSTERDAM	2	780	9824
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	OOCL HOUSTON	10	780	1956
Newcastle	SP		Weapons Trials Vessel	HMAS TOBRUK	1	768	451
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	MERCURY	2	651	5604
Newcastle	W4	WESTERN BASIN NO.4	Weapons Trials Vessel	HMAS KANIMBLA	1	640	776
Newcastle	SP		Weapons Trials Vessel	HMAS KANIMBLA	1	640	776
Newcastle	FD		Weapons Trials Vessel	HMAS KANIMBLA	1	640	776
Jackson	ADI	GARDEN ISLAND	Passenger/Cruise	QUEEN ELIZABETH 2	1	607	17007
Jackson	CW	CRUISER	Weapons Trials Vessel	HMAS KANIMBLA	1	601	776
Jackson	FB3	FLEET BASE 3	Weapons Trials Vessel	HMAS SUCCESS	6	600	964
Jackson	FB2	FLEET BASE 2	Weapons Trials Vessel	HMAS KANIMBLA	1	577	776
Jackson	FB3	FLEET BASE 3	Weapons Trials Vessel	USS JOHN S MCCAIN	1	573	4729
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	CSCL QINGDAO	9	553	1414
Jackson	GLB7	GLEBE ISLAND 7	General Cargo Ship	PIONEER	10	539	409
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	CSCL CHIWAN	6	533	1953
Botany	2ABD	BROTHERSON DOCK 2A	Container Ship (Fully Cellular)	DA HE	7	490	1950
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	MAERSK DENTON	6	487	2752
Jackson	BWBCN	BLACKWATTLE PIONEER	Aggregates Carrier	CLAUDIA 1	85	484	83
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	ANL WINDARRA	8	483	1956
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	MAERSK DECATUR	5	480	2752
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	MAERSK DECATUR	6	466	2752
Newcastle	CAR		Yacht	SERENA M	1	463	68
Newcastle	T1	THROSBY NO.1	Weapons Trials Vessel	HMAS NEWCASTLE	1	462	3935
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	KAMAKURA	11	450	1535
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	ANL WARRINGA	8	449	1956
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	MAERSK DRAMMEN	7	440	2199
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	CSCL DALIAN	5	437	1955
Jackson	GOR1	GORE COVE 1	Crude/Oil Products Tanker	HELIX	13	437	826
Kembla	109	BLUESCOPE NO 2 PRODUCTS	General Cargo Ship	CAPE CONWAY	2	434	1544
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	MAERSK DAMPIER	6	432	2199
Kembla	106	AAT PORT KEMBLA TERMINAL	General Cargo Ship (with Ro-Ro facility)	VASILIY BURKHANOV	6	426	845
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	MAERSK DENTON	4	416	2752
Newcastle	W4	WESTERN BASIN NO.4	Tug	SEA FOX 6	1	415	182
Newcastle	L5		Tug	SEA FOX 6	1	415	182
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	QUEEN VICTORIA	1	394	11273
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	ANL WANGARATTA	4	392	1956
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	CSCL MELBOURNE	5	350	1956
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	XUTRA BHUM	12	349	1101
Kembla	112	BLUESCOPE NO 1 DISCHARGE	Bulk Carrier, Self-discharging	IRON CHIEFTAIN	17	348	315
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	OOCL PANAMA	4	334	1956

Port	Berth	Berth Name	Vessel Type	Vessel Name	Visits	Total AE energy MWh	Max AE power kW
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	CSCL MELBOURNE	4	332	1956
Botany	2ABD	BROTHERSON DOCK 2A	Container Ship (Fully Cellular)	COSCO FUZHOU	6	325	1688
Jackson	DH8	DARLING HARBOUR WHARF 8	Passenger/Cruise	DAWN PRINCESS	4	321	8199
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	APL SYDNEY	6	320	1711
Jackson	FB2	FLEET BASE 2	Weapons Trials Vessel	HMAS MANOORA	1	315	776
Botany	1BD	BROTHERSON DOCK 1	Container Ship (Fully Cellular)	MSC KRITTIKA	7	302	1052
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	ANL WYONG	5	300	1368
Newcastle	L5		Pusher Tug	MICLYN LEGEND	1	294	41
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	WANA BHUM	11	289	1101
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	MAERSK DAMPIER	4	288	2199
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	ANL WARRINGA	5	286	1956
Botany	KUR3	KURNELL 3	Crude/Oil Products Tanker	SEASERVICE	9	280	750
Newcastle	T1	THROSBY NO.1	Cutter Suction Dredger	URSA	1	280	194
Newcastle	KSA		Cutter Suction Dredger	URSA	1	280	194
Botany	2ABD	BROTHERSON DOCK 2A	Container Ship (Fully Cellular)	KOTA PUSAKA	4	275	1517
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	CSCL DALIAN	3	274	1955
Botany	2BD	BROTHERSON DOCK 2	Container Ship (Fully Cellular)	H RELIANCE	2	270	3329
Jackson	ICCD	CAPTAIN COOK DRY IN	Ro-Ro Cargo Ship	TASMANIAN ACHIEVER	1	268	920
Newcastle	SP		Fishery Research Vessel	SOUTHERN SURVEYOR	1	264	688
Jackson	GOR1	GORE COVE 1	Products Tanker	RESOLVE	11	264	857
Kembla	113	BLUESCOPE NO 1 PRODUCTS	General Cargo Ship	CAPE DELFARO	3	263	869
Botany	2BD	BROTHERSON DOCK 2	Container Ship (Fully Cellular)	NORTHERN VICTORY	5	262	1281
Botany	BLB1	BULK LIQUID BERTH 1	LPG Tanker	SUMMIT TERRA	6	259	982
Botany	KUR3	KURNELL 3	Crude Oil Tanker	ALTAIR VOYAGER	8	257	743
Jackson	ADI	GARDEN ISLAND	Weapons Trials Vessel	SEAHORSE SPIRIT	1	257	275
Jackson	FB2	FLEET BASE 2	Weapons Trials Vessel	HMAS SUCCESS	2	256	964
Jackson	DH8	DARLING HARBOUR WHARF 8	Passenger/Cruise	VOLENDAM	1	251	7686
Jackson	CWGI	CRUISER GARDEN I	Weapons Trials Vessel	HMAS SUCCESS	3	250	964
Newcastle	B6		Chemical Tanker	SEAKAP	19	249	340
Botany	KUR2	KURNELL 2	Products Tanker	PALMERSTON	7	241	663
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	APL BANGKOK	3	233	1711
Botany	2ABD	BROTHERSON DOCK 2A	Container Ship (Fully Cellular)	THEODOR STORM	4	233	1350
Newcastle	B6		Chemical/Products Tanker	RATHBOYNE	20	233	353
Newcastle	K2	KOORAGANG NO.2	LPG Tanker	EMERALD STAR	14	231	505
Newcastle	CAR		Yacht	BIG ARON	1	231	107
Jackson	GLB1	GLEBE ISLAND 1	Vehicles Carrier	ROCKIES HIGHWAY	7	231	853
Botany	KUR3	KURNELL 3	Crude Oil Tanker	CASTOR VOYAGER	10	230	652
Newcastle	E1	EASTERN BASIN NO.1	General Cargo Ship	PACIFIC ADVENTURER	6	226	743
Botany	KUR1	KURNELL 1	Products Tanker	PALMERSTON	6	222	663
Botany	2BD	BROTHERSON DOCK 2	Container Ship (Fully Cellular)	SOPHIA BRITANNIA	5	222	1968
Botany	5BD	BROTHERSON DOCK 5	Container Ship (Fully Cellular)	CSCL NEW YORK	2	221	1956
Botany	3BD	BROTHERSON DOCK 3	Container Ship (Fully Cellular)	ANL YARRUNGA	19	220	521
Jackson	ATH4	ATHOL BUOY 4	Passenger/Cruise	PACIFIC DAWN	1	218	6918
Kembla	113	BLUESCOPE NO 1 PRODUCTS	General Cargo Ship	CAPE DELGADO	4	217	869
Botany	6BD	BROTHERSON DOCK 6	Container Ship (Fully Cellular)	CAPE MARTIN	5	215	1101
Jackson	SCPT	SYDNEY COVE	Passenger/Cruise	SEVEN SEAS MARINER	1	214	5978
Kembla	113	BLUESCOPE NO 1 PRODUCTS	General Cargo Ship	CAPE CONWAY	2	212	1544
Botany	4BD	BROTHERSON DOCK 4	Container Ship (Fully Cellular)	CARPATHIA	5	210	1350
Kembla	202	NO.6 JETTY OUTSIDE NORTH	Container Ship (Fully Cellular)	ALBERT RICKMERS	1	209	1117

Table B-8 summarises the details of the cruise ships which called at Jackson for the inventory year. The cruise ship terminals at Sydney Cove (Overseas Passenger Terminal) and Darling Harbour 8 are the terminals at which shore power is likely to be of most benefit given their proximity to the city centre. Sun Princess was the second most frequent visitor for the inventory year and has shore power capability. In fact, four of the Princess Line vessels calling at Jackson are known to have shore power capability (Dawn, Sun, Sapphire and Diamond). If these four Princess Line vessels had been supplied with shore power for the whole duration of their berth time in the inventory year, the emissions avoided would have been 17 tonnes of NO_x, 14 tonnes of SO_2 and 1.6 tonnes of PM_{10}. Holland America Lines have converted a number of their vessels but not the ones which called at Sydney. Frequent visitors Pacific Dawn and Rhapsody of the Seas do not appear to have the shore power capability installed.

Table B-8: Auxiliary engine emissions for Cruise Ships in Port Jackson in 2008

Berth	Vessel Name	Visits	Total AE energy MWh	Max AE power kW	AE fuel and emissions tonnes/annum				
					Fuel	NOx	SO2	PM10	PM2.5
DARLING HARBOUR 8	PACIFIC DAWN	33	2,169	6,918	492.3	31.9	25.7	3.09	2.84
DARLING HARBOUR 8	SUN PRINCESS	13	1,558	8,199	353.7	22.9	18.5	2.22	2.04
OVERSEAS PT	RHAPSODY OF THE SEAS	8	1,065	8,967	241.8	15.7	12.6	1.52	1.40
OVERSEAS PT	MILLENNIUM	2	813	8,896	184.5	11.9	9.6	1.16	1.07
OVERSEAS PT	SAPPHIRE PRINCESS	5	811	10,800	184.1	11.9	9.6	1.16	1.06
OVERSEAS PT	AMSTERDAM	2	780	9,824	177.1	11.5	9.2	1.11	1.02
OVERSEAS PT	MERCURY	2	651	5,604	147.9	9.6	7.7	0.93	0.85
GARDEN ISLAND	QUEEN ELIZABETH 2	1	607	17,007	137.8	8.9	7.2	0.86	0.80
OVERSEAS PT	QUEEN VICTORIA	1	394	11,273	89.5	5.8	4.7	0.56	0.52
DARLING HARBOUR 8	DAWN PRINCESS	4	321	8,199	72.8	4.7	3.8	0.46	0.42
DARLING HARBOUR 8	VOLENDAM	1	251	7,686	57.0	3.7	3.0	0.36	0.33
ATHOL BUOY 4	PACIFIC DAWN	1	218	6,918	49.5	3.2	2.6	0.31	0.29
OVERSEAS PT	SEVEN SEAS MARINER	1	214	5,978	48.5	3.1	2.5	0.30	0.28
DARLING HARBOUR 8	ASUKA II	1	194	6,149	44.0	2.8	2.3	0.28	0.25
OVERSEAS PT	VOLENDAM	2	193	7,686	43.9	2.8	2.3	0.28	0.25
OVERSEAS PT	NAUTICA	1	188	4,703	42.6	2.8	2.2	0.27	0.25
OVERSEAS PT	AURORA	1	170	9,964	38.7	2.5	2.0	0.24	0.22
DARLING HARBOUR 3	NAUTICA	1	170	4,703	38.6	2.5	2.0	0.24	0.22
OVERSEAS PT	DIAMOND PRINCESS	1	166	10,800	37.6	2.4	2.0	0.24	0.22
OVERSEAS PT	CRYSTAL SERENITY	1	164	9,287	37.3	2.4	1.9	0.23	0.22
DARLING HARBOUR 3	SEVEN SEAS VOYAGER	1	159	4,227	36.0	2.3	1.9	0.23	0.21
OVERSEAS PT	BLACK WATCH	1	154	2,391	34.9	2.3	1.8	0.22	0.20
DARLING HARBOUR 8	ALBATROS	1	149	3,096	33.8	2.2	1.8	0.21	0.20
OVERSEAS PT	PACIFIC DAWN	2	145	6,918	33.0	2.1	1.7	0.21	0.19
BANK1	DELPHIN VOYAGER	1	135	2,426	30.6	2.0	1.6	0.19	0.18
OVERSEAS PT	ORIANA	1	122	7,072	27.6	1.8	1.4	0.17	0.16
OVERSEAS PT	THE TOPAZ	1	120	3,926	27.2	1.8	1.4	0.17	0.16
DARLING HARBOUR 8	MONA LISA	1	112	3,298	25.4	1.6	1.3	0.16	0.15
DARLING HARBOUR 8	PACIFIC SUN	2	108	4,183	24.5	1.6	1.3	0.15	0.14
OVERSEAS PT	SAGA ROSE	1	103	3,141	23.4	1.5	1.2	0.15	0.13
DARLING HARBOUR 3	AMADEA	1	96	3,295	21.8	1.4	1.1	0.14	0.13
OVERSEAS PT	SUN PRINCESS	1	85	8,199	19.3	1.3	1.0	0.12	0.11
DARLING HARBOUR 8	VAN GOGH	1	80	2,356	18.2	1.2	0.9	0.11	0.10
OVERSEAS PT	DAWN PRINCESS	1	78	8,199	17.7	1.1	0.9	0.11	0.10
DARLING HARBOUR 8	STATENDAM	1	74	6,149	16.8	1.1	0.9	0.11	0.10
DARLING HARBOUR 3	STATENDAM	1	70	6,149	15.8	1.0	0.8	0.10	0.09
OVERSEAS PT	PACIFIC SUN	1	64	4,183	14.6	0.9	0.8	0.09	0.08
OVERSEAS PT	PACIFIC PRINCESS	1	53	3,459	12.0	0.8	0.6	0.08	0.07
DARLING HARBOUR 8	PACIFIC STAR	1	44	3,481	9.9	0.6	0.5	0.06	0.06
OVERSEAS PT	SILVER WHISPER	2	38	2,041	8.6	0.6	0.5	0.05	0.05
OVERSEAS PT	GEMINI	1	29	2,334	6.6	0.4	0.3	0.04	0.04

Berth	Vessel Name	Visits	Total AE energy MWh	Max AE power kW	AE fuel and emissions tonnes/annum				
					Fuel	NOx	SO2	PM10	PM2.5
OVERSEAS PT	ASTORIA	1	28	1,727	6.2	0.4	0.3	0.04	0.04
DARLING HARBOUR 8	GEMINI	1	27	2,334	6.1	0.4	0.3	0.04	0.04
DARLING HARBOUR 8	SILVER WHISPER	1	22	2,041	4.9	0.3	0.3	0.03	0.03

For a broader perspective, fuel consumption and emissions for auxiliary engines at berth, by broad vessel category, for the inventory year are show in Table B-9. The vessel types which stand out are Container Vessels at Botany, then Cruise Ships at Jackson, followed by Tankers at Botany.

Table B-9: Emissions from auxiliary engines at berth, by vessel category, for 2008.

Port	Vessel Type	AE fuel consumption and emissions in tonnes/annum				
		Fuel	NOx	SO_2	PM_{10}	$PM_{2.5}$
Botany	Bulk Carrier	0.2	0.0	0.00	0.00	0.00
Botany	Container	11,508.9	745.2	596.51	71.75	66.01
Botany	General Cargo	60.2	3.8	0.74	0.10	0.09
Botany	Reefer	0.3	0.0	0.00	0.00	0.00
Botany	Tanker	2,004.1	129.2	82.29	10.00	9.20
Newcastle	Bulk Carrier	1,908.2	121.9	38.08	4.86	4.47
Newcastle	Container	37.9	2.4	0.48	0.06	0.06
Newcastle	Cruise	35.8	2.3	1.87	0.22	0.21
Newcastle	General Cargo	1,333.6	83.9	40.26	5.00	4.60
Newcastle	Miscellaneous	359.5	19.0	5.40	0.76	0.70
Newcastle	Naval	720.2	46.5	30.49	3.70	3.40
Newcastle	Reefer	6.7	0.4	0.35	0.04	0.04
Newcastle	Tanker	272.2	17.4	4.12	0.54	0.50
Kembla	Auto Carrier	502.1	32.5	26.03	3.13	2.88
Kembla	Bulk Carrier	788.0	50.4	20.08	2.51	2.31
Kembla	Container	105.1	6.8	4.04	0.49	0.45
Kembla	General Cargo	1,302.3	83.7	49.88	6.08	5.60
Kembla	Miscellaneous	7.4	0.4	0.05	0.01	0.01
Kembla	Naval	6.0	0.3	0.04	0.01	0.01
Kembla	Reefer	12.3	0.8	0.64	0.08	0.07
Kembla	RORO	385.4	25.0	20.12	2.42	2.23
Kembla	Tanker	91.9	5.9	3.01	0.37	0.34
Jackson	Auto Carrier	872.6	56.5	43.56	5.25	4.83
Jackson	Bulk Carrier	219.1	11.6	2.51	0.37	0.34
Jackson	Container	405.9	26.3	21.15	2.54	2.34
Jackson	Cruise	2,999.2	194.2	156.33	18.80	17.30
Jackson	General Cargo	204.5	13.0	3.12	0.41	0.38
Jackson	Naval	1,472.4	95.1	70.52	8.51	7.83
Jackson	Reefer	0.4	0.0	0.01	0.00	0.00
Jackson	RORO	492.7	31.9	25.72	3.09	2.85
Jackson	Tanker	1,110.0	71.6	44.04	5.36	4.93

If all container vessels visiting Botany for the inventory year utilised shore power for their total berth duration, the emissions avoided would be 745 tonnes of NO_x, 597 tonnes of SO_2 and 72 tonnes of PM_{10}. If all cruise ships visiting Jackson for the inventory year utilised shore power for their total berth duration, the emissions avoided would be 194 tonnes of NO_x, 156 tonnes of SO_2 and 19 tonnes of PM_{10}.

B.13 Vessel Speed Reduction (VSR)

Reducing vessel speed can reduce fuel consumption and thus emissions. A 10% speed reduction may reduce emissions by approximately 20%. A 20% speed reduction may reduce emissions by approximately 35%. The potential impact of these changes was estimated using the inventory model by assuming reduced speed in the ocean cruise mode within the NSW GMR for all visits for the inventory year. For these broad estimates, the main engine emissions are reduced by the relevant percentages. No adjustment is made to allow for added auxiliary engine and auxiliary boiler emissions due to the increased transit time as these quantities are small in cruise mode compared with the main engine emissions. More accurate determination of the emissions benefits of VSR would require improved modelling of ship traffic patterns. As described in Section B.9 the emissions benefits for measures within the GMR were calculated by modelling the reductions in emissions during the cruise mode for the whole of the GMR. This gives an upper estimate. Roughly, a boundary between 20nm and 30nm would take in most of the modelled cruise paths. By comparison, the VSR zone for the San Pedro Bay Area (Ports of Los Angeles and Long Beach) extends out to 40nm. Shippers obtain benefits by complying within 20nm. Extra benefits are available for complying between 20nm and 40nm. The CARB low sulfur fuel zone extends out to 24nm.

For the 10% speed reduction scenario the emissions avoided would be 1280 tonnes of NO_x, 755 tonnes of SO_2 and 103 tonnes of PM_{10}. For the 20% speed reduction scenario the emissions avoided would be 2240 tonnes of NO_x, 1322 tonnes of SO_2 and 181 tonnes of PM_{10}.

For the NSW ports, the port boundaries at sea are defined by an arc centred on a defined point at the harbour entrance (the heads). For Botany and Jackson, the radius of the arc is 4 nautical miles. For Newcastle it is 3 nautical miles and for Kembla it is 2.5 nautical miles. The Restricted Speed Zones generally begin at the harbour entrance. They exist for operational safety within the confined harbour waters. Ships generally approach and depart the ports at ocean cruise speed.

The vessel speed reduction described here applies to the ocean transits to and from the harbours, where ships routinely travel at normal cruise speed. Normal cruise speeds for broad vessel types are summarised in Table B-10. These data are taken from the ship particulars supplied by Lloyds for the 2008 inventory. The speed given in the Lloyds data tables is a maximum speed and this was reduced in the present analysis by 6% to give a better indication of actual cruise speed. The maximum speed is the speed at which the ship would travel if the propulsion engines were operating at maximum power and the hull was clean.

Ships do not travel at the maximum speed, and applying a factor of 0.94 to the maximum speed to obtain the cruise speed is common practice. At 94% of cruise speed, the ships engines are operating at about 83% of maximum power, if the hull is clean and depending on weather conditions.

Table B-10: Normal and proposed cruise speeds for the vessels visiting NSW

broad vessel type	normal cruise speed (knots)	20% reduced (knots)
bulk carrier	16 to 11	13 to 9
container	24 to 18	19 to 14
cruise	23 to 17	18 to 14
general cargo	14 to 10	11 to 8
tanker	14 to 13	11 to 10
vehicles carrier	21 to 17	17 to 14

The San Pedro Bay VSR program aims for all vessels to travel at a maximum of 12 knots in the VSR. Los Angeles and Long Beach launched a voluntary program in May 2001 that requests vessels to reduce their speed to 12 knots at a distance of 20 nautical miles from the ports. Ship owners that achieve a 90 percent compliance rate with the speed reduction program, called the Green Flag program, are eligible for a 15 percent reduction in dockage fees.

B.14 Reduced Anchorage Time

A cooperative effort between port managers, ship operators and cargo handlers could potentially reduce anchorage time. Some ship operators would benefit by reducing cruise speed on the passage to NSW. This slow steaming yields fuel cost savings. Some engine adjustments may be necessary to allow the main engines to operate at reduced cruise speed for extended periods, but the technological expertise is well developed. By timing arrival at port to more closely match berth availability, significant reductions in waiting time might be achievable.

In 2009, the Newcastle port Corporation commenced implementation of a Vessel Arrival System (VAS). Vessels notify their estimated time of arrival between 14 and 7 days prior to arrival, and are allocated and Estimated Time of Loading. The system avoids extended anchorage times to queue for loading, with vessels instead slow steaming to Newcastle to meet the notified arrival time.

If anchorage times were reduced across the board by 20% the emissions avoided would be 121 tonnes of NO_x, 134 tonnes of SO_2 and 14 tonnes of PM_{10}.

APPENDIX C: FURTHER DETAILS ON SHIP EMISSIONS MITIGATION MEASURES

C.1 Case Studies for Differentiated Fees and Direct Levies

C.1.1 Swedish Differentiated Port Fees

Thirty major Swedish ports are participating in a scheme that prescribes differentiated port dues for individual vessels based on their NO_x emissions. Whilst the conditions for application and implementation vary for each port, the criteria for each port are transparent, and are published and available for vessel operators via the Internet.

An example is the Port of Gothenburg tariff schedule. Discounts are also given to ships that use low-sulfur bunker oil, as well as to ships that use catalytic exhaust emission control (Selective Catalytic Reduction) or other emission reduction technologies such as humidification, water injection or water emulsion. For passenger vessels conducting regular services, the basic fee at the Port of Gothenburg is 1.3 SEK/GT. The level of discounting is shown in Table C-1.

Table C-1: Port of Gothenburg Discount on Fees in terms of NO_x Emissions

NO_x Emissions (g/kWh)	Discount (SEK/GT)
6.0 to 9.9	0.05
2.0 to 5.9	0.10
0 to 1.0	0.2

For vessels calling at the Port of Gothenburg, a sulfur charge is levied from 0 SEK/GT for sulfur content up to 0.2% sulfur and 0.2 SEK/GT above 0.5% sulfur. (AB August Leffler & Son, 2010)

C.1.2 Norwegian NO_x Tax

Norway levies a NO_x tax on all industries including domestic shipping to meet Gothenburg Protocol obligations (Norwegian Maritime Directorate, 2008). The tax applies to ships which have a total installed engine power of more than 750 kW and applies to NO_x emissions from main and auxiliary engines as well as boilers. Vessels in direct traffic between Norwegian and foreign ports are exempted.

A ship with an engine certified to MARPOL Annex VI Tier 1 would pay around 27,000 NOK for activities consuming 30 tonnes of fuel in the main engines and around 4 tonnes of fuel in the auxiliary engines and boiler.

Selective Catalytic Reduction (SCR) is commonly employed in this context. Other NOx control options include water injection, inlet air humidification, fuel/water emulsions, and Exhaust Gas Recirculation (EGR). Engine upgrade kits which use optimised fuel injection, combustion chamber shape, compression ratio and charge air cooling to reduce NO_x emissions in-cylinder are also an option.

A number of methods can be used to verify NO_x reductions, such as continuous emission monitoring or use of a source-specific emission factors. For systems using reagents, such as SCR, the usage of reagent must be quantified.

C.1.3 Norwegian NO_x Fund

The Norwegian NO_x Fund finances NO_x reduction measures for ships, offshore installations and land-based industry. In joining the NO_x Fund, the Norwegian NO_x tax of NOK 16 per kg NO_x

emitted is reduced to NOK 4 per kg NO_x, and participants have the right to apply for funds to carry out technical measures to reduce NO_x emissions. The applications must be for dedicated ships (NHO, 2011; Wold, DNV, 2010).

The Norwegian NO_x Tax and NO_x Fund have encouraged switching to LNG fuel, which reduces the NO_x emissions by 85-90%. There are currently 22 ships operating on LNG in Norway, including two small LNG carriers. Of these, the NO_x Fund has granted funding to two platform supply vessels, three passenger ferries and one gas carrier. An additional 15 LNG fuelled vessels currently being planned or already under construction have also been granted funding. The total funding for these 21 vessels amounts to almost 400 million NOK. LNG fuelled ships are eligible for grants of 150 NOK per kg of yearly NO_x emission reductions, limited to 75% of the additional cost of LNG propulsion (Wold, DNV, 2010).

C.1.4 Environmental Ship Index

The Environmental Ship Index (ESI) is a voluntary measure that represents emissions of NO_x, SO_x and CO_2 from sea-going vessels as universal standard, under the auspices of the International Association of Ports and Harbours (IAPH), World Port Climate Initiative (WPCI). The ESI awards points (from 0 to 100) for achievements over and above relevant statutory requirements. It can be linked to differentiated harbour dues. For example, from 1 January 2011, the cleanest sea-going vessels in the ports of Rotterdam, Dordrecht and Moerdijk will receive a discount of on average 5% of the port dues.

C.1.5 Northwest Ports Clean Air Strategy

The Ports of Vancouver, Seattle and Tacoma in the Puget Sound have implemented a clean air strategy involving incentives for use of low sulfur fuel and shore power at berth (Ross & Associates, 2007; Hemmera, 2010). The ports and relevant air agencies aim to develop and implement incentives such as grants, low interest loans, fee-based responses and/or recognition programs that stimulate investment in cleaner fuels, improved technologies, and enhanced operating practices.

Port Metro Vancouver introduced a Differentiated Harbour Dues Program in April of 2007. Vessels that implement one of a number of eligible emission reduction measures (eg low sulfur fuel) pay lower harbour due rates. Note the Port only charges harbour dues on the first five calls in twelve consecutive months. The program also applies to tugs, barges and integrated tugs and barges. Port Metro Vancouver has also implemented shore power for cruise ships and a total of 11 test connections were made in the latter part of the cruise season in 2009. They expect that 58 shore power connections will be made by cruise vessels in 2010.

In January 2009, the Port of Seattle launched the At Berth Clean Fuels Vessel Incentive Program (ABC Program). The ABC Program provides a $1,500 per call incentive for use of 0.5% (or less) sulfur fuels in auxiliary engines while at berth to shipping lines that call at the Port of Seattle five or more times per year. The payment is intended to cover 50% of the cost differential of more expensive fuel. In 2010 the ABC Fuels incentive increased to $2,250 to reflect longer berthing times and higher fuel costs.

In 2009, 61.5% of frequent cruise vessel calls at the Port of Tacoma met or exceeded the 2010 performance measure for ocean going vessels through use of shore power (84 calls) or participation in the ABC Fuels incentive (50 calls). 40% of frequently calling container vessels (236) participated in the ABC Fuels initiative. The Port rates the ABC program as highly successful. The Port of Tacoma continued to work towards 100% use of distillate fuel for hotelling auxiliary engine operations by all ocean-going vessels. Through a USEPA Diesel Emissions Reduction Act Grant, two frequent calling RoRo ships and one port terminal will be retrofitted to provide shore power for those vessels.

C.1.6 Maritime Singapore Green Initiative

The Maritime Singapore Green Initiative announced on 12 April 2011 seeks to reduce the environmental impact of shipping and related activities to promote clean and green shipping. It is a comprehensive initiative comprising three programs - 'Green Ship Program', 'Green Port Program' and 'Green Technology Program'. The Maritime and Port Authority of Singapore (MPA) will invest up to S$100 million over the next five years in the initiative.

Under the Green Ship Program targeted at Singapore-flagged ships, MPA will provide incentives to ship owners to adopt energy efficient ship designs that reduce fuel consumption and carbon dioxide emissions. Singapore-flagged ships which go beyond the requirements of IMO's Energy Efficiency Design Index will enjoy a 50% reduction of Initial Registration Fees (IRF) and a 20% rebate on Annual Tonnage Tax (ATT) payable. Ship owners will also be recognised through certificates and a new "SRS Green Ship of the Year" award starting from the next Singapore International Maritime Awards.

The Green Port Program is aimed at encouraging ocean-going ships calling at the Port of Singapore to reduce the emission of pollutants like sulfur oxides and nitrogen oxides. Ships that use type-approved abatement/scrubber technology or burn clean fuels with low sulfur content beyond MARPOL requirements within the port can enjoy a 15% reduction on port dues payable.

The Green Technology Program aims to encourage local maritime companies to develop and adopt green technologies through co-funding of up to half of qualifying costs. For a start, MPA will set aside S$25 million from the Maritime Innovation and Technology (MINT) Fund for this program. If response is good, MPA will set aside another S$25 million for this program.

C.1.7 San Pedro Bay Ports Clean Air Action Plan

Since 2001, the Ports of Long Beach and Los Angeles have participated in a successful voluntary vessel speed reduction (VSR) program. Since 2005, the Port of Long Beach has further increased compliance with VSR by offering the Green Flag Program, which provides financial incentives to vessels that participate in the program. To comply with the VSR Program vessels reduce their speed to 12 knots within 40 nm of Point Fermin on arrivals and departures to the Ports. Vessel speeds in the speed reduction zone are monitored and recorded in order to track compliance and to quantify emission reductions. Speed reduction is an operational change that all vessels can make to reduce both NO_x and PM10 emissions, and it doesn't require any modifications to the vessel.

The Ports are currently developing the necessary infrastructure for shore power and are placing requirements into leases to use the infrastructure. In addition, the California Air Resources Board (CARB) has adopted a statewide regulation requiring container, cruise, and reefer vessels to use shore power while in port.

The Ports jointly committed up to $19 million for a one-year incentive program to encourage vessel operators to use low sulfur (0.2 percent sulfur or less) Marine Gas Oil (MGO) or Marine Diesel Oil (MDO) in their main engines during their approach or departure, out to 20 or 40 nautical miles from Point Fermin. During the one-year program, the ports provided funding to cover the cost differential between the cleaner burning low-sulfur fuel and the heavy bunker fuel typically used. To receive the incentive, vessel operators were required to be compliant with the Vessel Speed Reduction Program speed limit of 12 knots over the distance they wished to receive the incentive (40 nm or 20 nm) and use low sulfur fuel in their auxiliary engines while at berth.

On March 23, 2009, the Port of Long Beach Harbor Commission approved a 50 percent increase in the incentive rate for the program, above the existing incentive amount, for participants that call at the Port of Long Beach. The increased incentive was intended to help cover the vessel operator's transitional costs when switching from the heavy bunker fuel to the low-sulfur fuel prior to entering the 20 or 40 nautical mile area. The program was in place from July 1, 2008 through June 30, 2009, after which time the California Air Resources Board (CARB) fuel sulfur regulation came into effect.

C.2 Typical Designations and Properties of Marine Fuels

Fuel type	Name	Density at 15°C kg/litre	Sulfur content % by mass	Viscosity at 50°C for RO and at 40°C for distillates cSt (mm^2/s)	Heating Value (LHV) MJ/kg	Source	Appearance
RO	intermediate fuel oil (IFO)	0.95 to 0.99	1.0 to 3.5	180, 380	40.0 to 41.0	refinery residue + distillate	dark, opaque
MDO	marine diesel oil	0.9	0.1 to 2.0	2 to 11	42.0 to 43.0	distillate + traces of RO	clear to opaque
MGO	marine gas oil	0.89	0.1 to 1.5	2 to 6	42.0 to 43.0	distillate	clear and bright
ULSD	ultra low sulfur diesel	0.83 to 0.835	0.001	2 to 4.5	43.0 to 43.5	distillate	clear and bright

Under the ISO 8217 Fuel Standard (ISO, 2010), Intermediate fuel oil is designated as RME180, RMG180 and RMG380. Heavy fuel oil is designated as RMK380. The main difference between Intermediate fuel oil and heavy fuel oil is the fuel density. RMK380 has density greater than 1 kg/litre. Most residual oil used is intermediate fuel oil.

Bunker suppliers now commonly sell 'LS180' and 'LS380'. These are intermediate fuel oils with low sulfur content, typically 1%.

Under the ISO 8217 Fuel Standard, MDO is designated as 'DMB' and MGO is designated as 'DMA'.

All marine fuels must have a flash point greater than 60°C.

C.2.1 Further Notes on Low Sulfur Fuels

The most straightforward method of reducing SO_2 emissions (and associated particles) is to reduce fuel sulfur content. There is a limit to how far the sulfur content of heavy fuel oil can be reduced. Heavy fuel oil is largely composed of the thick residue from the crude oil refining process, to which lighter components have been added to bring it to a useable consistency. It is black in colour. Higher quality marine diesel fuels are available, but at a greater cost. These lighter fuels are known as Marine Diesel Oil (MDO) or Marine Gas Oil (MGO). Ultra Low Sulfur Diesel (ULSD), MGO and MDO are known generally as distillates. Some ships use MGO or MDO in their auxiliary engines for generating electricity. MDO and MGO are available at low sulfur content, down to around 0.1%. MDO and MGO are not generally available in Australia, and if ships were required to use fuel other than heavy fuel oil in or near port, they would either bring MDO or MGO with them or use Australian made ULSD, which has very low sulfur content. Natural gas is another alternative fuel, but is not as easy to implement as low sulfur distillate.

Many ships are built to operate on heavy fuel oil only and they may have problems in burning MGO unless design modifications are made. This applies also to boilers where the burners have to be redesigned when the fuel is changed over from HFO to MGO. All modifications have to be Class approved.

Residual Oil (RO, IFO180, IFO380) is maintained at around 90°C to 100°C in the service tank and must be further heated to around 130°C before injection to ensure that the viscosity is low enough for proper atomisation. The viscosity of MGO is low enough that it can be injected without heating. The lower viscosity of MGO can lead to increased internal leakage in fuel pumps and increased flow rates through nozzles, restrictors and injectors. The low viscosity of MGO is linked to low lubricity, so fuel pumps may not be sufficiently lubricated resulting in accelerated wear or seizure. If MGO is heated to temperatures significantly in excess of 40°C its viscosity will be much too low. If the fuel is changed from high temperature RO to low temperature RO too quickly, fuel pumps may seize due to thermal gradients.

Generally, it takes between 45 minutes and 4 hours to completely change from heavy fuel to distillate for a typical slow speed marine diesel engine. This process requires light fuel to gradually be mixed with heavy fuel in a mixing tank, or a mixing valve system, as the injection system temperature drops.

Engine cylinder lubricating oils are formulated to neutralise acids resulting from the sulfur content of the fuel. When the fuel sulfur content is changed significantly for long periods, it may be necessary to change the grade of lubricating oil or change oil feed rates. In some engines it is not feasible to change oil feed rates. Some RO requires a certain content of low molecular weight aromatic hydrocarbons to prevent high molecular weight asphaltenes from precipitating out. The necessary mixing of RO and MGO during changeover could result in unwanted precipitation.

Some boiler atomisation nozzles may not be suitable for low viscosity fuel and may need to be modified. Boiler operational procedures may need to be revised to ensure, for instance, longer purge time before attempting to relight as the more volatile MGO can result in greater accumulation of vapours than for RO. The increased heating value of MGO compared with RO may require reduced fuel flow rate to avoid excessive smoke emissions.

Ivanov warns: "There are serious concerns that switching from RO to low sulfur MGO in existing boilers, which are constructed for RO use, could lead to operational problems and potential safety risks, including flame failure and, in extreme cases, an increased risk of explosion. In California, where similar fuel switching regulations have been in force since 1 July 2009, there were 15 reported casualty investigations attributed to fuel switching in the three months following implementation. The San Francisco Bar Pilots now say they have seen an incident every 1 – 3 days, involving engine failures, start failure whilst at berth and/or changes in speed which affect manoeuvrability. Consequently, it is clear that many vessels trading to/from EU ports will need to conduct modifications extending to boilers, engines, and associated fuel storage, supply and control systems, in order to ensure safe compliance with the Directive." (Ivanov, 2010).

EU Recommendation 2009/1020/EU states that: "There may be operational problems and safety risks associated with the use of marine diesel and gas oil in ships that have not been designed to use such fuels or have not undergone the necessary technical adaptation. The Commission has considered the risks associated with the change of fuels and concluded that the main safety risk relates to use in ships' boilers which have not yet been assessed and certified for use with the required type of fuel. While boilers can use heavy fuel oil or distillate fuels, a risk arises because marine diesel and gas oils are less viscous and more volatile and heating of the fuel system, which is required for heavy fuel oil, is not necessary for distillate fuels. The numbers of affected ships and the probability of such occurrences are difficult to assess precisely. There is a need for boiler and engine manufacturers to develop specific recommendations and procedures for the retrofitting of these solutions, while shipowners should develop and implement specific operational procedures and provide appropriate training to crews." (EU, 2009).

Fortunately, significant experience is being obtained regarding fuel changeover and operation on low sulfur fuels. Documentation is available, see for example DNV, 2009; ABS, 2009; FOBAS, 2009. Technological developments will occur in line with the regulatory requirements. For instance, MAN Diesel and Turbo have produced an electronically controlled "diesel switch" which handles fuel changeovers in a controlled way to avoid rapid temperature deviations and fuel pump seizures. Estimates have been published of the impact of fuel sulfur content on PM_{10} emissions (Woodyard, Marine Propulsion, 2011).

Table C-2: Auxiliary Engine emissions factors and reductions in PM_{10} with various fuels

Reference	fuel sulfur content	Emission Factor g/kWh								comments
		CO	VOCs	NOx	PM10	PM2.5	SO2	FC	CO2	
SMED (Cooper and Gustaffson, 2004)	RO 2.3%	0.9	0.2	14.5	0.5	0.5	10.4	227	722	
	MD 0.4%	0.9	0.2	13.8	0.2	0.2	1.7	217	690	
	RO to 0.4%MDO			-5%	-60%		-84%			
Port of Los Angeles 2007 (Starcrest, 2008) http://www.arb.ca.gov/regact/2008/fuelogv08/fuelogv08.htm; Appendix D, Tables II-6 to II-8.	RO 2.7%	1.1	0.4	14.7	1.5	1.2	12.3		683	NOx for MY <1999
	MD 0.1%	x1	x1	x0.94	x0.17	x0.17	x0.04		x1	
	RO to 0.1%MDO			-6%	-83%		-96%			
Entec 2007 Mediterranean (draws on IVL database) (Entec, 2007; ICCT, 2007)	RO 2.7%		0.4	12.7	0.8		12.3	227	722	assumes 50% of AE are HSD
	MD 0.2%		0.4	12.0	0.3		0.9	217	690	
	RO to 0.2%MDO			-5.5%	-62%		-93%			
ICCT (ICCT, 2007)	RO to 0.5% MDO				-75%		-80%			
	RO to 0.1%MDO/MGO				->80%		->90%			
US EPA Best Practices (ICF, 2009)	RO 2.7%	1.10	0.4	14.7	1.44	1.32	11.98	227	722.54	
	MDO 1.0%	1.10	0.4	13.9	0.49	0.45	4.24	217	690.71	
	MGO 0.5%	1.10	0.4	13.9	0.32	0.29	2.12	217	690.71	
	MGO 0.1%	1.10	0.4	13.9	0.18	0.17	0.42	217	690.71	
	RO to 0.1% MGO				-88%		-96%			
Entec 2005 (Entec, 2005a)	2.7%RO to 1.5%RO		±	±	-18%		-44%			
	2.7% RO to 0.5%RO		±	±	-20%		-81%			

Some of these estimates of the effect of reduced fuel sulfur content on PM_{10} emissions are possibly optimistic. Lack et al (Lack et al, 2009) measured PM_{10} emissions in the plumes of around 200 commercial vessels. They concluded that around 50% of PM_{10} measured within a few minutes of emission is a result of fuel sulfur and that there is a large potential for much more PM_{10} from secondary formation of sulfate from SO_2. Petzold et al (2008) and Agrawal et al (2008) measured PM_{10} emissions from marine diesel engines on RO and found around 62% of PM_{10} mass consisted of sulfates.

Mass of PM_{10} emissions is dependent on fuel sulfur content, fuel type, engine type and state of engine maintenance. Maldanova et al (2009) measured PM_{10} emissions from a ship engine on RO of 1.9% sulfur content, using a dilution tunnel. Increase of the PM_{10} in the exhaust upon cooling was associated with increase of organic carbon and sulfate. Analysis of the adsorbed phase in the cooled exhaust showed presence of a rich mixture of polycyclic aromatic hydrocarbon (PAH) species with molecular mass 178–300 amu while PM_{10} collected in the hot exhaust showed only four PAH masses. Organic carbon particles originating from unburned fuel or/and lubricating oil were observed. They also identified soot aggregates; significantly metal polluted; char particles, clean or containing minerals; mineral and/or ash particles. Hazardous constituents from the combustion of heavy fuel oil such as transitional and alkali earth metals (V, Ni, Ca, Fe) were observed in the PM_{10} samples.

Fuel type has a significant bearing on PM_{10} emissions. Unlike MDO/MGO, RO tends to produce char particles from polymerisation of high molecular weight components such as asphaltenes within the fuel droplets (Garaniya and Goldsworthy, 2007). RO has a significant metal content. RO tends to require higher lubricating oil feed rates to neutralise sulfur products and remove char and ash. Formation of soot aggregates within the burning fuel spray (accumulation mode PM10) is promoted by the presence of volatile aromatic hydrocarbons in the fuel.

C.3 Ship Emission Mitigation Measures

Following is a summary of nine different ship emissions control measures potentially applicable to NSW ports. Various technological options are covered. The two most important options over which regulatory bodies may have direct control are the use of low sulfur fuel and shore power. There are a number of options for the level of fuel sulfur and the extent of the control regime. There are a number of options for the means of producing the electricity for shore power. Further control measures include vessel speed reduction, use of exhaust gas scrubbers for sulfur emissions, emissions capture and treatment, restrictions on use of incinerators, vapour recovery systems. Various technologies are available for reduction of NOx emissions.

Mandatory switch to low sulfur fuel , 0.1%S MGO								
Description	Option 1. Auxiliary engines and auxiliary boilers use fuel <0.1%S at berth Option 2. Main engines, auxiliary engines and auxiliary boilers use fuel <0.1%S within a certain distance of the coast and in ports							
Emissions Benefits [a]	CO	VOC	NOx	PM_{10}	$PM_{2.5}$	SO_2	Fuel	CO_2
	-0%	-0%	-5-6%	-80-90%	-80-90%	-80-90%	-4%	-4%
Comments	Option 1 is the approach presently used in EU ports; Option 2 is the approach followed by California Air Resources Board (0.1%S in 2012) within 24nm of coast; Option 2 will also apply in IMO ECAs in 2015; the distance from the coast at which Option 2 would apply needs to be determined by diminishing returns based on the predicated public health benefit; Option 1 avoids the use of low sulfur fuel in main engines and associated risks; see Appendix B for further details on PM10 reduction							
Costs	About 50-60% higher cost for low sulfur MGO compared with standard RO (IFO380, IFO380) on current pricing, (Entec 2010 cites +80% cost); increased complexity of fuel handling systems							
Barriers	Added fuel cost, risk of fuel pump seizure; boiler safety considerations; need to source and carry sufficient supply of MGO							
Co-benefits	Reduced engine maintenance costs due to use of cleaner fuel; reduced production of sludge from RO pre-processing; facilitates use of EGR and SCR for NOx reduction							
Status	Proven (i.e. commercially available)							
References	(Entec, 2005a; ICCT, 2007; Cooper and Gustaffson, 2004; Starcrest, 2008; Entec, 2007; ICF, 2009; EU, 2005; US_EPA, 2010; IMO, 2009a)							

[a] Here the emissions benefits are indicative only and are estimated from published values for switching from RO at average sulfur content to distillate at 0.1% S in auxiliary engines (see Appendix B). Similar reductions will be seen in main engines and boilers.

The actual reduction in emissions in the NSW GMR will depend on a number of factors including:

- The proportion of auxiliary engines which normally operate on RO;
- Whether Option 1 or 2 is applied;

- Total berth emissions relative to transit and manoeuvring emissions. For instance the 2010 ship inventory shows that for the NSW GMR, only 27% of total ship PM_{10} emissions occur at berth. Thus, switching fuel at berth only will have a limited benefit in terms of totals. The benefit will, however, be more substantial in terms of emissions of air pollutants avoided near population centres.

Mandatory switch to low sulfur fuel, but sulfur content higher than 0.1% and not necessarily MGO	
Description	Fuel alternatives include: low sulfur RO eg 1.5%, 1.0%, 0.5%; low sulfur MDO eg 0.5%, 0.2%. Option 1. Auxiliary engines and auxiliary boilers use low sulfur fuel at berth Option 2. Main engines, auxiliary engines and auxiliary boilers use low sulfur fuel within a certain distance of the coast and in ports
Emissions Benefits	Benefits and costs are proportional to sulfur content and also dependent on fuel type; for 1% RO, PM10 reduction around 20%, SO_2 reduction 50% to 60%; see Appendix B for further details of impact on particle emissions
Comments	Less effective options than 0.1%S MGO; use of low sulfur RO reduces problems with fuel changeover; 1% low sulfur RO available (LS180, LS380) could be used as an option for transition to 0.1%S MGO; the distance from the coast at which Option 2 would apply needs to be determined by diminishing returns, based on air dispersion and public health benefit analysis
Costs	Added fuel cost compared with standard RO (IFO380): on current pricing from about 50-60% higher cost for low sulfur MGO and marginal cost increase for 1% S RO[a]; increased complexity of fuel handling systems
Barriers	Added fuel cost, risk of fuel pump seizure; boiler safety considerations if not RO; need to source and carry sufficient supply of alternative fuel
Co-benefits	Reduced engine maintenance costs due to use of cleaner fuel; reduced production of sludge from RO pre-processing if using MDO; facilitates use of EGR and SCR for NOx reduction
Status	Proven (i.e. commercially available)
References	(Entec, 2005a; ICCT, 2007; Cooper and Gustaffson, 2004; Starcrest, 2008; Entec, 2007; ICF, 2009; EU, 2005; US_EPA, 2010; IMO, 2009a)

[a] While low sulfur RO is currently available at a marginally higher cost than higher sulfur fuel, it is possible that increased usage will see prices increase due to the limited supply of low sulfur crude oil.

Shore Power (Cold Ironing)	
Description	Auxiliary engines switched off at berth and ship electricity supplied from shore Option 1 use of electricity supplied from land grid Option 2 use of low emissions diesel or gas turbine cogeneration systems located near the port, with the waste heat used to supply an industrial heating task Option 3 use of alternative electrical generation systems on shore such as wind, solar or fuel cells.
Emissions Benefits	Significantly reduced emissions of air pollutants close to population centres; ship diesel generators are more fuel efficient than central power stations or gas turbines, so likely to increase greenhouse gas emissions with use of shore power supplied from central power stations or gas turbines; emissions benefits depend on contribution of auxiliary boilers to total emissions because auxiliary boilers still burning fuel; emissions benefits depend on emissions produced in the alternative electrical generation systems and the savings in emissions from supply of waste heat to industry with the cogeneration option
Comments	Percentage reduction in hotelling emissions from provision of shore power depends on the percentage uptake of the option; some time at berth and in port where the auxiliary engines are operating before and after connection to shore power
Costs	Installation of facility $1M to $4M per berth + cost to bring sufficient power to terminal; installation of facility per ship $0.5M
Barriers	High capital investment for ports and shipowners; still running auxiliary boilers; some ships may require power connection from a barge to avoid interference between cable and cargo operations
Co-benefits	Reduced auxiliary engine maintenance costs; purchase cost of electricity potentially less than cost of fuel to run ship auxiliary generators, depending on the means used to generate the shore power
Status	Proven (i.e. commercially available)
References	(Entec, 2005b; Tzannatos, 2010; Omni_Engineering, 2007; Petersen et al, 2009; Yorke_Engineering, 2007; Eason, 2011)

Restrict use of incinerators	
Description	Prohibit use of ship board incinerators within NSW waters
Emissions Benefits	Reduced emissions of air toxics
Comments	CARB prohibits incinerators within 3 nm of the coast; AMSA prohibits use of incinerators in port limits
Costs	No cost if incineration can be done outside restricted zone
Barriers	Some cost if the prohibition necessitates discharge of sludge, etc to shore facilities
Co-benefits	
Status	Proven (i.e. commercially available)
References	(CARB, 2008; AMSA, 2011)

California is currently amending it's *Airborne Toxic Control Measure for Cruise Ship Onboard Incineration*, which prohibits cruise ships from conducting onboard incineration of any material with in three nautical miles of the California coast, to include ocean-going ships.

On-board exhaust gas aftertreatment to reduce SO_2 and particles								
Description	Installation of scrubbers on engine and boiler exhausts – allow as alternative to low sulfur fuel							
Emissions Benefits [a]	CO	VOC	NOx	PM_{10}	$PM_{2.5}$	SO_2	Fuel	CO_2
	-0%	-0%	-0-10%	-20-80%	-20-80%	-85-95%	-0%	-0%
Comments	Significant development effort underway; EU fuel sulfur directive and IMO ECA allow scrubbers as alternatives to low sulfur fuel							
Costs	20% to 50% of cost of switching to MGO; capital cost 210 $/kW; operating cost 0.4 $/MWh; there is high uncertainty regarding scrubber costs due to the small number of scrubbers currently in operation							
Barriers	May require continuous monitoring system to ensure compliance;							
Co-benefits	Removes sulphates, some NO_2 and hydrophilic organic PM10							
Status	Demonstration (prototype)/Proven (commercially available)							
References	(Entec, 2010; ICCT, 2007)							

[a] The reductions shown here are for any given engine. Entec (2010) has studied a number of key reports and concluded that the most common type of scrubbing for marine applications is sea water scrubbing (SWS) with an abatement efficiency of 90-95 % for SO_2.

There is a significant effort underway to develop exhaust gas scrubbers for marine application. The achievable reductions in emissions from an individual engine are: SOx, -85 to -95%; particles -20 to -80%; NOx 0% to -10%. There is considerable inconsistency in the limited published material as to the extent of reduction of particle emissions with the use of scrubbers.

However there is no legislated requirement concerning the level of particles in the exhaust.

Scrubber technologies include open (sea water), closed (fresh water) and dry. Seawater scrubbers use seawater directly in contact with exhaust gases to dissolve out oxides of sulfur. The wash water is diluted with more seawater prior to discharge. Freshwater scrubbers operating on a closed loop can hold all the contaminants removed from the exhaust and discharge them to land based facilities. Initially scrubbers have mainly been installed on auxiliary generator engines, to allow ships to burn high sulfur fuel in EU ports. Installations now include main engines, which will allow ships to burn high sulfur fuel in IMO ECAs.

Entec (2010) has studied a number of key reports on scrubbers. Some concerns raised include the ecological impacts of wash water disposal; availability of space on vessels; adverse interaction of scrubbing systems with other abatement technologies such as selective catalytic reduction (SCR) for NO_x; possible fuel consumption penalty; and uncertainty over costs and technology.

The Entec report emphasises that as scrubbers for marine operation are still under development and only a small number is in operation, there is considerable uncertainty as to costs. Capital cost may be in the order of 210 $/kW, and operating cost around 0.4 $/MWh (ICCT, 2007). However, over a reasonable time span for recovery of the initial capital investment, the cost of scrubbers may be 20% to 50% of the added fuel cost for operating on 0.1%S MGO.

Further details of scrubber types and scrubbers in service are given in Appendix 4. The anecdotal evidence points to the possibility of scrubbers becoming a viable alternative to low sulfur fuel, driven by substantial operating cost savings.

Vessel speed reduction (VSR)	
Description	Mandatory reduction of vessel speed within a specified geographical limit
Emissions Benefits	Fuel consumption and emissions roughly proportional to the square of speed, for a given distance covered; 10% speed reduction may reduce emissions by approximately 20%; 20% speed reduction may reduce emissions by approximately 35%; emissions reduction also depends on the effect of engine load on specific emissions rates
Comments	Port of Los Angeles and Long Beach vessel speed reduction program requires 12 knots during transiting outside the harbour
Costs	little cost if logistics permit altered schedules Ports of Los Angeles and Long Beach VSR program estimated costs: Vessel owner/operators daily cost due to a one hour delay (time it takes to slow vessel to 12 knots out from 24 nm) range from $250 to $600 Port costs could range from $50,000 to $100,000 per year (administrative costs) Fuel cost benefits within VSR zones Potential fuel cost increases outside VSR zone due to increased speeds to make up for lost time Refined shipping operational costs including onshore and onboard labor Cost of VSR impacts due to schedule changes and shipping cost of delivering goods Costs ports charge to ship operators/owners to run VSR program
Barriers	Potential negative impact on schedules and costs
Co-benefits	Reduced fuel costs
Status	Proven (commercially available)

Vapour recovery systems	
Description	Provide on-shore facilities for recovery of VOCs discharged from vessel tanks during loading of petroleum products
Emissions Benefits	Significant reduction in VOC emissions
Comments	IMO MARPOL Annex VI requires use of vapour recovery systems if mandated by Port States and shore reception facilities provided
Costs	Many tankers likely to have systems installed, as the United States Coast Guard has required vapour recovery since 1990; refineries have facilities for VOC removal
Barriers	
Co-benefits	
Status	Proven (commercially available)
References	(IMO, 2009b)

Shore side emissions capture and treatment	
Description	Capture all stack gases and process dockside with dedicated plant to remove harmful components
Emissions Benefits	Greater benefits than the use of low sulfur fuel and/or shore power as it has the potential to remove most air pollutants from auxiliary engines as well as auxiliary boilers
Comments	Some emissions before fitting and after removal of device; limited data available on development progress
Barriers	Early stages of development; numerous individual systems required to cater for all ships in port at any one time
Status	Concept/demonstration (prototype)
References	(ICCT, 2007)

Provision of LNG bunkering facilities								
Description	Plan for provision of facilities at ports for supplying LNG powered vessels with fuel eg Port of Gothenburg							
Emissions Benefits [a]	CO	VOC	NOx	PM_{10}	$PM_{2.5}$	SO_2	Fuel	CO_2
			-80%	-80-95%	-80-95%	-100%	0%	-0-30%
Comments	Encourage uptake of LNG fuelling, a growing international trend offering large emissions reductions at relatively low cost; potential to share production and distribution infrastructure with local LNG production for road transport;							

	overall benefit depends on uptake
Barriers	Primarily restricted to new port berths; possibly significant CH_4 emissions in engine exhaust as well as fugitive emissions associated with fuel handling (leakage, emergency venting); bunkering systems still under development
Co-benefits	Indigenous fuel in plentiful supply
Status	Proven (commercially available) On-board storage and handling systems and LNG marine engines are proven; bunkering systems need further development; methane oxidation catalysts need further development
References	(Sexton, 2010)

[a] emissions reductions shown are for engines operating on LNG. Reduced CO_2 due to lower carbon to hydrogen ratio, but CH_4 emissions can negate that benefit as CH_4 is a greenhouse gas

C.4 Available NOx Control Technologies

Various technological options for reducing NO_x emissions from ship engines are presented in Table C-3. Emissions benefits are detailed in Table C-4.

Table C-3: Description of NOx Control Technologies

Status: 1 Concept; 2 Demonstration (prototype); 3 Proven (commercially available)

Measure	Description	Comments	Costs	Barriers	Co-benefits	Status
engine modification to reduce NOx "in-cylinder"	combine modified injection nozzle geometry, retarded injection timing, increased compression ratio, increased turbocharger boost, increased air charge cooling; electronic common rail injection	best value for money	capital cost 0.4 to 7 $/kW operating cost 0 $/MWh			3
EGR to reduce NOx	recirculate cooled and filtered exhaust gases in charge air; seawater scrubber used to clean exhaust before recirculation if RO	still under development for RO; well developed for HSD using low sulfur distillate; retrofit feasible		may be difficult with RO	reduced SO_2 and PM10 if scrubber used to clean exhaust gas	1/2
direct water injection to reduce NOx	direct injection of water into engine cylinders (Wartsila)	mainly developed for Wartsila medium speed diesels	capital cost 12 to 24 $/kW operating cost 3 $/MWh	only available on Wartsila medium speed		3
fuel water emulsion	inject fuel water emulsion to reduce NOx	mainly developed for MAN B&W slow speed diesels		higher injection temperatures and pressures; need freshwater supply		3
HAM to reduce NOx	humidification of charge air to reduce NOx		capital cost 140 $/kW operating cost 0.2 $/MWh			2
on-board exhaust gas aftertreatment to reduce NOx	Selective Catalytic Reactor (SCR)	apparently combined with an oxidation catalyst in some ship installations; more effective for low sulfur fuel; can be combined with Particulate Oxidation Catalyst for smaller engines if fuel sulfur <50ppm	capital cost 50 to 80 $/kW operating cost 4 to 20 $/MWh	may require continuous monitoring system to ensure compliance		3

Table C-4: Emissions Benefits of NOx Control Technologies

Measure	Emission Benefit								References
	CO	VOCs	NOx	PM10	PM2.5	SO_2	Fuel	CO_2	
engine modification to reduce NOx "in-cylinder"			-20 -30%	possible decrease			possible decrease	possible decrease	(ICCT, 2007)
EGR to reduce NOx	+ >100%	possible slight decrease	-35 -50%	-20% if scrubber used		-85-95% with scrubber	possible slight increase	-0%	(ICCT, 2007; Pon-Power, 2011; MAN_B&W, 2004)
direct water injection to reduce NOx			-50%	possible slight increase			possible slight increase		(ICCT, 2007)
fuel water emulsion			-20 -50%	possible slight decrease			possible slight decrease		(ICCT, 2007; MAN_B&W, 2004)
HAM to reduce NOx	+>100%	possible slight decrease	-70%	possible slight increase		0%	possible slight increase		(ICCT, 2007; MAN_B&W, 2004)
on-board exhaust gas aftertreatment to reduce NOx	0% if no oxidation catalyst	0% if no oxidation catalyst	-85 -95%	-20% if no oxidation catalyst, -40% with oxidation catalyst	-20%	0%	0%	0%	(ICCT, 2007; stt_emtec, 2011)

APPENDIX D: STAKEHOLDER CONSULTATION

D.1 Consultation Process

A component of this study was consultation with key stakeholders involved in NSW ports operations in the areas of shipping, stevedoring, freight and governance. The stakeholder organisations listed below were contacted:

- Australian Shipowners Association
- Sydney Ports Corporation
- Australian Maritime Safety Authority
- Newcastle Port Corporation
- Port Kembla Port Corporation
- Shipping Australia
- NSW Maritime
- Ports Australia
- RTA
- DP World
- Asciano Ltd:
    - Patrick
    - Pacific National

A consultation report was prepared for the stakeholders, setting out the key background issues and the technical issues and options associated with emissions management separated into the basic functional aspects of port operations: shipping, cargo handling and freight (road and rail).

The consultation report contained a questionnaire at the end of each technical section. Stakeholders were invited to respond to the questionnaires relevant to their activities. Telephone discussions were held with stakeholders and in some cases these discussions provided more detailed information to assist with responses, and also to elaborate on responses.

Consultations were conducted over the period April to June 2011.

D.2 Consultation Questions

This sections sets out the questions that were asked in the Consultation Report.

Consultation Questions for Shippers

Do your shippers have any experience operating in ports where any of the above programs or policies has been in place? (e.g., low sulfur fuel, NO_x levy, shore power, incentive schemes, etc). Please elaborate.

Do many of your members' ships use low sulfur fuels in other ports? Please outline any operational consequences for ship operators resulting from use of low sulfur fuels.

Are many of your members' ships equipped with exhaust emission reduction equipment? If so, what type of equipment?

Are any of your members' ships that use NSW ports equipped to allow connection to shore power?

Do your members have experience with the use of shore power? Please outline any operational consequences for ship operators resulting from use of shore power.

How would vessel speed restrictions within a given distance of the coast affect shipping operations?

Have any of your members had any experience with LNG fuelling? If so, are there issues you think should be considered?

Consultation Questions for Port Authorities

Please outline your perspective on the use of shore power in your Port. Are there any berths which are particularly suited to establishment of a shore power facility?

Would your Port consider the use of differentiated port fees to encourage use of low sulfur fuel or NOx reduction technologies? If so, what would be your preferred model for determination of fees? What is the current port fee structure and what issues impact on port fees?

Consultation Questions on Cargo Handling

What is the approximate number and proportion of engines in your cargo handling fleet that would be able to accept retrofitting technologies?

Do you have any experience with any of the above strategies to reduce emissions from cargo handling equipment, including monetary and non-monetary incentives? Please elaborate.

If you have experience, what led you to implement or consider these strategies?

In your view what types of non-financial incentives could make retrofitting attractive to your company (such as public promotion of participation in a clean technology program)?

How could any requirement for emission standards impact your fleet?

What is the average age of cargo handling equipment in your fleet and how often do you rebuild or replace engines?

Do you think offering financial incentives to accelerate fleet turnover would be attractive?

Have you had any experience with automated cargo systems?

Do you think a system could work in NSW?

What benefits would an automated cargo system bring your business?

Have you or has your organisation had any experience with idle reduction programs?

Would you consider installing automatic shut-off devices on some equipment? What factors would make it worthwhile?

Do you have cargo handling equipment that would require electric plug-in power to reduce idling?

What type of incentives could be practically used to promote greater use of plug-in electric power?

Has your organisation used alternative fuels? If so please elaborate which fuels and why?

Would you take advantage of subsidies or incentives for using cleaner alternative fuels to run your cargo handling equipment?

Consultation Questions on Rail Freight

Has your organisation any experience retrofitting exhaust treatment to locomotives?

What incentives, non-monetary and monetary, would make retrofitting attractive (such as advertisement of participation in a clean technology program) to your company? If so, please provide examples.

Would you be willing to trial hybrid technology?

Is a 40-60% reduction in fuel consumption sufficient incentive to invest in Hybrid Diesel-Electric technology? What payback period would your organisation require?

What non-monetary incentives would make converting to a diesel hybrid more attractive (such as advertisement of participation in a clean technology program)? If so, please provide examples.

What is the average age of locomotives your organisation currently uses?

At what age do your rebuild or retire engines?

What subsidy would be required to retire or re-power your oldest engines?

Are there non-monetary incentives (such as advertisement of participation in a clean technology program) that would make such a program more attractive? If so, please provide examples.

Is electrification of the Botany-Enfield freight line a feasible strategy for reducing emissions?

Approximately how many locomotives do you operate that travel on this line?

How would your company respond if the Port Botany – Enfield track was electrified?

Would non-monetary incentives make switching to electric-ready engines more attractive (such as advertisement of participation in a clean technology program)? If so, please provide examples.

Have you any experience of rail-replacement systems?

Are rail-replacement systems relevant technology options for NSW ports?

Consultation Questions on Road Freight

Accelerated Fleet Turnover

What is the average age of vehicles currently in use?

Would an AFT program result in a significantly newer, cleaner fleet?

What type of incentives would make an AFT attractive to your company? (such as advertisement of participation in a clean technology program)? If so, please provide examples.

Low Emission Zones for Ports

Have you any experience of low emission zones?

Do you think low emission zones have potential relevance to NSW ports?

What key issues would need to be considered in scoping a low emission zone for NSW ports?

Retrofitting

Is retrofit technology currently used in NSW Ports?

What retrofit technology is fitted? Why?

What incentives would attract you to use retrofit technology?

Tolling Programs – Consultation Questions

Have you any experience with tolling programs?

Are tolling programs relevant to NSW Ports?

What key issues would need to be considered prior to scoping a tolling program?

Diesel-Electric Engines

Do you have any experience using diesel electric engines? Please elaborate.

Alternatives Fuels

Do you have any experience using alternative fuels?

Are they a relevant policy option to consider for NSW ports?

APPENDIX E: OPTIONS EVALUATION MATRIX

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
Ship emissions					
Mandatory low sulfur fuel at berth	~50% increase in fuel costs. \$6,800-\$34,000 retrofit costs per boiler. ~2,200 t/y reduction in SO_2.	State implementation would likely require renegotiation of EPLs to include berth as part of premises. Verifying compliance can be difficult and costly.	Currently required in EU ports, required in IMO ECAs in 2015 and Californian coast in 2012.	Best mandated through IMO conventions. Preference for national approach if developed. Positive towards incentives for ships with better performance.	
Mandatory low sulfur fuel in NSW GMR	~50% increase in fuel costs. \$6,800-\$34,000 retrofit costs per boiler. ~6,900 t/y reduction in SO_2.	Implementation would require the NSW GMR to be declared an ECA by the IMO. The Commonwealth Government would have to make this application. Verifying compliance can be difficult and costly.	Most EU ports have been declared IMO ECAs, with low sulfur fuel required from 2015. Low sulfur fuel required off the Californian coast from 2012.	Preference for national approach if developed. Support for incentives for ships with better performance.	
Shore power	\$4 million or more per berth, \$0.5 million per ship. ~700 tonnes of NO_x, 600 tonnes of SO_2 for container ships visiting Botany. ~200 tonnes of NO_x, 160 tonnes of SO_2 for cruise ships visiting Port Jackson.	Limited by space at wharves for infrastructure and ships that can be cost-effectively converted. Could consider assessing the need for shore power for new and major redevelopments of port	Shore power is used at the Ports Gothenburg, Los Angeles, San Diego, San Francisco, Seattle and Vancouver.	Little support due to implementation costs. Only seen as effective for ships that visit NSW regularly (e.g. car carriers).	Would preclude mandatory low sulfur fuel at berth.

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
		berths under EPLs. Any EPL option would need to clearly demonstrate it does not impact on the commercial operation of affected businesses. Logistics of local shipping mean few ships can accept power when visiting NSW ports.			
Vessel speed reduction on approach or departure from ports	Small increase in costs to ship operators ($250 to $600) relative to total port costs. Ship operators save fuel if permitted speed is moderate. 10% speed reduction leads to ~750 less tonnes of SO_2 20% speed reduction leads to ~1300 less tonnes of SO_2	Vessel speeds will be of interest to the relevant Port Authority and Maritime NSW. Suggest MOU between the NSW Government and the Australian Shipping Association and individual shipping owners.	Los Angeles and Long Beach implemented a voluntary program in 2001 tied to a reduction in docking fees.	Reported that ships are already operating at reduced speed overall to conserve fuel costs. Generally favourable support for reducing speed near the coast.	May be used in tandem with other actions.
Diesel powered equipment					
Diesel particulate filters (DPF)	~$14,000 per system for heavy vehicles. Reduce particulate emissions by 50-90%, and VOCs and CO	NSW Diesel Retrofit program already provides incentives and arranges retrofits.		Stakeholders recommend incentives for installing DPFs.	Alternative to partial particulate filters and DOCs.

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
	emissions by 60-90%.				
Partial particulate filters (PDPF)	~$8,000 per system for on road vehicles. Reduce particulate emissions by ~50% and VOCs and CO emissions by 50% or more.	NSW Diesel Retrofit program already provides incentives and arranges retrofits. Difficult to segregate port equipment from rest of economy cost-effectively (from supplier perspective).		Partial particle traps are preferred. Stakeholders recommend incentives for installing PDPF.	Alternative to diesel particulate filters and DOCs.
Diesel oxidation catalysts (DOC)	~$4,000 per system for on-road vehicles. Reduces PM by around 30% and CO and VOCs emissions by 50% or more.	NSW Diesel Retrofit program already provides incentives and arranges retrofits. Difficult to segregate port equipment from commercial cost sensitivities (from supplier perspective).		Stakeholders recommend incentives for installing DOCs.	Alternative to DPF and PDPF.
Lean NO_x catalysts	$6,500 to $10,000 per system. ~25% reduction in NO_x emissions	Difficult to segregate port equipment from commercial cost sensitivities (from supplier perspective).		Stakeholders recommend incentives for conversion of technology.	Alternative to selective catalytic reduction and NO_x adsorber catalysts.
Selective catalytic reduction	$15,000 to $27,500 per system. Reduces NO_x emissions by up to 90%.	Difficult to segregate port equipment from commercial cost sensitivities (from supplier perspective).		Stakeholders recommend incentives for conversion of technology.	Alternative to lean NO_x catalysts and NO_x adsorber catalysts.
NO_x adsorber catalyst	Up to 70% reduction in NO_x emissions.	Very low sulfur (10-15 ppm) diesel required. Difficult to segregate port equipment from commercial cost sensitivities (from supplier perspective).		Stakeholders recommend incentives for conversion of technology.	Alternative to lean NO_x catalysts and selective catalytic reduction.

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
Accelerated fleet turnover	Significant costs. ~4,400 t/y NO_x and ~200 t/y $PM_{2.5}$	Would require government mandate or significant financial incentives. High industry compliance cost.	Los Angeles and Oakland for port road vehicles.	If considered, stakeholders recommend significant incentives for conversion of technology.	Alternative to retrofitting technologies above.
Idle reduction programs	Can lead to industry cost savings. Cost to regulator to implement and promote system depends on extent of the system.	Could be pursued through the existing NSW Clean Machines program.	Ports of New York and New Jersey.	Stakeholders recommend incentives for conversion of technology.	
Diesel emulsions	~20% for NO_x and ~50% for particulate matter.	Increase in fuel consumption (15% for 85% diesel emulsion). There are no standards for diesel emulsion additives in Australia.		Stakeholders recommend incentives for use.	Alternative to biodiesel, fischer-tropsch diesel, e-diesel, fuel additives and natural gas.
Biodiesel	Reduces emissions of CO by ~50%, VOCs up to 90%, NO_x by 10-15%, particulate matter up to 70%, and sulfur up to 90%.	Limited by availability of fuel.	NSW Government mandates 2% of diesel sold be biodiesel, although ports are not specifically designated.	Stakeholders recommend incentives for use.	Alternative to diesel emulsions, fischer-tropsch diesel, e-diesel, fuel additives and natural gas.
Fischer-Tropsch diesel	Reduces NO_X emissions by 4-12%, CO by 18-36%, PM_{10} by 24-26% and VOCs by 20-40%.	Fischer-Tropsch diesel is not commercially available in Australia.		Stakeholders recommend incentives for use.	Alternative to diesel emulsions, biodiesel, e-diesel, fuel additives and natural gas.
E-diesel	Reduces PM_{10} by 20-40% and CO by 20-28%, NO_x by 1-6%.	No standards for E-diesel in Australia.		Stakeholders recommend incentives for use.	Alternative to diesel emulsions, biodiesel, fischer-tropsch diesel,

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
					fuel additives and natural gas.
Natural gas conversion	$30,000 to $70,000 cost per engine. $500,000 to $1,000,000 cost for refuelling station at each port if supply required for port only equipment. Reduces power available from equipment. Reduction of 50-80% NO_x and 90-95% particulate matter, with small increases in CO_2, CO and VOCs.	High capital cost is a barrier.		Stakeholders would require significant incentives for conversion of technology.	Alternative to diesel emulsions, biodiesel, fischer-tropsch diesel, e-diesel and fuel additives.
Cargo handling equipment	Cargo handling is a negligible contributor to total port emissions (up to 15.8% depending on the pollutant).				
National non-road engine emission standards	National emission reductions management options including regulation are currently being reviewed.			Generally supportive of industry-wide standards in preference to port-specific standards.	
Retrofitting technologies	See *Diesel Powered Equipment* above.	Difficult to segregate port equipment from commercial costs sensitivities (from supplier perspective).	Ports of Long Beach, Oakland and Los Angeles encourage retrofit through the use of grants.	Partial particle traps are preferred.	See *Diesel Powered Equipment* above

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
Accelerated fleet turnover	See *Diesel Powered Equipment* above.				
Idle reduction programs	See *Diesel Powered Equipment* above.				
Alternative fuels	See *Diesel Powered Equipment* above.				
Automated cargo handling systems	Significant implementation costs.	Requires significant investment by port owner/operator.	Ports of Singapore and Rotterdam	Some improvements in cargo handling are underway at some ports as capital for investment becomes available.	Capital investment in non-automated systems that can't be incorporated into the automated cargo handling system.
Rail emissions					
Accelerated fleet turnover	\$0.5 to \$1.5 million per locomotive. ~38% reduction in line haul and ~62% reduction in switch emissions for NO_x for upgrade to US EPA Tier 2 standards. ~35% reduction in line haul and ~54% reduction in switch emissions for PM_{10} for upgrade to US EPA Tier 2 standards.	Very high costs.		If considered, stakeholders would need significant incentives for conversion of technology.	Alternative to retrofitting technologies.
Retrofitting technologies	See *Diesel Powered Equipment* above.	Suppliers find it difficult to differentiate port vehicles from others.		Partial particle traps are preferred.	See *Diesel Powered Equipment* above.
Track electrification	Requires significant investment. Reductions of ~72% CO,	Very high capital costs. Users and owners of track differ.		Requires significant investment. A number of practical issues also cited.	Precludes alternative fuels, alternatives to rail and retrofit technologies.

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
	~99.9% VOCs, ~81% NO_x, ~77% particulate matter and 24% CO_2 could be achieved.				
Alternative fuels (CNG, LNG, Hybrid diesel)	\$400,000 to \$800,000 per engine to convert to dual fuel (natural gas / diesel). Emissions of NOx can reduce by up to 78%. Hybrid diesel can reduce emissions of NO_x by 50-90%, particulate matter by 50-90%, SO_2 by 40-60% as well as reducing fuel consumption and associated CO_2 emissions by 40-60% each. \$6-8 million in retrofit costs.	Significant investment incentives or government mandate required. Hybrid diesel is unproven technology. Differences in Australian industry standards mean that technology would need to be specifically designed for Australian operators.	US is introducing 15 ppm SO_2 for diesel locomotives by 2015.	If considered, stakeholders recommend significant incentives for conversion of technology. No enthusiasm for trialling hybrid technology, which is unproven.	
Alternatives to diesel locomotives	Highly site-specific in the order of \$ millions.	Ports are a small contributor to overall rail emissions.	Port of San Diego, California has an electromagnetic cargo conveyer.	Minimal component of the trip is based in the port. Best value achieved if the measures are aimed at rail overall, not rail in ports specifically. Retrofit costs will be large. Stakeholders recommend significant incentives for conversion of technology if pursued.	
Diesel road vehicles					

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
Idle reduction programs	Up to 20% reduction in fuel consumption, similar cost savings for operators.	Could be pursued through the existing NSW Clean Machines program.	Idle Free, British Columbia		
Reduced truck trips involving empty containers	Requires significant infrastructure investment.	Containers owned by a variety of operators.	Coast 2000, Virginia		
Mode switching					
Low emission zones for ports		If Port Botany, compliance would need to be monitored and enforced through the truck tag system that is part of the Port Botany Landside Improvement Plan.	Ports of Los Angeles, Long Beach, London and Milan.	Australia has no experience in low emission zones at ports. Some operators already have relatively high standards (e.g. Euro 3). Disadvantages small operators with older fleets.	May favour retrofit.
Accelerated fleet turnover	~4500 t/y in NO_x and ~200 t/y in $PM_{2.5}$	Fleet composition at ports not well understood but could be characterised at Port Botany through the truck tag program. Potential emission reductions could be inaccurate.	Ports of Seattle, Long Beach and Los Angeles	Some operators have relatively new fleets. Disadvantages leading operators.	Alternative to retrofitting technologies.
Retrofit technologies	See *Diesel Powered Equipment* above	Incentives would need to be significant. Suppliers find it difficult to differentiate port vehicles from others.	Widely used internationally.	Partial particle traps are preferred. DOCs, DPFs and PDPFs have been retrofitted to some older trucks as part of the NSW Diesel Retrofit project. Access to the port area is	See *Diesel Powered Equipment* above

Emission Reduction Measure	Approximate Cost and Effectiveness	Practical Considerations and Barriers to Implementation	Success Elsewhere	Stakeholder Preferences	Synergies or Preclusions
				the most influential incentive for any port freight carrier.	
Tolling programs	Significant reduction in vehicles not favoured by the tolling regime. Could be cost-neutral overall for government although unfavoured technologies would bear costs.	The newly implemented Port Botany Landside Improvement Program provides differentiated access fees for peak/off peak freight collection time slots.	PierPASS in California Toll Collect in Germany	Consideration should be given to smoothing truck demand at key times. Differentiated access charges related to pick up times already reduce emissions by reducing congestion.	
Diesel electric engines	See *Diesel Powered Equipment* above	Technology not yet widely available in Australia.			
Alternative fuels (CNG, LNG, hybrid)	See *Diesel Powered Equipment* above.	Incentives would need to be significant and targeted towards port related vehicles.		No incentive to switch fuels at this stage. Some perception that cost is prohibitive. Perception of numerous practical barriers to the adoption of biofuels.	