White Bay Cruise Terminal

Shore Power Feasibility, Costing and Emission Benefits Study

May 2017

PORT AUTHORITY
OF NEW SOUTH WALES

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Glossary of Acronyms and Terms

AMSA	Australian Maritime Safety Authority
AMSA Direction	Direction as outlined in the AMSA Marine Notice 21/2016, authorised under Subsection 246(1)(b) of the Navigation Act 2012
CARB	California Air Resources Board
CO_2	carbon dioxide
Cruise Ships Regulation	Protection of the Environment Operations (Clean Air) Amendment (Cruise Ships) Regulation 2015
ECAs	Emission Control Areas
ECGS	exhaust gas cleaning system, also known as a scrubber
EPA	Environment Protection Authority
EU	European Union
IMO	International Maritime Organisation
kV	kilovolt
LGA	local government area
LOD	limit of detection
MARPOL	International Convention of the Prevention of Pollution from Ships
NEPM	National Environment Protection Measure
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
PM_{10}	particulate matter less than 10 microns
$PM_{2.5}$	particulate matter less than 2.5 microns
Port Authority	Port Authority of New South Wales
ppm	parts per million
RAN	Royal Australian Navy
SHFA	Sydney Harbour Foreshore Authority
SO_2	sulphur dioxide
SO_x	sulphur oxides
GMR	Greater Metropolitan Region - Sydney, Illawarra, lower Hunter
VOC	volatile organic compounds
WBCT	White Bay Cruise Terminal

Executive Summary

White Bay is located in Balmain, in the local government area of Inner West Council. The White Bay Cruise Terminal (WBCT) has been in operation since 15 April 2013. Since that time, some local residents have expressed concerns about air emissions, odour and noise impacts from cruise ships berthed at WBCT.

In March 2015, as an election commitment, the NSW Government (Minister for the Environment) pledged to provide a benefit-cost analysis of installing shore power at each of the major NSW shipping ports used by the cruise industry, in conjunction with the investigation of the introduction of low sulphur fuel as a means to mitigate emission impacts at WBCT.

The Department of Premier and Cabinet's post-election *Policy Implementation Plan* required Port Authority of NSW (Port Authority) to prepare a report on the feasibility and cost of providing shore power to cruise terminals in Sydney Harbour.

On 13 August 2015, further reinforcing this commitment, the NSW Government response to Recommendation 12 of the Legislative Council General Purpose Standing Committee No. 5 inquiry into the Performance of the NSW Environment Protection Authority (EPA), committed to the Port Authority to undertaking a feasibility study of shore power.

In subsequent discussions with the EPA, Port Authority was requested to augment its technical feasibility study with some benefit-cost analysis. It was agreed to focus the study on the feasibility and costs of installation of shore power at WBCT, with investigation of the associated emissions benefits also to be undertaken.

This report includes the results of the Port Authority's investigations into the feasibility of the installation of shore power, the associated costs and potential environmental emissions benefits. It does not, however, address the associated health impacts or health costs in detail.

Port Authority acknowledges that there are sensitive receivers in close proximity to WBCT, with residences located at distances and elevations relative to WBCT where air emissions, odour and noise issues have arisen from cruise ships that have resulted in community concerns. It should be noted that the emissions modelling undertaken for the purpose of this report (total annual cruise ship emissions) has been at a scale that does not assess the direct emission benefits due to shore power at individual receivers. The noise assessment however has considered the benefits of shore power at the nearest receivers.

Port Authority has prioritised the investigations based on WBCT, however, these investigations could be extended to include other locations in NSW or to provide a detailed benefit-cost analysis of shore power and other emission control options.

'Shore power' is an emissions control measure that provides a connection to the local land-side power grid, rather than utilising the ship's engines when at berth.

Key findings of Port Authority's investigations are summarised as follows:

- Uptake of shore power by cruise lines will be minimal unless incentivised or mandated by Government:
    - 25% of vessels currently calling at WBCT are capable of using shore power. The additional cost estimated within the modelling to retrofit the fleet currently calling at WBCT is in the order of $27 million;
    - Use of shore power is not aligned with industry plans for emission control measures, with both key customers of NSW cruise terminals (Carnival Corporation and Royal Caribbean Cruise Lines, representing over 90% of vessel visits to Sydney) having announced significant programs for the progressive installation of exhaust gas cleaning systems, also referred to as 'on-board scrubbers', to meet International Maritime Organisation shipping industry requirements for emission control by 2020.
- There are 10 international ports with shore power for cruise ships, but none of these are in Australia:
    - Shore power has been implemented primarily as an emission control strategy in the Pacific Northwest of the United States where:

      (i) the potential for emission reductions and benefits to the community, as well as government regulation, were the main drivers;

      (ii) there was an excess of clean, renewable and lower cost power (hydroelectric) with necessary infrastructure already in close proximity to the port; and

      (iii) there was Federal Government funding which facilitated the implementation.
- Shore power at WBCT is technically feasible, with an estimated landside infrastructure cost of $36 million[1], based on a two-year installation period.
- The introduction of Low Sulphur Fuel Requirements through the Protection of the Environment Operations (Clean Air) Amendment (Cruise Ships) Regulation 2015 (Cruise Ships Regulation) which was subsequently replaced by the Australian Maritime Safety (AMSA) Direction as outlined in the AMSA Marine Notice 21/2016, authorised under Subsection 246(1)(b) of the Navigation Act 2012 (AMSA Direction), have had a major positive effect on reducing cruise ship-related air emissions in Port Jackson – reducing the potential for subsequent benefits of shore power.

[1] The estimated lower to upper cost is $23-28 million, and with an assumed margin of error ranges from $21-36 million.

- Port Authority modelling of air emissions at WBCT[2] demonstrates an 87% reduction in sulphur oxides (SO_x) and a 69% reduction in particulate matter less than 2.5 microns ($PM_{2.5}$) emissions, as a result of the AMSA Low Sulphur Fuel Requirements. Installation of shore power would provide negligible further incremental reduction in SO_x and a further 10% in $PM_{2.5}$;

- Air quality data collected from the Port Authority's air monitoring station located in Grafton Street, Balmain, indicates that whilst there has been a significant reduction in SO_x since the introduction of Low Sulphur Fuel Requirements, $PM_{2.5}$ concentrations are not discernibly different between ship and non-ship days at WBCT and appear to be dominated by sources other than cruise ships at WBCT. All SO_x and $PM_{2.5}$ measured emissions are below national ambient air quality standards set by the National Environment Protection (Ambient Air Quality) Measure.

➢ Based on modelling including the land-side power grid emissions (as well as the emissions at the source at WBCT), shore power would increase the overall air emissions of SO_x and carbon dioxide (CO_2) within Sydney's Greater Metropolitan Region (unless clean energy was sourced for the supply of electricity).

➢ Port Authority modelling of air emission at WBCT demonstrates shore power will provide a reduction in the emission of nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which are not significantly reduced by Low Sulphur Fuel Requirements. However, as existing levels emitted from cruise ships are at relatively low levels when compared to relevant national ambient air standards, the introduction of shore power will not provide a significant emissions reduction benefit.

➢ Shore power would provide a reduction in odorous emissions. However, the reduction in odour may not be discernible as there would still be odours related to diesel boilers (which are used on ships to generate heat when a ship is using shore power).

➢ Shore power provides a reduction to noise emissions. However, it is not the most cost-effective solution for reducing audible noise, as the points below demonstrate:

- Shore power would reduce audible noise in the order of 9–10 decibels, which provides similar benefit to other noise reduction measures, but is comparatively expensive. For example, the installation of a noise barrier would provide a similar reduction in audible noise at a significantly lower cost (estimated at $2.5–4 million);

- Shore power capable vessels at WBCT represent 25% of vessel calls, reducing to 8% of overnight stays (based on 2015–16 visits) and noise benefits will vary from ship to ship;

[2] It is noted that all modelling of the benefits of shore power was based on an assumed regulatory requirement that cruise companies calling more than 20 times would need to reduce emissions via shore power and all ships with shore power capabilities will plug in; similar to the shore power regulation scheme in California (namely, the modelling assumed for 2015–16 there were 116 calls out of 132 that were shore powered; and 10 ships with shore power infrastructure). The reality is that for the 2015–16 cruise season, currently 6 of 24 cruise ships are shore power-ready, and those ships make 29 of 132 calls or 22% of visits.

- Port Authority has completed investigations as outlined in the Noise Mitigation Strategy for WBCT and conducted community consultation as documented in a Response to Submissions Report prepared for the consideration of the NSW Department of Planning and Environment. The investigation comprised evaluation of all identified noise mitigation options including operational and engineering changes to ships and treatment of receivers. The Final Noise Mitigation Strategy is to be considered by the Department following their review of the Response to Submissions Report;

- The key elements of the Noise Mitigation Strategy are a Noise Restriction Policy, Noise Attenuation Program, and Noise Logging. Port Authority has allocated $5.3 million to fund the implementation of the Strategy.

- Air emission strategies can be assessed using a number of different methods. This assessment employed a methodology used by the California Air Resources Board (CARB). Using the CARB benchmark, shore power at the WBCT was not found to be a cost effective solution:

    - Projects with values less than the benchmark (i.e. a ratio less than 1.0) are considered cost-effective, while those higher than the benchmark are not considered cost-effective. The investigation found that the use of shore power would range from 2 to over 7 times higher than the benchmark and would therefore not be considered cost-effective;

    - Additionally, using the NSW EPA method for assessing the health impacts, the benefit of implementing shore power is approximately 11 to 24 times less than the cost of the project over the 10 year implementation period;

    - Shore power is only one possible emission control solution. Other options include:

        - engine and boiler technologies
        - after treatment technologies
        - alternatively fuelled on-board energy generation
        - alternatively generated power systems
        - operational efficiency improvements.

Recommendation

Based on investigations and potential air emissions benefits, Port Authority of NSW does not recommend the installation of shore power at White Bay Cruise Terminal as a cost effective solution.

It is further recommended that Port Authority of NSW continues working collaboratively with relevant stakeholders to implement the Noise Mitigation Strategy for White Bay Cruise Terminal in 2017.

1 Introduction

1.1 Background

'Shore power' is an emissions control measure that provides a connection to the local land-side power grid, rather than utilising the ship's engines when at berth.

White Bay is located in Balmain, in the local government area (LGA) of Inner West Council[3].

Port Authority has prepared this report to investigate the potential provision of shore power for cruise ships berthed at the White Bay Cruise Terminal (WBCT) as a possible means of reducing impacts of air emissions, odour and noise on the local community.

It is important to note that the Port Authority's investigations of shore power include a quantification of environmental emissions, but do not address emissions-related health impacts in detail (e.g. quantification or assessment of health impacts to nearby residents and detailed evaluation of associated health costs) as these linkages between environmental emissions and health impacts are complex and require highly specialised expertise to interpret. However, an indication of health impact is provided for information, as an estimated health benefit (cost saving).

Port Authority has prioritised the investigations based on WBCT. However these investigations could be extended to include other locations in NSW or to provide a detailed benefit-cost analysis of shore power and other emission control options.

It is important to note that shore power does not reduce ship emissions to zero. Emissions at berth are only reduced (not eliminated) for a portion of the total time the ship is at-berth (the time the ship is powered by the electricity grid).

Firstly, the ship is not connected to the land-side power grid instantaneously when it arrives, nor disconnected instantaneously when it departs. A complex sequence of events needs to take place before the ship can shut down or restart its engines, which typically takes approximately an hour upon arrival and an up to hour prior to departure. While the ship is connected, shore power shifts locally generated emissions from the ship's engines (typically auxiliary engines) to regionally generated emissions associated with the power grid servicing the terminal.

In addition to the auxiliary engines operating prior to connecting and disconnecting to the grid, shore power does not eliminate all at-berth (locally) generated emissions. When a cruise ship is connected to and operating on shore power, the waste heat from the diesel-electric generators drops (because the engines are off) and the auxiliary boilers must be turned on to service hot water and steam needs for the ship.

[3] Inner West Council was proclaimed on 12 May 2016. It is made up of the former local government areas (LGAs) of Ashfield, Leichhardt and Marrickville. References to the Leichhardt LGA throughout this report refer to the former Leichhardt LGA, which is now part of the Inner West LGA.

1.2 Global Regulation of Shipping Emissions and Industry Response

KEY FINDING

- **Uptake of shore power by cruise lines will be minimal unless incentivised or mandated by Government.**

  - 25% of vessels currently calling at WBCT are capable of using shore power. The additional cost estimated within the modelling to retrofit the fleet currently calling at WBCT is in the order of $27 million;

  - Use of shore power is not aligned with industry plans for emission control measures, with both key customers of NSW cruise terminals (Carnival Corporation and Royal Caribbean Cruise Lines, representing over 90% of vessel visits to Sydney) having announced significant programs for the progressive installation of exhaust gas cleaning systems, also referred to as 'on-board scrubbers', to meet International Maritime Organisation (IMO) shipping industry requirements for emission control by 2020.

In recent years there has been a global initiative to reduce air emissions from shipping.

The global context of regulatory regimes regarding shipping emissions is complex, but most are based on the International Convention of the Prevention of Pollution from Ships (MARPOL). The applicable Annex VI of MARPOL regulates emissions to air from marine engines and separates the consideration of emissions within and outside the so-called Emission Control Areas (ECAs).

The ECAs in the Baltic Sea and North Sea limit the sulphur content of maritime fuel to 0.1% from 1 January 2015, with the non-ECA regions limited to 0.5% sulphur content by 2020.

The ECAs in North America and the Caribbean, as well as placing limitations on the sulphur content of fuels, also focus on nitrogen oxides (NO_x). The NO_x regulation operates on a three tier system, of which Tier I and Tier II regimes apply globally (including in Australia). Tier III was enforced from 1 January 2016 within the applicable ECAs and is applied to ships built after this date. It aims to reduce NO_x emissions between Tier II and Tier III by approximately 70%.

Port Authority obtained key information from the cruise lines, particularly with regard to their plans for scrubber installations on their fleet and their position on shore power. Port Authority was informed cruise companies are not retrofitting more ships to enable connection to shore power, and there are no significant plans to build new ships that are capable of using shore power. In order to meet the requirements of MARPOL and the existing ECAs globally, the cruise industry has taken a number of approaches – not only the procurement of low sulphur fuel. Carnival Corporation's latest Sustainability Report (2015)[4] noted that there was a

[4] http://www.carnivalcorp.com/phoenix.zhtml?c=140690&p=irol-sustainability_env, accessed March 2017

commitment within the organisation to increase shore power (or 'cold ironing') capabilities of their fleet. However, due to the requirement for all non-ECA regions to meet the 0.5% sulphur content by 2020 across all ship operational modes (including ocean transit, manoeuvring, at-berth, etc.), Carnival Corporation has primarily invested in the installation of exhaust gas cleaning systems (EGCS or 'scrubbers', which can be used at sea and at-berth), costing in the order of US$800 million. Similarly, Royal Caribbean Cruise Lines are investing heavily in scrubber technology to meet IMO requirements.

Of the ships calling in at WBCT during the 2015–16 season, 6 of 24 cruise ships, or 25%, are shore power-ready.

Costs estimates were obtained for shipboard modifications to retrofit shore power connection facilities and this was estimated to be between A$700,000 and A$2.7 million per vessel. These estimates are dependent on a number of factors including:

- supply voltage and frequency provided at the berth;
- number of vessels in the fleet requiring shore connection capability;
- compatibility of existing ship hardware and shore power connection supplier;
- vessel configuration;
- geographical location;
- location on-board of the switchboard and proposed shore power point of ingress or connection point to ship;
- control and automation system integration;
- requirement for structural works;
- safety system modifications;
- Classification Society and/or Flag State requirements;
- requirements for out-of-service time.

Additionally, some vessels may not have the capacity to provide for the shore power reception facilities. The physical space on board the ship required to house the connection equipment may render retrofitting unfeasible as it will hamper vessel operations or capability to such an extent that owners/operators will not be able to install the required equipment.

It should be noted that there is no global initiative to reduce noise emissions from ships.

1.3 Shore Power Global Context

KEY FINDING

- **There are 10 international ports with shore power for cruise ships, but none of these are in Australia.**

  - Shore power has been implemented primarily as an emission control strategy in the Pacific Northwest of the United States where the potential for emission reductions and benefits to the community, as well as government regulation, were the main drivers; where there was an excess of clean, renewable and lower cost power (hydroelectric) with necessary infrastructure already in close proximity to the port; and there was Federal Government funding which facilitated the implementation.

Shore power is an emission control strategy that shifts a ship's on-board electrical generation to the local land-side power grid servicing the terminal. Instead of the ship generating its own electricity, the grid supplies the ship through a sophisticated system of cables, circuit breakers, transformers and control circuits.

The following is a summary of the international context of shore power for the cruise industry based on research, discussion and correspondence with each of the 10 shore power enabled ports in the world. In this summary, shore power for cruise ships is considered high-voltage – typically running at 6.6 kilovolts (kV) or 11 kilovolts. The key points are:

- Ten international ports currently make shore power available at cruise terminals.
- Shore power related to cruise ships started in Juneau Alaska in 2001. It has broadened to Seattle (2005), Vancouver (2009), San Francisco (2010), San Diego (2010), Los Angeles (2011), Long Beach (2012), Halifax (2014), Hamburg (2015) and Brooklyn New York (2016).
- Shanghai, Montreal and Quebec have indicated that they intend to install shore power for cruise ships, however, this has not yet commenced.
- The Port of Auckland has recently commissioned a feasibility study to look at the potential implementation of shore power and alternative strategies to reduce emissions from visiting cruise ships. The study is anticipated to be released during the second quarter of 2017.
- For the North American, Pacific Northwest ports of Juneau, Vancouver, Seattle and San Francisco, a key consideration was that there was an excess of clean, renewable and cheap power (hydroelectric) with necessary infrastructure already located close to the berths, which considerably reduced the overall costs of providing shore power.
- Hong Kong (May 2015) announced that it will not pursue shore power due to it being a costly system that few cruise ships would use[5].

[5] http://www.scmp.com/news/hong-kong/health-environment/article/1810888/hong-kong-pulls-plug-shore-power-supply-cruise, accessed October 2015

- Copenhagen has released a study evaluating the financial feasibility of shore power at Copenhagen Malmö Port[6]. The study shows that it is only possible to establish a shore power facility for cruise ships in Copenhagen with substantial public funding.
- The California Air Resources Board (CARB) is the only regulatory agency in the world that has a broad shore power-based regulation, although the CARB regulation effectively limits the use of shore power (up to a maximum 80% of calls) due to the complexities of the strategy and the maritime industry.
- All shore power installations, except for Long Beach which is a Carnival-owned facility, have generally involved a consortium of parties contributing to the cost, including several levels of government, the cruise industry and the port. It should be noted that the cruise terminal in Long Beach is actually leased from the City of Long Beach to Carnival, and is not part of the Port of Long Beach.
- Victoria is Canada's busiest cruise port of call. The Greater Victoria Harbour Authority had considered shore power in 2014, but decided not to pursue it and has identified scrubber technology as the preferred option for the mitigation of air quality impacts from cruise ships. Cruise ships are also required to use 0.1% sulphur fuel (or equivalent technologies) in Victoria Harbour as it is within the North American ECA, designated through the IMO. Together, these initiatives are seen as ensuring the continuity of good air quality while ships are within the vicinity of Victoria Harbour, not just at berth. In June 2016, the port reopened[7] its review of shore power related to home-ported cruise ships, however no decision has been published.
- Charleston, South Carolina has had significant community concerns regarding cruise ship impacts, including on air quality. This port has not been able to justify installing shore power and they note that their air quality monitoring is "not showing any concerns" (P. Moore, 2015, pers. comm., 2 June).
- The European Union (EU) does not have an established shore power program and only recently had its first high voltage cruise ship berth commissioned. The Hamburg Port Authority (HPA) just started operations in the summer of 2015 at its Altona cruise terminal (one berth)[8], which is the EU's first high voltage shore power berth. The Port of Amsterdam has moved forward with a study relating to shore power (also called 'on-shore power supply' or OPS), stating:

  > "The sector has acknowledged that the only way to realize on shore power supply for sea cruise ships is to use a European approach. On shore power supply will only be feasible if a certain critical mass is reached. A large investment is needed in on-board connectors by cruise lines. This investment will only be made, if a significant amount of terminals along the usual sailing routes will offer on shore power supply. Therefore, the port of Amsterdam as major European cruise port, in close cooperation with Cruise Europe, ports in North and Western Europe and cruise lines sailing in Europe

[6] http://www.cmport.com/~/media/docs/corporate%205/reports/shoreside%20report_enggb_final.ashx, accessed December 2015

[7] CBC News, www.cbc.ca/news/canada/british-columbia/victoria-harbour-cruise-power-1.3644808, accessed April 2017

[8] http://www.hamburg-news.hamburg/en/cluster/port-logistics/shore-power-altonas-cruise-terminal/, accessed October 2015

> has taken the lead to realize a European project for on shore power supply: OPS Sea Cruise Europe."

The ultimate goal of the OPS Sea Cruise Europe project is to build four OPS facilities in Europe based on the projects findings.

- In March 2017, the United States Environmental Protection Agency (USEPA) published a Shore Power Technology Assessment at U.S. Ports[9]. This assessment was compiled based on review of numerous sources and provides a method of assessing shore power for ports throughout the US.
- It should be noted that it is uncommon for all the berths at a terminal or within a port to be equipped with shore power due to costs and operational flexibility.

[9] USEPA, https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports, accessed April 2017

1.4 White Bay Cruise Terminal Development

White Bay is located in Balmain, in the LGA of Inner West Council. It has been a working port in Sydney since the mid-1800s and along with Glebe Island, continues to operate as a port 24/7. White Bay Berth No. 5 (WB5) operated as a general stevedoring terminal until 2006 and continued as an overflow area for car stevedoring until late 2008.

White Bay's evolution to a cruise terminal came with the closure of Darling Harbour berth 8 Cruise Terminal to make way for the Barangaroo development.

The NSW Government's Passenger Cruise Terminal Steering Committee, which included representatives from the Sydney Harbour Foreshore Authority (SHFA), Tourism and Transport Forum, NSW Maritime, Tourism NSW, Royal Australian Navy (RAN), major cruise companies and Sydney Ports Corporation (now Port Authority), collectively saw White Bay as the home for Sydney's second cruise passenger facility. This decision was based on the availability of the WB5 berth along with the unsuitability of attempting to run cruise operations at Barangaroo.

Port Authority prepared an environmental assessment, including preparation of air quality and noise impact assessment studies from cruise ships and terminal operations.

In the planning approval for the WBCT, received from the NSW Department of Planning and Environment, noise limits were set that the environmental assessment modelling predicted would be exceeded under certain circumstances, particularly in certain adverse weather conditions. The planning approval also specified air quality criteria for key pollutants based in the environmental assessment, namely sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter less than 10 microns (PM_{10}), in accordance with National Environment Protection Measure and the NSW Environmental Protection Authority (EPA, then Department of Environment and Conservation) criteria outlined in *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales*.

The conditions of approval require noise and air quality monitoring to be undertaken to assess compliance against the criteria.

Following approval, the WBCT was constructed by the then Sydney Ports Corporation and opened on 15 April 2013.

Air Emissions at White Bay Cruise Terminal

Prior to the 2015 NSW State Government election, in response to increasing community concern from some local residents about emissions from cruise ships at WBCT, the NSW Government committed to regulate sulphur content in fuels used by cruise ships in Sydney Harbour. This was despite the results of monitoring of air quality conducted by Port Authority showing that it was in compliance with national ambient air standards.

The NSW Government (Minister for the Environment) also committed to a benefit-cost analysis of installing shore to ship power at each of the major NSW shipping ports used by the cruise industry as part of its 2015 election commitment, in conjunction with the introduction of low sulphur fuel as a means to mitigate emission impacts at WBCT.

The NSW Government’s response to the Upper House Inquiry into the Performance of the EPA also included a commitment for Port Authority to undertake a feasibility study of shore power (response to Recommendation 12).

Following consultation with EPA it was agreed to focus this study on the feasibility and costs of installation of shore power at WBCT, with investigation of the associated emissions benefits also to be undertaken.

The EPA regulated sulphur content in fuel commencing on 1 October 2015 via the implementation of the Protection of the Environment Operations (Clean Air) Amendment (Cruise Ships) Regulation 2015 (Cruise Ships Regulation) under the Protection of the Environment Operations Act 1997 (NSW). As such, fuels used by cruise ships are limited to a maximum of 0.1% sulphur content. This was estimated by the EPA[10] to result in a 70% reduction in fine particle emissions.

It is noted that this sulphur content is lower than current limits defined by international MARPOL regulations, which set global sulphur levels at 0.5% by 2020 in areas outside the ECAs established under MARPOL Annex VI for sulphur oxides (SO_x). Within those ECAs the limit is set at 0.1%.

In May 2016, EPA became aware that the Commonwealth Government introduced amendments to the Protection of the Sea (Prevention of Pollution from Ships) Act 1983 into Parliament in September 2015, which were assented to in December 2015, and resulted in the 2015 Cruise Ships Regulation being inoperative from January 2016.

In December 2016 the Commonwealth announced a new direction to protect Sydney Harbour from harmful ship emissions. The AMSA Direction as outlined in the Marine Notice 21/2016[11], authorised under Subsection 246(1)(b) of the Navigation Act 2012[12] which became effective in December 2016, directs cruise vessels to limit sulphur emissions while at-berth in Sydney Harbour. This direction is applicable to cruise ships capable of accommodating more than 100 passengers and requires the use either one or a combination of the following options:

(i) 0.1% sulphur content fuels;

(ii) certified exhaust gas cleaning systems (EGCS); and/or

(iii) shore power.

The limit on sulphur emissions applies from one hour after the vessel's arrival at-berth until one hour before the vessel's departure.

In the interim between the Cruise Ships Regulation being inoperative (January 2016) and the start of the AMSA Direction (December 2016), EPA was able to obtain agreement with both Carnival Australia and Royal Caribbean to voluntarily continue to comply with the at-berth requirements of the 2015 Cruise Ships Regulation.

Port Authority, through an expert consultancy, and in discussion with the EPA, has also commenced additional air quality monitoring in Balmain which is over and above the requirements of the planning approval. Particulate matter less than 2.5 microns ($PM_{2.5}$) and SO_2 is being continuously monitored with near real-time results publicly available on a dedicated Port Authority web page. Monthly reports are also provided on the Port Authority website. Monitoring of VOCs has been undertaken during one 24-hour period whilst a cruise ship was at WBCT.

[10] http://www.epa.nsw.gov.au/resources/air/150604-regulation-statement.pdf, accessed March 2016

[11] AMSA, https://apps.amsa.gov.au/MOReview/MarineNoticeExternal.html, accessed January 2017

[12] Federal Register of Regulation, https://www.legislation.gov.au/Series/C2012A00128, accessed January 2017

In addition to air quality issues, concerns about odour from cruise ship exhaust have been raised by the community, with odour complaints continuing to be received in the period following the introduction of the Cruise Ships Regulation.

Noise Emissions at WBCT

Noise from cruise ships is a concern for the local community and noise monitoring indicates the noise from cruise ships berthed at WBCT does exceed the criteria set in the project approval. Monitoring against the project approval noise limits has involved 129 readings over 17 vessel visits. The monitoring indicates there were 35 exceedances including 25 at locations closest to WBCT at Grafton Street and Cameron's Cove. The exceedances have been measured over day, evening and night-time periods. It is noted that the majority of ships are at berth during the day-time period. The percentage of cruise ship visits staying overnight for the current cruise season is approximately 12% of visits, which equates to less than 5% of the year.

Port Authority has investigated a range of noise mitigation measures to address the exceedances of the noise limits as part of a Noise Mitigation Strategy which has been prepared for the consideration of the NSW Department of Planning and Environment. The reduction of noise through the implementation of shore power was one of the options assessed under the Noise Mitigation Strategy. Other options considered included:

(i) source reduction (operational and engineering changes to ships);

(ii) treatment of receivers; and

(iii) noise barriers.

Port Authority has also completed community consultation as documented in a Response to Submissions Report prepared for the consideration of the NSW Department of Planning and Environment. The Final Noise Mitigation Strategy to be implemented by Port Authority comprising a Noise Restriction Policy, Noise Attenuation Program, and Noise Logging, is to be considered by the Department following their review of the Response to Submissions Report.

2 Feasibility and Costing

2.1 Infrastructure Requirements for White Bay Cruise Terminal

KEY FINDING

- **Shore power at WBCT is technically feasible, with an estimated landside infrastructure cost of $36 million[13], based on a two-year installation period.**

Port Authority contracted Navari Pty Limited to prepare a feasibility study to investigate the feasibility, estimated cost and timeframe for providing shore power to the WBCT. This report is included in Appendix 1.

A shore power rating of 15 mega-volt amperes has been modelled at the WBCT site, which is compatible with the products currently available from shore power equipment manufacturers.

Based on information received from the electricity provider (Ausgrid Pty Limited), the optimum connection point is a 33 kilovolt connection from Rozelle Sub-transmission Substation, which would require an underground cable from Rozelle to the WBCT site, at an estimated length of 2.5 kilometres.

Investigations to date have not identified any issues that would make the upgrade of the local electricity network impossible. Installation of shore power infrastructure at WBCT also appears physically and technically possible.

It should be noted that preliminary investigations (i.e. initial discussions with energy provider) into shore power installation at the Overseas Passenger Terminal at Circular Quay have also been undertaken.

2.2 Cost Estimates

The total budget cost estimate for a complete shore power facility at WBCT, including all of the design and investigation costs, 33 kilovolt (kV) cable, shore power equipment, and cable system is $23 million–$28 million as outlined in Table 1, and allowing for a potential range in cost estimates, the upper estimate could be in the order of $36 million.

Table 1 – Summary of Budget Costs

Item	Budget Cost [1]	Comments
Ausgrid Design Costs	$200,000	Includes: design, design certification, and construction supervision. Assumes no Rozelle substation upgrade required

[13] The estimated lower to upper cost is $23-28 million, and with an assumed margin of error ranges from $21-36 million.

Item	Budget Cost [1]	Comments
Design of 33kV Cable Connection to the WBCT site	$400,000	Includes coordination of design of cable from the Ausgrid nominated Connection Point, cable rating studies, field investigations, earthing considerations, thermal resistivity testing, geotechnical, environmental study
Supply and installation of the 33kV Cable	$5–7M	Installation to Ausgrid Network Standard NS168. Includes: – supply of 2.6 kilometres of underground rated 33kV cable and associated works
Design and installation of the shore power equipment	$10–12M	Cost based on prices from suppliers. Includes: – overall design – 33kV incoming switchboard switching of Ausgrid cable. – 33kV/440V 15MVA transformer – 3 phase static frequency conversion equipment – variable voltage 15MVA output transformer
Design and installation of cable connection system	$2–3M	Cost based on prices from suppliers. Includes: – overall design from output transformer on shore power equipment to ship – auto or manual connection from shore to ship
Project Management	$2.9M	Oversight of design, procurement and ongoing management
Contingency	10%	Typical for a project of this nature due to construction unknowns
Total cost	$23–28M	Suggest a +30%/–10% margin. Refer to note 2 below
Lower – upper cost estimate	**$21–36M**	Based on above margins

Note 1: The above budget cost is based on an exchange rate of 1 Australian dollar being equivalent to 72 cents US dollar.

Note 2: The +30%/–10% margin is based on the cost for the design and installation of the shore power construction work and equipment quoted by the various suppliers was on the basis that the quote was not accurate or binding. They all quoted similar figures for the shore power equipment, and for the cable connection system, but it was on the understanding that they had not visited the site and had not carried out any detailed studies into the system they would be offering to suit the WBCT site.

3 Environmental Emissions Benefits

3.1 Air Emission Benefits

Modelling of emissions reduction was undertaken by Starcrest Consulting Group LLC to understand relative emission reduction benefits of various options. It has included the following scenarios for vessels scheduled to berth at WBCT between 1 October 2015 and 30 September 2016:

- **Baseline** – represents pre-Low Sulphur Fuel Requirements, assuming ships use 2.7% sulphur fuel at berth;
- **AMSA Direction Low Sulphur** – represents compliance with the AMSA Low Sulphur Fuel Requirements using 0.1% sulphur fuel, including a one hour changeover period from 2.7% to 0.1% sulphur fuel upon arrival at and departure from the berth;
- **EPA Low Sulphur** – represents compliance with the long term intent of the Cruise Ship Regulation using 0.1% sulphur fuel for the entire period at berth;
- **Scrubbers** – represents alternative compliance with Low Sulphur Fuel Requirements using on-board scrubbers, whilst using low sulphur fuel; and
- **Shore Power** – represents vessels connecting to shore power (based on CARB's shore power regulation scheme[14]), and using 2.7% sulphur fuel for one hour upon arrival at and departure from the berth. For this scenario, emissions from the land-side grid in providing the electricity for shore power were also estimated for the NSW Greater Metropolitan Region (GMR).

Modelling methods were based on those used by the internationally recognised CARB, which have been utilised for assessment of numerous ports in North American and Asia and are consistent with IMO methodologies.

The modelling focussed on emissions at berth as these comprise approximately 80% of total emissions from a cruise ship's entire call to Sydney Harbour.

Port Authority acknowledges that there are sensitive receivers in close proximity to WBCT, with residences located at distances and elevations relative to WBCT where air emissions, odour and noise issues have arisen from cruise ships that have resulted in community concerns. It should be noted that the emissions modelling undertaken for the purpose of this report (total annual cruise ship emissions) has been at a scale that does not assess the direct emission benefits due to shore power at individual receivers.

Forecast estimates have not been included as the scenarios were selected to specifically analyse the relative benefits of shore power against the baseline emissions and low sulphur fuel. It is acknowledged that vessel visits are forecast to increase due to an increase to about 2 million passengers in Australia by 2020 (an approximate annual growth rate of 12.5%, based on Cruise Lines International Association data), which would lead to an increase in total annual emissions. However, it is considered that the relative benefits of shore power

[14] It is noted that all modelling of the benefits of shore power was based on an assumed regulatory requirement that cruise companies calling more than 20 times would need to reduce emissions via shore power and all ships with shore power capabilities will plug in; similar to the shore power regulation scheme in California (namely, the modelling assumed for 2015–16 there were 116 calls out of 132 that were shore powered; and 10 ships with shore power infrastructure). The reality is that for the 2015–16 cruise season currently 6 of 24 cruise ships are shore power-ready, and those ships make 29 of 132 calls or 22% of visits.

would remain largely similar. The effects of the MARPOL 0.5% sulphur requirements due to be introduced globally in 2020 are not expected to alter the emission estimates as the scenarios tested account for low sulphur fuel usage (0.1% sulphur at berth), assuming this requirement continues.

The complete report is included in Appendix 2.

KEY FINDING

- **The introduction of Low Sulphur Fuel Requirements through the Protection of the Environment Operations (Clean Air) Amendment (Cruise Ships) Regulation 2015 which was subsequently replaced by the Australian Maritime Safety (AMSA) Direction as outlined in the AMSA Marine Notice 21/2016, authorised under Subsection 246(1)(b) of the Navigation Act 2012, have had a major positive effect on reducing cruise ship-related air emissions in Port Jackson – reducing the potential for subsequent benefits of shore power.**

  - Port Authority modelling of air emissions at WBCT demonstrates an 87% reduction in sulphur oxides (SO_x) and a 69% reduction in particulate matter less than 2.5 microns ($PM_{2.5}$) emissions as a result of the AMSA Low Sulphur Fuel Requirements. Installation of shore power would provide negligible further incremental reduction in SO_x and 10% in $PM_{2.5}$.

  - Air quality data collected from the Port Authority's air monitoring station located in Grafton Street, Balmain, indicates that whilst there has been a significant reduction in SO_x since the introduction of Low Sulphur Fuel Requirements, $PM_{2.5}$ concentrations are not discernibly different between ship and non-ship days at WBCT and appear to be dominated by sources other than cruise ships at WBCT. All SO_x and $PM_{2.5}$ measured emissions are below national ambient air quality standards set by the National Environment Protection (Ambient Air Quality) Measure.

The modelling of sulphur oxides (SO_x) emissions provided by Starcrest LLC, predicted 104.4 tonnes annually being reduced to 13.1 tonnes annually following the introduction of the AMSA Low Sulphur Fuel Requirements. This is a reduction of SO_x in the order of 87%.

By comparison, the modelled benefits of either scrubbers or shore power are incrementally low, providing an additional benefit in the order of 11% for scrubbers and no benefit for shore power, as demonstrated in Figure 1.

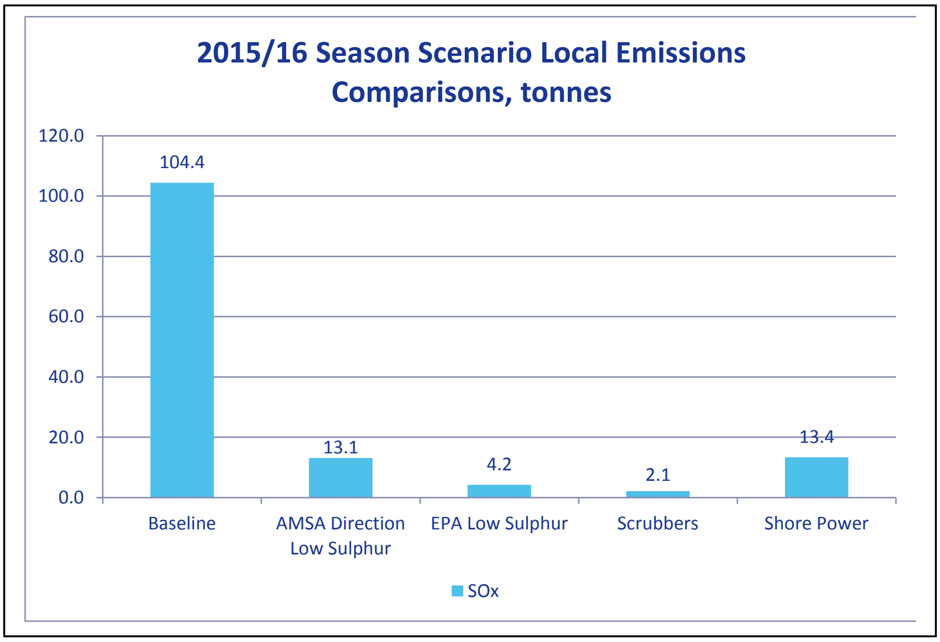

Figure 1 – Modelling of Sulphur Oxides (SO_x)

Further to the modelling provided by Starcrest LLC, comparison has also been made with air quality data collected from the Port Authority's air monitoring station located in Grafton St, Balmain. This data also indicates that SO_2 concentrations were much lower on cruise ship days in October 2015 compared to September 2015, which is attributed to the introduction of the EPA Low Sulphur Fuel Requirements on 1 October 2015.

The modelling of particulate matter ($PM_{2.5}$) emissions provided by Starcrest LLC, predicted 10.2 tonnes annually being reduced to 3.2 tonnes annually following the introduction of the AMSA Low Sulphur Fuel Requirements. This is a reduction of $PM_{2.5}$ in the order of 69%.

By comparison, the modelled benefits of either scrubbers or shore power are incrementally low, providing an additional benefit in the order of 10%, as demonstrated in Figure 2.

Further to the modelling provided by Starcrest LLC, comparison has also been made with air quality data collected from the Port Authority's air monitoring station located in Grafton St, Balmain. This data indicates that $PM_{2.5}$ concentrations were not discernibly different between ship and non-ship days at WBCT, and all levels are below the national ambient air standards.

In summary, the monitoring indicates that the Low Sulphur Fuel Requirements have had a similar effect to that predicted by the modelling prepared by Starcrest in terms of SO_2. However, the reduction in $PM_{2.5}$ could not be observed and appears to be dominated by sources other than cruise ships at WBCT.

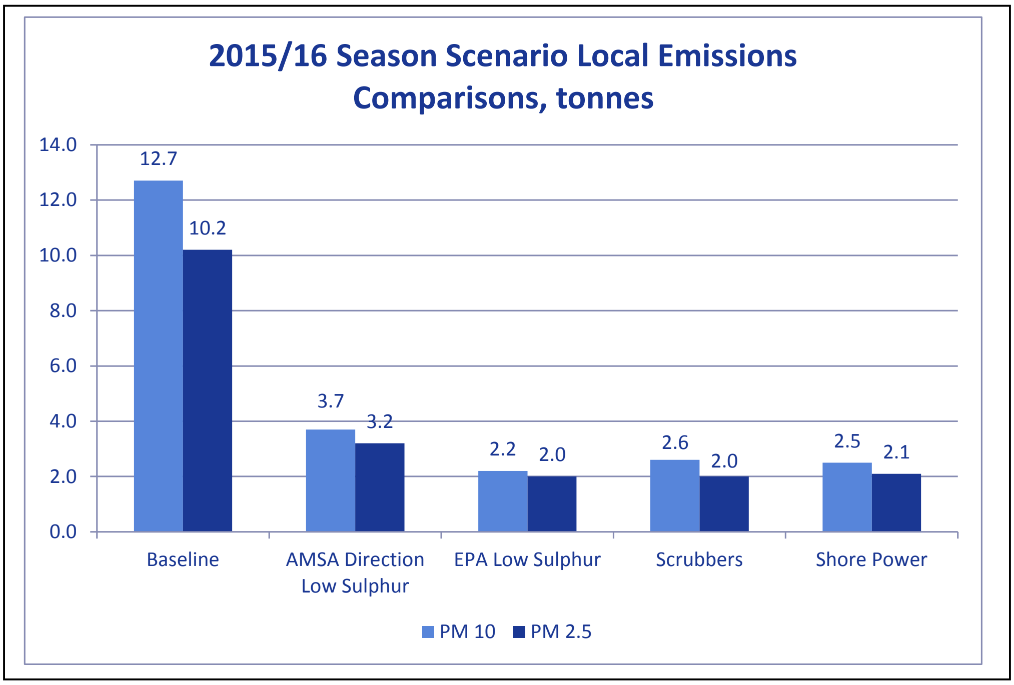

Figure 2 – Modelling of Particulate Matter

KEY FINDING

- **Based on modelling including the land-side power grid emissions (as well as the emissions at the source at WBCT), shore power would increase the overall air emissions of SO_x and carbon dioxide (CO_2) within Sydney's Greater Metropolitan Region (unless clean energy was sourced for the supply of electricity).**

Shore power does not reduce emissions to zero. Shore power shifts localised ship-generated auxiliary engine emissions to regional land-side power grid generated emissions. As such, further to modelling emissions that only considered emissions from the ship, Starcrest LLC also undertook modelling which included the emissions from the land-side power grid. In addition a ship's diesel fuelled boilers, which are normally off due to the use of waste heat recovery, would need to be switched on while connected to shore power.

It should be noted that the land-side power grid emissions could be offset through contracting only for the supply of clean energy. However this would require further exploration to ensure there is not significant additional supply cost.

The modelling of regional emissions (including both ship plus power station emissions) of sulphur oxides (SO_X) provided by Starcrest LLC, predicted 13.1 tonnes annually based on the AMSA Low Sulphur Fuel Requirements, which would increase to 26.6 tonnes annually following the introduction of shore power. This would be an increase to the existing overall air emissions of SO_x within Sydney's GMR by approximately 100%, as demonstrated in Figure 3.

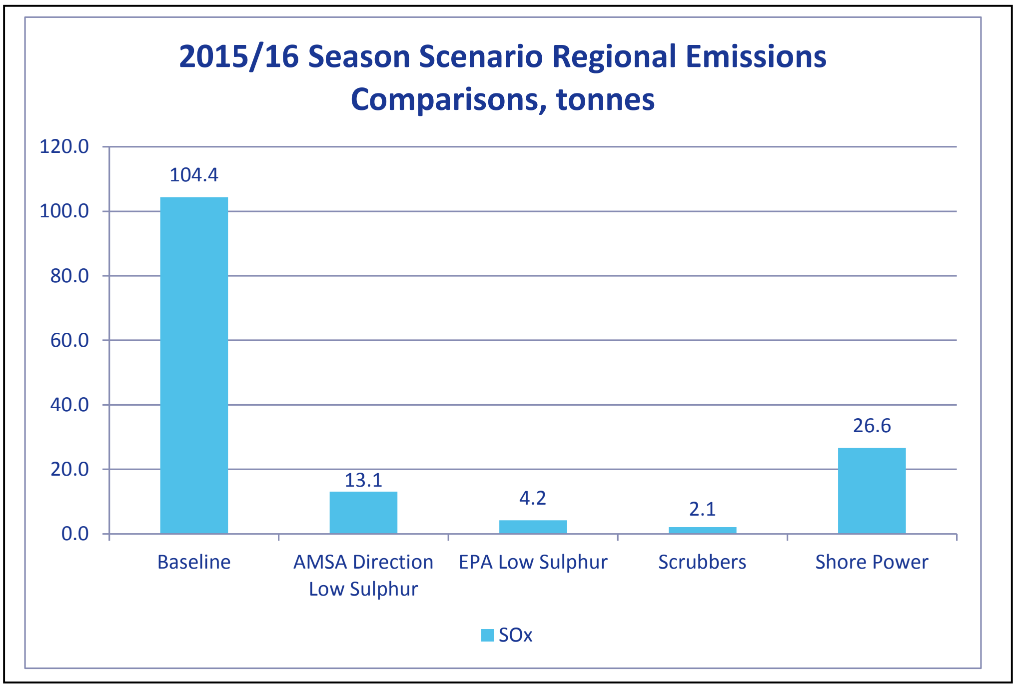

Figure 3 – Modelling of Sulphur Oxides (SO_x) including both Ship and Power Station Emissions

Similarly, the modelling of regional emissions (including both ship plus power station emissions) of CO_2 emissions provided by Starcrest LLC, predicted 5880 tonnes annually based on the AMSA Low Sulphur Fuel Requirements, which would increase to 6869 tonnes annually following the introduction of shore power. This would be an increase to the overall air emissions of CO_2 within Sydney's GMR of 16%, as demonstrated in Figure 4.

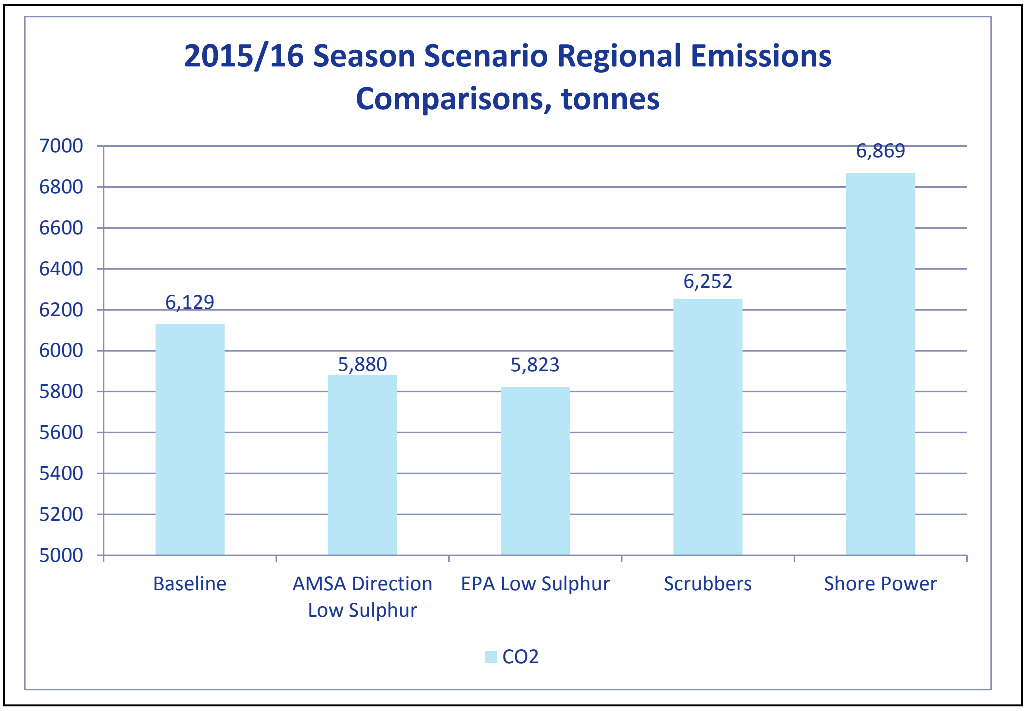

Figure 4 – Modelling of Carbon Dioxide (CO_2) including both Ship and Power Station Emissions

The modelled case above calculated the CO_2 emissions based on the current state of electricity generation in NSW, incorporating 21% renewables and 12% gas. Implementation of shore power at WBCT could require the use of renewable energy sources to reduce CO_2 contributions. One option would be to specify use of grid connected wind power (or other renewable source) in any long-term electricity agreement for the additional 8–12MW of power required for shore power at WBCT. This may not necessarily lead to any additional costs as alternative energy sources such as wind power can be similar to base load power prices and provision for 8MW is available, given the relatively small level power of electricity generation involved. It is understood a similar condition specifying use of grid connected wind power was a requirement for the operation of the Kurnell desalination plant.

KEY FINDING

Port Authority modelling of air emission at WBCT demonstrates shore power will provide a reduction in the emission of nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which are not significantly reduced by Low Sulphur Fuel Requirements. However, as existing levels emitted from cruise ships are at relatively low levels when compared to relevant national ambient air standards, the introduction of shore power will not provide a significant emissions reduction benefit.

Shore power will provide a reduction in the emission of NO_x and VOCs, however, existing levels are both below relevant national ambient air standards and comparable to or below reported levels of exposure at other locations in NSW.

The modelled case for both NO_x and volatile organic compounds VOCs has formed the basis of emissions benefits analysis. This has been supported by a program of monitoring of actual levels of a suite of VOCs, which indicated that most compounds were not at a concentration that was detectable.

Nitrogen Oxides (NO_x)

Key findings of the analysis of NO_x emissions include:

- Shore power would reduce baseline NO_x emissions by 64% (NO_x emissions are not addressed significantly by the Low Sulphur Fuel Requirements).
- Based on dispersion modelling of NO_2 emissions at WBCT, the exposure at the nearest sensitive receivers in Balmain comply with the National Environment Protection (Ambient Air Quality) Measure.
- Current levels of NO_x in the former Leichhardt LGA (including emissions from WBCT) are comparable to other areas such as Canada Bay, North Sydney and the former Marrickville LGA and are significantly lower than areas such as Parramatta, Sydney City and Botany Bay.

The modelling of nitrogen oxides (NO_x) emissions provided by Starcrest LLC, predicted 117.2 tonnes annually being reduced to 44.0 tonnes annually following the introduction of shore power. This is a reduction of NO_x in the order of 63%, as demonstrated in Figure 5.

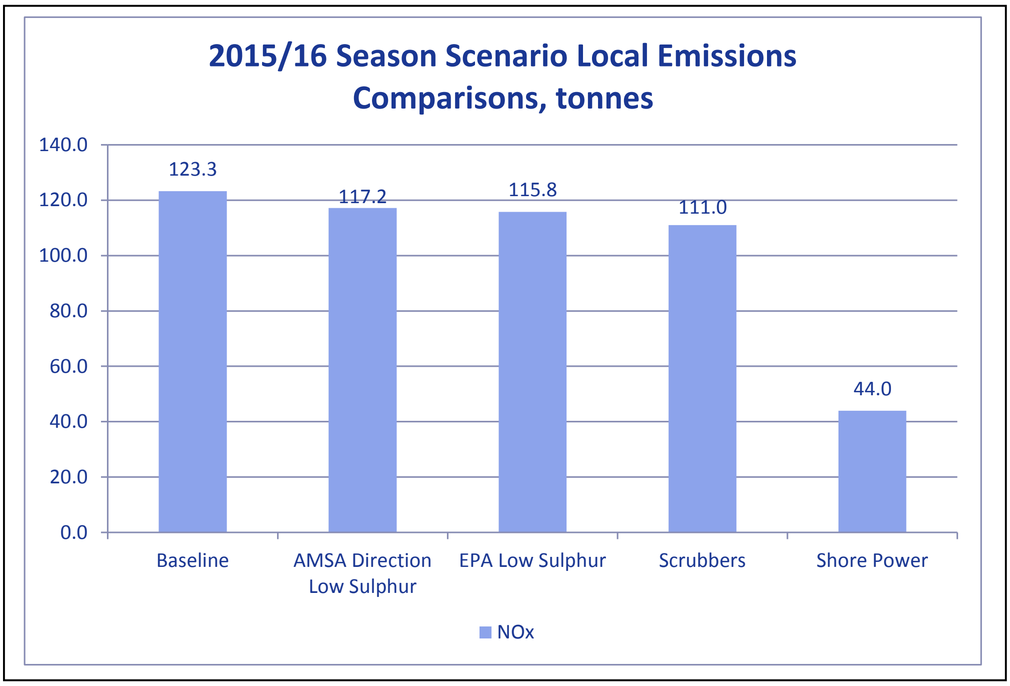

Figure 5 – Modelling of Nitrogen Oxides (NO_x)

Further investigation was undertaken by air quality consultants, Jacobs Pty Limited, with particular reference to NO_x emissions and abatement. This report is included in Appendix 3.

The potential reductions in NO_X offered by shore power are more substantial than for SO_2 and $PM_{10}/PM_{2.5}$ when the reductions in emissions for these pollutants already achieved by the requirement for cruise ships to use low sulphur fuel while berthed at WBCT is taken into consideration. Hence the further assessment undertaken by Jacobs was focussed on NO_x emissions to provide information in regard to existing levels and the potential relative benefits of shore power compared to other alternatives, which have not already been addressed via the introduction of low sulphur fuel.

Considering industrial and diffuse sources of NO_x across the Sydney GMR the former Leichhardt LGA (which includes Balmain) is exposed to similar levels of NO_x emission to other inner Sydney LGAs. Leichhardt generally has lower NO_x emissions than outer Sydney LGAs e.g. Parramatta, Blacktown and Liverpool, as demonstrated in Figure 6.

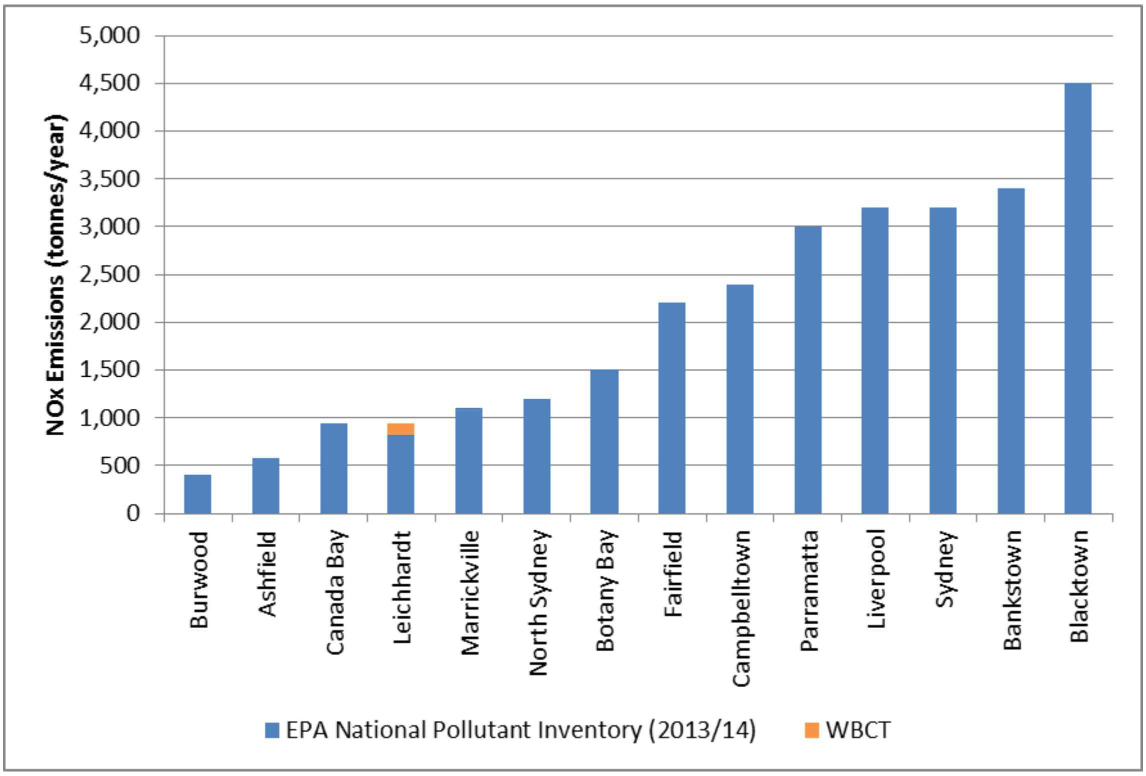

Figure 6 – Modelling of Nitrogen Oxides (NO_x) in various LGAs

Volatile Organic Compounds (VOCs)

Key findings of the analysis of VOC emissions include:

- Shore power would reduce baseline VOC emissions by 62% (VOC emissions are not addressed significantly by the Low Sulphur Fuel Requirements).
- Based on dispersion modelling of VOC emissions at WBCT, the exposure at the nearest sensitive receivers in Balmain complies with the National Environment Protection (Ambient Air Quality) Measure.
- Current levels of VOCs have been monitored by Port Authority adjacent to WBCT and the results indicate that VOCs are significantly lower than the relevant EPA criteria with most compounds being undetectable.
- Those that were detected were approximately 100 times lower to 900 times lower than the relevant criteria.

The modelling of volatile organic compound (VOC) emissions provided by Starcrest LLC, predicted 3.5 tonnes annually being reduced to 1.3 tonnes annually following the introduction of shore power. This is a reduction of VOCs in the order of 62%, as demonstrated in Figure 7.

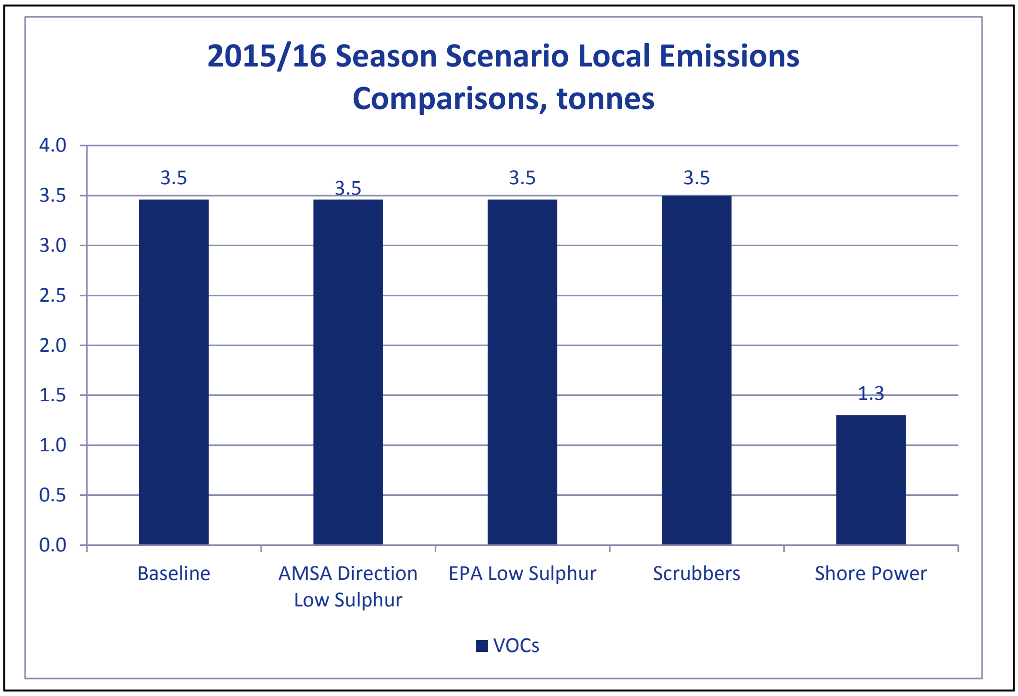

Figure 7 – Modelling of Volatile Organic Compounds (VOCs)

Port Authority has conducted VOC monitoring (including a suite of over 80 compounds) in the vicinity of WBCT. Monitoring was undertaken for a 24-hour period on a day when a cruise ship was berthed at WBCT and the source of the ship's exhaust was downwind of the monitoring equipment, i.e. southerly winds.

The results for the suite of the VOCs analysed indicate that most of the measured compounds were below the limit of detection (LOD) adjacent to WBCT, which was 0.5 parts per billion (ppb) for the majority of compounds. The LOD represents the lowest concentration at which a compound can be detected in the air samples.

The results, where they were detectable, ranged from approximately one hundred times lower to 900 times lower than the relevant criteria as shown in Table 2. The concentrations for the four VOC compounds that were detectable but for which there are no national or state criteria were similarly extremely low.

Table 2 – Summary of VOC Monitoring Results adjacent to WBCT

Compound	Measured Concentration (ppb)	NEPM (2011) Criteria[1] (ppb)	EPA (2005) Criteria[2, 3] (ppb)
Chloromethane	0.8	n/a	900
Toluene	0.8	1000	90
Acetone	12.5	n/a	9200
Isooctane	0.7	n/a	n/a
Isopropyl alcohol	4.4	n/a	n/a
2-Butanone	0.7	n/a	n/a
Propene	1.1	n/a	n/a

Note 1 National Environment Protection (Air Toxics) Measure. National Environment Protection Council, Canberra, ACT, 2011
Note 2 Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales, EPA 2005
Note 3 Note that these are one hour average assessment criteria

Odour

KEY FINDING

- **Shore power would provide a reduction in odorous emissions. However, the reduction in odour may not be discernible as there would still be odours related to diesel boilers (which are used on ships to generate heat when a ship is using shore power).**

When a cruise ship is connected to and operating on shore power, the waste heat from the diesel-electric generators drops (because the engines are off), requiring the use of the auxiliary boilers to be increased to service hot water and steam needs for the ship. There would still be odour generated from exhaust emissions from the boiler use.

Port Authority has not conducted a specific study into the emission benefits in relation to odour as this is a highly subjective concern.

3.2 Noise Benefits

KEY FINDING

- **Shore power provides a reduction to noise emissions. However, it is not the most cost-effective solution for reducing audible noise, as the points below demonstrate:**

  - Shore power would reduce audible noise in the order of 9–10 decibels, which provides similar benefit to other noise reduction measures, but is comparatively expensive. For example, the installation of a noise barrier would provide a similar reduction in audible noise at a significantly lower cost (estimated at $2.5–4 million);

  - Shore power capable vessels at WBCT represent 25% of vessel calls, reducing to 8% of overnight stays (based on 2015–16 visits) and noise benefits will vary from ship to ship.

  - Port Authority has completed investigations as outlined in the Noise Mitigation Strategy for WBCT and conducted community consultation as documented in a Response to Submissions Report prepared for the consideration of the NSW Department of Planning and Environment. The investigation comprised evaluation of all identified noise mitigation options including operational and engineering changes to ships and treatment of receivers. The Final Noise Mitigation Strategy is to be considered by the Department following their review of the Response to Submissions Report;

  - The key elements of the Noise Mitigation Strategy are a Noise Restriction Policy, Noise Attenuation Program, and Noise Logging. Port Authority has allocated $5.3 million to fund the implementation of the Strategy.

Port Authority has not identified any cruise port in its investigations that has initiated the provision of shore power for the primary purpose of mitigating noise.

There is currently no global initiative to encourage reduction of audible noise emissions from ships. The focus of the majority of noise investigation is typically related to underwater noise from ships.

Noise emissions from cruise ships berthed at WBCT, on occasion, exceed the criteria set in the project approval based on audible noise.

As part of the Noise Mitigation Strategy which has been prepared and submitted to the NSW Department of Planning and Environment, shore power was identified as a potential noise mitigation option and has been investigated in terms of the potential noise benefits it may provide. The alternative solutions evaluated are:

(i) source reduction (operational and engineering changes to ships);

(ii) treatment of receivers; and

(iii) noise barriers.

A consultant report has been prepared by SLR Consulting Pty Ltd to review the potential reduction in noise levels when cruise ships berthed at WBCT are operated using shore based power. The noise assessment has been based on the vessel *Pacific Jewel,* being typical of the vessels that berth at the WBCT. A 3D computer noise model of the vessel has been used which includes significant noise sources, as based on nearfield measurements and manufacturer's data. The model has then been used to predict noise levels under normal operation and shore based power. The report is included in Appendix 4.

Noise levels from the *Pacific Jewel* have been previously measured to be 50 dBA, at the nearest receivers to the WBCT in Grafton Street. The provision of shore based power will enable the ship's generators to be shut down and the associated mechanical ventilation systems either switched off or reduced in capacity. The resultant noise level at the nearest receiver is predicted to decrease by an estimated 9–10 dBA.

However, as part of the Noise Mitigation Strategy investigations, SLR Consulting have advised that other options, such noise attenuation, could provide similar reductions to the level of audible noise. It is noted that residences to the north-west and north-east would receive limited benefit. A noise barrier is estimated to cost in the order of $2.5–$4 million.

Although not referenced by the project approval, as well as audible noise, SLR Consulting considers that shore power may provide additional benefits associated with reducing low frequency noise.

It should be noted that shore power capable vessels at WBCT currently represent 25% of vessel calls, reducing to 8% of overnight stays (based on 2015-16 visits) and noise benefits will vary from ship to ship.

Prediction of noise reduction due to shore power is difficult to model, but Port Authority considers that overall ship noise levels would be reduced. However, it would be difficult to recommend shore power solely on this basis.

Port Authority has completed investigations as outlined in the Noise Mitigation Strategy for WBCT and conducted community consultation as documented in a Response to Submissions Report prepared for the consideration of the NSW Department of Planning and Environment. The investigation comprised evaluation of all identified noise mitigation options including operational and engineering changes to ships and treatment of receivers. The Final Noise Mitigation Strategy is to be considered by the Department following their review of the Response to Submissions Report.

The key elements of the Noise Mitigation Strategy are as follows:

- Noise Attenuation Program: noise attenuation comprising of physical treatments to homes to a defined area of residences where noise modelling indicates that average noise levels reach or exceed 55 decibels at night ('attenuation eligibility threshold').
- Noise Restriction Policy: a new policy restricting on-deck music and public announcements not related to safety and restrictions for ships which cause further exceedances of the attenuation eligibility threshold. Non-compliant ships will be given an initial warning to make improvements; a second non-compliance will result in overnight relocation of the ship; and a third non-compliance will result in future bookings not being allowed.
- Noise Logging: continuous real-time logging to monitor noise levels and guide ongoing noise management, including ensuring compliance with the Noise Restriction Policy.

Port Authority has allocated $5.3 million to fund the implementation of the Strategy.

4 Cost Effectiveness Analysis and Alternative Options

KEY FINDING

- **Air emission strategies can be assessed using a number of different methods. This assessment employed a methodology used by the California Air Resources Board (CARB). Using the CARB benchmark, shore power at the WBCT was not found to be a cost effective solution:**

- Projects with values less than the benchmark (i.e. a ratio less than 1.0) are considered cost-effective, while those higher than the benchmark are not considered cost-effective. The investigation found that the use of shore power would range from 2 to over 7 times higher than the benchmark and would therefore not be considered cost-effective;

- Additionally, using the NSW EPA method for assessing the health impacts, the benefit of implementing shore power is approximately 11 to 24 times less than the cost of the project over the 10 year implementation period;

- Shore power is only one possible emission control solution. Other options include:

  - engine and boiler technologies
  - after treatment technologies
  - alternatively fuelled on-board energy generation
  - alternatively generated power stem
  - operational efficiency improvements.

The emissions benefits analysis was prepared by Starcrest LLC based on the estimated annual emission reductions for PM_{10} and NO_x (with a weighting of 20:1 for PM_{10}:NO_x to account for the health effects of particulates).

The analysis tested the cost effectiveness of adopting shore power with 0.1% sulphur fuel as shown in Tables 3 and 4 based on the low and high costs estimates for the implementation of shore power at WBCT, over both a 10-year and a 20-year evaluation period. The approach adopted to assess these results uses CARB's guideline benchmark value of $21,522/tonne to determine whether the project is cost effective.

Table 3 – Shore Power Cost Effectiveness Analysis – 10-year Evaluation Period

	Cost Effectiveness $/weighted tonne (ratio to benchmark)		**CARB Cost Effectiveness Benchmark**
Scenario	**Based on Low Cost Estimate**	**Based on High Cost Estimate**	
Shore power with 0.1% sulphur fuel – Local emissions	$48,924/tonne (2.3 times higher)	$125,126/tonne (5.8 times higher)	$21,522/tonne
Shore power with 0.1% sulphur fuel – GMR emissions	$59,565/tonne (2.8 times higher)	$152,343/tonne (7.1 times higher)	$21,522/tonne

Projects with values less than the benchmark (i.e. a ratio less than 1.0) are considered cost effective, while those higher than the benchmark are not considered cost effective. Based on this analysis, using a 10-year evaluation period the use of shore power would range from 2.3 to over 7 times higher than the benchmark and would therefore not be considered cost effective.

Table 4 – Shore Power Cost Effectiveness Analysis – 20-year Evaluation Period

	Cost Effectiveness $/weighted tonne (ratio to benchmark)		**CARB Cost Effectiveness Benchmark**
Scenario	**Based on Low Cost Estimate**	**Based on High Cost Estimate**	
Shore power with 0.1% sulphur fuel – Local emissions	$42,878/tonne (2.0 times higher)	$132,258/tonne (6.1 times higher)	$21,522/tonne
Shore power with 0.1% sulphur fuel – GMR emissions	$52,204/tonne (2.4 times higher)	$161,025/tonne (7.5 times higher)	$21,522/tonne

Using a 20-year evaluation period the use of shore power would range from 2.0 to over 7 times higher than the benchmark and would not be considered cost effective. The consultant's findings are included in Appendix 2.

Whilst a detailed analysis of monetised health benefits of shore power has not been undertaken as part of this study, for information purposes, an alternative cost-effectiveness analysis looking at the value of the related health impacts of changes in particulate matter emissions, typically expressed as "damage-cost"[15] per tonne of $PM_{2.5}$ emissions has also been undertaken.

NSW EPA has provided advice on valuing health impacts resulting from changes in particulate emissions[16]. For the Sydney urban area, the particulate matter related health benefits are estimated by EPA at $280,000/tonne $PM_{2.5}$ (based on 2011 value, which is estimated to be $311,000 in 2017), which is the benefit of reducing $PM_{2.5}$ emissions by one tonne.

The net reduction in $PM_{2.5}$ emissions estimated from the implementation of shore power, as provided by Starcrest LLC, is 1.06 tonnes per year, which would equate to a damage-cost, or conversely a cost saving due to improved health, of $330,000 per year.

When shore power is considered over a 10-year implementation period, the cost savings due to health benefits would range from $3.3 million, while the implementation of shore power including operational costs and retrofitting ships would range from $37–80 million over the same period. This evaluation indicates the benefit of implementing shore power is approximately 11–24 times less than the cost of the project over the 10-year implementation period.

For a 20-year implementation period, the cost savings would be $6.6 million, while the implementation costs would be $53–124 million over the same period. This is approximately 8–19 times less that the cost of the project over a 20-year implementation period.

Alternative Options

There are a number of options when looking at alternative emission reduction strategies for cruise ships at-berth, which can be grouped into the following categories:

(i) Engine and boiler technologies

(ii) After treatment technologies

(iii) Alternatively fuelled on-board energy generation

(iv) Alternatively generated power systems

(v) Operational efficiency improvements.

All options provide reductions to specific pollutants, and the selection of an appropriate option is dependent on the specific pollutant required to be reduced.

[15] Damage costs are a simple way to value changes in air pollution. They estimate the cost to society of a change in emissions of different pollutants

[16] Methodology for valuing the health impacts of changes in particle emissions, EPA, February 2013

Appendix 1 – Feasibility Study (Navari)

FINAL REPORT FOR SHORE POWER FEASIBILITY STUDY FOR WHITE BAY CRUISE TERMINAL

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17 to 19	17/12/2015 to 5/2/2016	Updated costings, general comments from Ports	DC	DC	MP	CF	
20,21,22	11/3/2016	Added Glossary, updated abbreviations, updated general comments	DC	DC	MP	CF	
23	11/3/2016	Minor corrections	DC	DC	MP	CF	
24	4/5/2016	Final Report	DC	DC	MP	CF	
Current revision		**24**					

CONTENTS

Acronyms and abbreviations

ABB	Supplier of Power and Automation Technologies
ASP3	Approved Level 3 Service Provider
Ausgrid	Sydney Electricity Distribution Company
EMP	Environmental Management Plan
FAT	Factory Acceptance Testing
GPO	General Power Outlet
HV	High Voltage
Hz	Hertz (frequency of AC current)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	Issue for Construction
IGBT	Insulated gate bipolar transistors
ISO	International Organisation for Standardisation
ITP	Inspection and Test plans
kV	Kilovolts
kWh	Kilowatt hours
LV	Low Voltage
MW	Megawatts
MVA	Mega Volt Amps
OEM	Original Equipment Manufacturer
O&M	Operations and Maintenance
OPT	Overseas Passenger Terminal
QA	Quality Assurance
SAT	Site Acceptance Testing
STS	Subtransmission Substation
UGOH	Underground to Overhead conductor connection
V	Voltage
WBCT	White Bay Cruise Terminal
WHS	Work Health and Safety

Glossary

ASP3

An accredited ASP3 is a competency based accreditation given by Ausgrid to an individual or company to design distribution and sub-transmission network assets.

High Voltage

Power supplied above 1000 Volts for alternating current.

Low Voltage

Power Supplied between 50 to 1000 Volts for alternating current.

Hertz

Hertz is the number of cycles that a voltage waveform repeats itself per second.

Megawatts

Megawatts is the measure of real consumption of power One megawatt (MW) = 1,000 kilowatts = 1,000 watts.

Sub Transmission substation

A subtransmission substation connects to a distribution substation. Typical connection voltages are between 66 kV to 132 kV

UGOH

The transition point from underground cable to overhead conductor.

Frequency Converter

Converts 50 Hz, Australian standard frequency, to 60 Hz required by the ships.

Executive Summary

The proposal to provide a shore power facility at the Port Authority's White Bay Cruise Terminal (WBCT) is technically feasible, although significant capital investment would be required.

A shore power rating of 15MVA, based on a maximum load of 12MW, at the WBCT site would be adequate for at least the next 20 years, and is within the current size available by shore power equipment manufacturers.

Ausgrid, in its report dated 20 November 2015, identified five key cable route options that would fit in with its overall network plans. Based on this information, the current optimum connection point would be the 33kV connection from Rozelle Subtransmission Substation (STS). A 33kV underground cable is required to be run from Rozelle STS to the WBCT site, an estimated length of 2.5km. Ausgrid has advised that a portion of the existing cable could be used; however, for this report, it is assumed that a new cable would be installed. The impact of the part use of the existing cable on the cost would be considered during the detail design phase.

Attached designs are as follows:

- A recommended cable route from Ausgrid's Rozelle STS to the WBCT site is included in the report.
- A suggested site layout of the WBCT site including the shore power equipment and a manual cable connection system from the site to a docked ship has been prepared.
- A gantt chart showing the overall program for the implementation of the shore power facility at the WBCT site is included as an attachment and indicates a program of approximately 2 years to complete the project. The total budget cost for the complete shore power facility at WBCT, including all of the design and investigation costs, 33kV cable, equipment, cable system is \$23m–\$28m. This does not include the costs to retrofit vessels to accept the power.

A breakdown of this cost is shown in the table below (Table 4 in report):

Summary of Overall Costs for the shore power facility at the WBCT

Item	**Budget Cost**
Ausgrid Design Costs	\$200,000
Design of 33kV cable connection from the Ausgrid nominated connection point to the WBCT Site	\$400,000
Cost for the supply and installation of the 33kV cable	\$5m–7m
Cost for the design and installation of the shore power equipment at Site	\$10–12m
Cost for the design and installation of the Ship to Shore Cable Connection System	\$2–3m
Project Management	\$2.9m

Project Contingency	10%
Total Budget cost to design and install the shore power facility	\$23m–\$28m
Annual Operating and Maintenance Costs	\$3.5m

Note 1: The above budget cost is based on an exchange rate of 1 Australian dollar being equivalent to 72 cents US dollars.

Note 2: The budget cost does not include the estimated cost to carry out the ship side shore power system retrofit which would be in the range \$700,000 to \$2.7 million.

The conclusions and recommendations are based on the assumptions listed in Section 2 of this report, and are summarised below:

- Ausgrid is able to provide a location in its Network for the nominated load of 15MVA for the WBCT site. A single 33kV supply from Ausgrid's nominated point of supply, Rozelle STS, to the WBCT site is adequate for this project. Dual supplies are not considered necessary for the type of load to be supplied. A consequence of choosing a single 33kV supply is that it cannot be used to supply standard commercial loads. Supply to commercial loads using this single supply would not be acceptable to Ausgrid.
- A 33kV cable route has been nominated in the report. Although this has to be confirmed by future studies, the route is not expected to cause any operational or loss of performance issues of equipment in Ausgrid's Network.
- All ships that are scheduled to visit the WBCT site operate at a system frequency of 60Hz. The Australian Network operates at a frequency of 50Hz. This anomaly is addressed in all supplies of shore power equipment by the supply off frequency converters (50–60Hz) as part of their design.
- The WBCT site can accommodate the proposed layout of shore power equipment. The proposed layout of this equipment is shown in Attachment B of this report.
- It is recommended to use prefabricated modular buildings for the shore-side switchgear and transformers. These are supplied by the shore power equipment manufacturers, and would be in lieu of using the two storey switchroom building currently on site, based on small cost savings offered, and increased site erection times.
- It is recommended that shore power equipment installed at the WBCT be specified to comply with the relevant IEC applicable standards. The relevant standards are listed in this report.

1. Introduction

1.1 Scope of Work

This study has been prepared on behalf of the Port Authority of NSW (Port Authority) and concerns the operation of the White Bay Cruise Terminal (WBCT) in Balmain, Leichhardt local government area, in Sydney. The Port Authority constructed and operates the WBCT on Roberts Road, White Bay. Arising from the operation of the site, noise and air pollution have arisen as sources of concern from local residents.

Cruise ships dock at the WBCT on a regular basis. From the data supplied, a total of 123 ships will dock at the WBCT over a 12 month period, the highest number in any one month being 19 ships, and the lowest being 3. Most ships dock at the WBCT for one day, arriving around 7am and departing around 6pm. Only a minority of ships remain docked at the terminal overnight.

The installation of shore power would require a high voltage (HV) supply from the local electrical distributor, Ausgrid, the installation of a HV cable from Ausgrid's nominated substation to the WBCT site, and the installation of appropriate equipment on the dock to allow connection of the shore power equipment to the docked ship. Shore power equipment has an operating life of 20 years, (as advised by the original equipment manufacturer), so any shore power solution is to be suitably rated to be effective over this period.

This study addresses the key costs involved in the provision of shore power, including Ausgrid's system design costs to allow system studies to be carried out, the cost of the design, supply and installation of the HV cable, and the cost for the installation of the equipment on the site.

1.2 Previous Study by Lend Lease

A report titled *White Bay Shore Power Pre-Feasibility Report* was prepared by Lend Lease in late 2014, on behalf of the Port Authority. The scope of this report was to explore the various options of HV power supply routes and to provide high-level costing estimates for each of these routes.

Two HV options were considered in the Lend Lease study – supply at 11kV and supply at 33kV. A single supply at 11kV has a limit imposed by Ausgrid of 7MW, which is a load of around 9MVA at an assumed power factor of 0.8. For loads exceeding 9MVA, up to the site load nominated by the Port Authority, it is possible to provide this load at 11kV using dual feeders. However, for loads of this magnitude, Ausgrid would usually provide a single 33kV supply point.

Based on the two HV supply options of 11kV and 33kV the Lend Lease report nominated the following possible supply points in the Ausgrid Network (without any reference to Ausgrid):

- 11kV – single supply for 9MVA load – Leichhardt Zone Substation
- 11kV – dual supply for nominated site load – Leichhardt Zone Substation
- 33kV – single supply for nominated site load – Rozelle Subtransmission Substation

Other substations mentioned as possible supply points in the report were Pyrmont and Strathfield Substations, at 33kV, and Camperdown Zone Substation at 11kV.

This report was based on preliminary information that was available to Lend Lease at the time. This was prior to the request to Ausgrid for its *Customer connection advice* document to be released.

The report also stated that further evaluations were recommended in the areas of:

- Ship power requirements during the docking phase
- The willingness of ships to connect to shore power
- What features may be available from the various shore power manufacturers
- Other solutions that may be available
- Ausgrid be engaged to perform a network study and provide the *Customer connection advice* report

1.3 Ausgrid Customer Connection Advice Report

The Ausgrid report dated 20 November 2015 gives a range of connection options as generally technical suitable for integration within its own network development plans for the area. Through this process, Ausgrid identified five key options that are available for further consideration:

1. One new 33kV feeder from Rozelle Subtransmission Substation
2. Reuse a portion of 33kV feeder number 763 from Rozelle Subtransmission Substation
3. Two new 33kV feeders from Rozelle Subtransmission Substation
4. Two new 11kV feeders from new Leichhardt Zone Substation
5. Three new 11kV feeders from new Leichhardt Zone Substation

As detailed in section 4.4, Option 1 above is considered to be the most cost-effective solution.

2. Assumptions

The following assumptions are made in the preparation of this feasibility report:

- A single 33kV cable of suitable capacity will be run from the Rozelle Subtransmission Substation (Rozelle STS) to the WBCT site. This option is the preferred option detailed in the Ausgrid *Customer connection advice* report issued by Ausgrid dated 20 November 2015.
- The 33kV cable route and cable size have been chosen without any prior soil thermal resistivity testing over the nominated route of the cable. This is not expected to have an impact on the cable size subsequently chosen for this project due to the soil conditions in the Sydney Basin; nevertheless it may turn out that this does become an important issue in choosing a suitable cable which may affect the overall cost.
- The study has been completed without any geotechnical studies being carried out. This is particularly applicable to the design and installation of the 33kV cable over the whole of the cable route.
- No soil contamination has been assumed over the cable route proposed.
- Shore power considerations for WBCT have been considered for Berth No. 5 only. Ships docking at Berth No. 4 at the WBCT site have not been considered at this time in this report due to the minimal number of cruise ship visits to Berth No. 4, and the additional cost considerations.
- In Section 3 of the report, data has been presented and analysed for ships expecting to dock at the WBCT site over the coming 12 months. It is assumed that this data and analysis is representative and so applicable for ships docking in future years also.
- The 33kV supply from Ausgrid is proposed as a single supply only. Such a supply is acceptable for the supply to the shore power system proposed at the WBCT site. However, it would not be acceptable for supplying normal commercial loads in the area.
- A power requirement of 15MVA being applicable for shore power to the WBCT site based on this being an adequate maximum size for at least the next 20 years and adequate for the maximum expected load of 12MW.

3. Shore power requirements at WBCT

3.1 Ship Study for White Bay Cruise Terminal

For the ships that have the ability to accept shore power at WBCT, the location of the connection point, and the connection point voltage, is shown below:

Table 1 – Ships that can accept shore power at the WBCT, including the connection point and voltage applicable.

Ship	Shipping Line	Connection Point	Connection Voltage
Europa	Hapag Lloyd Line	Unknown	Unknown
Europa 2	Hapag Lloyd Line	Unknown	Unknown
Amsterdam	Holland America Line	Midships/Starboard	Unknown
Noordam	Holland America Line	Midships/Starboard	Unknown
Dawn Princess	Princess Cruises	Port Side	6.6kV
Diamond Princess	Princess Cruises	Port Side	11kV
Emerald Princess	Princess Cruises	Port Side	6.6kV
Golden Princess	Princess Cruises	Port Side	6.6kV
Sea Princess	Princess Cruises	Port Side	6.6kV
Sun Princess	Princess Cruises	Port Side	6.6kV

Note: At the time of preparation of the report the connection point, and the connection point voltage was unavailable for a few of the ships that currently dock at the WBCT site.

The cost to install equipment on board ships to allow a retrofit of the connection to shore power equipment on the dock varies widely for various reasons. These include:

- The size of the ship and the number of passengers it carries (this varies from 450 to over 3000)
- The age of the ship
- The voltage used on board the ship (this varies from 440V to 11kV)
- The number of ships in the fleet that require the modification
- The physical layout of the ship, including the location of the HV switchboards on board and the ease of carrying out modifications to them

The cost to implement this ability to connect to shore power would be cheaper if installed from new.

Based on currently available information the estimated cost to carry out the ship side shore power system retrofit would be in the range $700,000 to $2.7 million.

3.2 Connection Options

The variations in the location of the connection points for different ships, as shown above, is proposed to be dealt with in the design of the shore power facility at the WBCT Site. For example, in the case of a manual connection from the shore power equipment to the ship, a Plug and Socket arrangement over the length of the dockside of Berth No. 5 is proposed, and is shown in Attachment B to this report.

- The Plug and Socket arrangement would be spaced at around 25m intervals along the length of Berth No. 5.
- A similar arrangement could be implemented for Berth No. 4 in the future if it was considered that a shore power facility should be made available for Berth No. 4.
- Without increasing the output rating of the shore power facility at the WBCT Site, the future installation of the Plug and Socket system on Berth No. 4 would allow the supply to one ship at a time at either berth.
- An alternative design, using an automated cable connection system, could also be implemented at the WBCT site.

3.3 Rating of the shore power Installation

Information on the rating of the shore power installation was discussed with the various shore power manufacturers and confirmed to Ausgrid as part of the request for it to provide a feasibility study into the provision of an acceptable HV supply from a nominated connection point in its network.

The maximum expected load that has been used in this study at the WBCT site is 12MW, which equates to a load of 15MVA at an assumed power factor of 0.8. This is the expected maximum load requirement at the WBCT site over the next 20 years. Although larger and larger cruise ships are being designed that will eventually be put into service, and which may require a larger shore power than the 15MVA nominated above, it will not be possible for these ships to dock at the WBCT terminal. These larger ships would be unable to pass under Sydney Harbour Bridge, and so would have to dock at the Overseas Passenger Terminal (OPT) at Circular Quay.

4. Ausgrid Connection Options for the WBCT Site

4.1 Cable Configuration and Redundancy Considerations

When Ausgrid provide an electrical supply to commercial customers, it does so generally on an 'N + 1' basis. This means that for a load supplied at 33kV, like the WBCT site, two separate 33kV cables would be run to the site and each cable would be rated for the full load. For reliability reasons, the two cables are usually supplied from different Ausgrid transformers in the same substation or from different substations. One cable would supply the whole of the load, and the second cable would act as a back-up. Using this approach Ausgrid can effectively guarantee a reliable supply to all customers. Loss of supply to a customer is then a very rare circumstance and this is confirmed in its operating statistics.

There are some instances, and the supply to the WBCT site for the shore power load is one such instance, where only one 33kV cable is used to supply a load. For such a case, due to the nature of the load, Ausgrid agrees that only one supply need be provided. The reasons why only one 33kV supply is necessary and acceptable for the shore power load are:

- Supply of the shore power supply to the docked ship is not critical as the ship is able to supply its own power. (On loss of the shore power supply, a diesel engine on board is programmed to automatically start, and the starting time would be less than 10 minutes. The ship can tolerate such a loss of supply for 10 minutes.)
- Supply to the ship can be interrupted without endangering people or equipment on board.
- The ship has emergency lighting systems on board that come into operation automatically on loss of normal supply. (This applies to a loss of either the on board supply, or the shore power supply.)

Ausgrid has agreed to the use of a single 33kV supply on the condition that it not be used for any commercial loads in the area. For this type of load an 'N + 1' type supply would be required.

It should be noted that installing a single 33kV feeder, whilst reducing project costs significantly, means that the supply will only be suitable for the use of shore power, and not for other commercial loads that generally require greater levels of redundancy and reliability. Future development and growth in the area of White Bay and Glebe Island can be allowed for by the installation of spare conduits. Installation of additional spare conduits in the cable trench with the 33kV feeder allows for the future installation of a second cable at much reduced cost.

4.2 Customer Connection Advice Report

Ausgrid commenced an initial System Planning investigation in late August 2015 at the request of the Port Authority. Ausgrid advised that, based on its normal internal procedures, the outcome of these studies would be made available in the form of a *Customer connection advice* report. This report was received on 20 November 2015. Arising from the acceptance of the *Customer connection advice* report, a design brief is then prepared.

This process includes a feasibility and technical review, and can take around 26 weeks to complete. At this point Ausgrid prepares a *Design Information for Contestable Works* package from which the ASP3 accredited designer prepares the actual package for the Ausgrid component of the work. This package is then submitted to Ausgrid for review and certification. This can take up to 20 weeks, subject to the extent of contestable work and the completeness of the design submitted.

4.3 Voltage and Frequency Considerations

Based on the nominated shore power load of 15MVA, as noted in Section 4.2 above, Ausgrid has advised that the likely outcome of its initial planning investigations will be that the supply voltage will be set at 33kV. This is because that loads up to 9MVA are traditionally supplied at 11kV by Ausgrid, and loads exceeding 9MVA, up to 30MVA, are supplied at 33kV.

The vast majority of ships in the world operate at a frequency of 60Hz and hence all generators on board generate at this frequency. The Ausgrid system operates at a frequency of 50Hz and so a Frequency Conversion System is required to be installed as part of the shore power system at the WBCT site. This matter is addressed by frequency converters supplied as part of the package by the various shore power manufacturers.

4.4 AusGrid Zone Substation connection options and choice of optimum connection point

During meetings held with Ausgrid in late August 2015 to discuss the planning investigations proposed as part of its study, it was indicated that the likely connection point from its initial network studies would be at Rozelle Subtransmission Substation, and at a voltage of 33kV.

The Ausgrid *Customer connection advice* report has reflected that connecting to the 33kV Rozelle Subtransmission Substation is feasible, and has also included details of 11kV options from the new 11kV Leichhardt Zone Substation. The 33kV connection options to the 33kV Rozelle Subtransmission Substation rely upon the completion of the new 11kV Leichhardt Zone Substation.

The five options provided in the Ausgrid *Customer connection advice* report are summarised in the table below.

Table 2 – Ausgrid supply options currently under consideration

Option	Connection Point	Comments
1	A new single 33kV cable from Rozelle Subtransmission Substation	This is the most likely option as it is the cheapest option at present and technically acceptable.
2	Reuse a portion of the existing 33kV cable	This is possible cheaper option but requires further assessment. Option 1 will be used in the costing evaluations.
3	Dual 33kV cables from Rozelle Subtransmission Substation	The second 33kV cable is to allow for future expansion of loads at the WBCT site. If the Port Authority or Ausgrid consider this is a likely situation, this option should be considered, or alternatively spare conduits should be installed to allow for this upgrade at a later date.

4	Two new 11kV feeders from new Leichhardt Zone Substation	For this option the Ausgrid supply to the WBCT site would be via two 11kV cables. This option is considered to be more expensive than Option 1 due the additional costs associated with supplying two cables rather than one, and the additional distance associated with connecting to the new Leichhardt Zone Substation.
5	Three new 11kV feeders from new Leichhardt substation	Again, for this option the Ausgrid supply to the WBCT site would be via three 11kV cables. Similar comments to option 4 apply.

4.5 Design work required to implement the chosen Connection Option

At the initial meetings with Ausgrid it was pointed out that as part of the process of implementing the shore power project, the following design work would have to be completed and was outside its scope of work:

- HV cable route selection
- Easement considerations, if required, for the HV cable route chosen
- Rating study in relation to the HV connection
- Proposed Site Layout and footprint for shore power equipment.

This work would be carried out in parallel with the design brief that Ausgrid would complete on the acceptance of its recommendations in its *Customer connection advice* report. The designs would be required to be carried out by a registered ASP3 Service Provider. An initial proposed cable route is shown from Rozelle to the site in Attachment A.

Ausgrid also advised that although it would take over the ownership of the HV cable on the completion of its installation and testing, the design work and the subsequent installation of the HV cable to Ausgrid's standard requirements would have to be carried out by others as this was not in its scope of work. The design considerations required by Ausgrid for a 33kV feeder installation are far more extensive than for an 11kV feeder, and would include such items as the proximity to other cables laid along the cable route and hence the potential effect on its rating.

As part of the process of installing the 33kV HV cable to meet Ausgrid's requirements, the three-phase cable is required to be run in a trench of approved design and dimensions and in a 200mm diameter conduit. Ausgrid also require a second spare conduit to be installed in the trench during the installation of the cable for future possible use. If the Port Authority were to consider the expansion of the shore power facility at the WBCT site to also provide shore power to Berth No .4 it is suggested that three spare conduits be laid in the trench at the time of installation of the cable. In this way a second 33kV cable could be very easily run to the site. The laying of the three spare conduits in lieu of the one is only a marginal increase in the cost.

The route length of the 33kV cable from Rozelle Subtransmission Substation to the WBCT Site is approximately 2.5km.

Irrespective of the route ultimately selected, the crossing of Victoria Road is required at some point along the road. Using Victoria Road as part of the route is not recommended due to the high traffic flows and hence the extreme difficulty in carrying out trenching operations to run the cable. The crossing of the road could be achieved by utilising existing buried Ausgrid conduits under Victoria Road or by carrying out under boring of the road at a suitable location along the route. Such a procedure is a very common practice and is relatively inexpensive.

Ausgrid imposes very strict requirements concerning the burying of power cables in the proximity of its existing power cables. These include easement restrictions and investigations into the possible impact on the ratings of these cables. This applies more so for 33kV cables compared to 11kV cables. To alleviate these restrictions and possible impacts, it is proposed that the new 33kV power cable be run in 'quiet backstreets' wherever possible in the final choice of the cable route.

Using the 'quiet backstreet' approach, a possible route is shown in Attachment A. This proposed cable route does not add any appreciable length to the overall route length of 2.5km.

4.6 Existing 11kV Cables on Site and Building housing HV and LV Switchgear

During the site visit to the WBCT, it was observed from electrical diagrams in the HV switchroom that there were two 11kV Ausgrid feeders currently connected to the site. These feeders provided substantial power to switchboards located in two buildings on the site. The majority of loads fed from these switchboards are now decommissioned. The remaining loads are at 415V and include area lighting, site GPOs, an office and a canteen.

In discussions with Ausgrid concerning the possible use of these two 11kV feeders for the supply to the shore power equipment at the WBCT site, it was advised that these feeders were now feeding commercial and residential loads in the area adjacent to the WBCT site and hence were not currently available to be used for the shore power facility.

As part of this study, consideration was given to using one of these two storey buildings by removing or replacing the current HV and LV switchboards associated with the No. 4 Berth White Bay Substation, and using the two storeys to house the shore power equipment, including the incoming power transformer, the frequency conversion equipment, and the outgoing power transformer. The outgoing transformer provides the power to the docked ship. Both the HV and LV switchboards are currently still in service.

One issue that would need to be addressed if this building was used to house the shore power equipment is the supply of the 415V loads mentioned above. An alternative source of supply would be required, possibly from a small 415V wall-mounted distribution board located at a suitable place in the building. The cost of this alternate route is negligible and covered within the tolerance of the estimate.

Other issues that may arise in the consideration of utilising this building include its suitability for the installation of the proposed equipment, and the possible presence of any hazardous materials.

In discussions with the various manufacturers of shore power equipment, Siemens, Schneider and ABB, the possible use of the building to house the shore power equipment was raised. They responded saying that while it was possible, it would not produce any substantial saving in the overall cost, and could impact on the erection program. The equipment is generally housed in prefabricated modular buildings. Such modular buildings are generally cheap and allow the components to be installed in its works and pre-commissioned prior to delivery to site. As a result, the installation and commissioning time on site is vastly reduced.

For the reasons stated above it is recommended that the prefabricated modular buildings supplied by the shore power equipment manufacturers be used in lieu of the No. 4 Berth White Bay Substation Building.

5. Shore power equipment suppliers and ratings available

A total of five companies are currently able to supply shore power equipment. They are:

- Siemens
- Schneider
- ABB
- Cochran Marine
- Thycon

These companies were contacted as part of the feasibility study and relevant information received from them is included below.

5.1 Siemens

Siemens has supplied shore power projects for commercial ports between 1MVA and 12MVA. For naval projects, shore power equipment has been supplied at ratings up to 50MVA. Siemens frequency converter is stage built, meaning it can effectively operate at smaller power requirements if necessary

Siemens has an automatic cable connection system for connection of the shore power equipment to the docked ship. Such a connection is more expensive, at $3m, compared to $2m for a manual system. The automated system has only been constructed at one port, Hamburg in Germany, and only two shipping lines currently have the necessary equipment installed on board to make use of this automated connection system.

5.2 Schneider

Schneider has supplied shore power projects for a number of commercial ports, mostly throughout Europe with some penetration into the USA and Asia markets. The typical load is between 1MVA and 15MVA. For the 15MVA system, two shore boxes are required – Shore box A (12m x 3.5m) and shore box B (12m x 2.5m) giving a 102m^2 total footprint. The shore boxes contain the various components of the shore power equipment, including the frequency converters and power transformers. Schneider provide a plug and socket system.

5.3 ABB

ABB has supplied equipment for several shore power projects worldwide, up to 8MVA to date. The most notable ports are Rotterdam, Goteborg, Ystad and Jurong. It is noted these facilities are not for cruise ships. ABB has 3 sizes of frequency converters, 4MVA (2.3 x 6.0 x 0.8m), 6MVA and 24MVA. ABB use a plug and socket systems but can supply a cable connection System through a third party propriety system.

5.4 Cochran Marine

Cochran Marine is the industry leader in the provision of cruise based shore power systems. It is based in the USA and generally supplies standard units of size 20MVA. Cochran Marine has indicated that it could supply custom sized frequency converters if required.

5.5 Thycon

Thycon has constructed frequency converter units for the Australian Navy. It has shore power equipment of size 3MVA to 15MVA. A 15MVA unit would require four frequency converters, with a footprint of 3.2m x 1.9m; four input transformers, with a footprint of 3.2m x 1.9m; and four output transformers, with a footprint of 2.9m x 1.6m.

5.6 International Standards applicable to shore power facilities

5.6.1 General

IEC/IEEE standards have been prepared concerning the standardisation of requirements for the various components that make up shore power equipment. The standards have been implemented by the various manufacturers of shore power equipment. The list of the applicable standards is shown below.

5.6.2 Shore Connection

- IEC/ISO/IEEE 80005-1 Ed. 1: Utility connections in port – Part 1: High Voltage Shore Connection (HVSC) Systems – General requirements
- IEC/ISO/IEEE 80005-3 Ed. 3: Utility connections in port – Part 3: Low Voltage Shore Connection (LVSC) Systems – General requirements
- IEC 62613-1: High-voltage plugs, sockets-outlets and ship couplers for high voltage shore connection systems (HVSC-systems) – Part 1: Dimensional compatibility and interchangeability requirements for accessories to be used by various types of ship
- IEC 62613-2: High-voltage plugs, socket-outlets and ship couplers for high-voltage shore connection systems (HVSC-systems) – Part 2: Dimensional compatibility and interchangeability requirements for accessories to be used by various types of ship

5.6.3 Low Voltage switchgear

- IEC 61439-1: Low voltage equipment – Part 1: General rules
- IEC 61439-2: Low voltage equipment – Part 2: Power equipment
- IEC 60947-2: Low voltage equipment – Part 2: Circuit breakers
- IEC 60947-3: Low voltage equipment – Part 3: Switches, disconnectors, combined disconnector fuses

5.6.4 Frequency convertors

- IEC 60146-1-1, 2009, General rules – Part 1-1 : Basic specifications

5.6.5 Prefabricated substation

- IEC 62271-202 High-voltage / low-voltage prefabricated substations

6. Budget Costs for provision of shore power at WBCT

6.1 Costs of Ausgrid design

Ausgrid has advised that a budget cost for all of its design work and approvals is of the order of $200,000. This includes the following work:

- Customer connection advice
- Preparation of a design brief
- Design review and certification of the ASP3 report
- Final approvals
- Construction supervision of the 33kV cable installation

6.2 Costs for the design, supply and installation of the 33kV HV Cable

Design considerations and approvals by ASP 3 designer – $400,000.
The work carried out by the ASP3 designer includes the following work:

- Design coordination with Ausgrid
- Cable rating studies and reporting
- Field investigations and survey
- Earthing considerations
- Thermal resistivity testing of the soil every 200m
- Geotechnical considerations
- Protection study
- Environmental study

Supply and Installation of the 33kV cable – $5m–$7m
The work carried out in completing the design and installation of the 33kV cable is as follows:

- Detailed requirements for cable types, use of cable types, joints, terminations, link boxes, pits and vaults
- Sheath bonding and earthing
- Use of sheath voltage limiters
- Requirements for the installation of route markers
- Design details of joint bays, pits and vault
- The design details of the Underground to Overhead (UGOH) poles if required
- Trenching details including details of the depth of cables, major road crossings, location and design of joints, and separation from other services and cables
- Bedding and backfill requirement
- Conduits and conduit accessories

Cost for the design and installation of the shore power equipment at Site – $10m–12m
The cost covers the following design and installation items:

- Overall design of the system to suit the WBCT site.
- 33kV incoming switchboard for termination and switching of the Ausgrid 33kV cable.

- 33kV/11kV or 33/6.6kV 15MVA transformer as input to the frequency conversion equipment.
- 3 Phase static frequency conversion equipment, including IGBTs (insulated-gate bipolar transistors), voltage regulator and control system.
- Variable voltage 15MVA output transformer for connection to the docked ship's power supply.

Cost for the design and installation of the ship to shore Cable Connection System – \$2–\$3m.
The cost covers the following design and installation items:

- Design and installation of the cable connection system from the output transformer on the shore power equipment to the ship, and to suit the WBCT site.
- Auto or manual connection from the shore to the docked ship, depending on the design and supplier chosen.

6.3 Operation and Maintenance (O&M) costs

The estimated O&M annual costs are based on the following:

Table 3: Estimated O&M annual costs

Item	Budget Cost	Comments
Electricity Costs	$2,990,000	• The cost is based on all 123 vessels per year berthing at WBCT using shore power • The vessels are spending 13 hours in port • The vessels draw a load of 15MVA • Connected to the shore power supply for 9 hours An assumed cost of $0.177/kWh (typical large user rate), and a Network Connection Service Charge of $43/day (applicable to a customer connected directly to a HV Ausgrid Substation)
Total Labour cost to operate and maintain the equipment	$400,000	• Full time operating staff of 2 people, and supervision • Includes total labour costs i.e. overheads, statutory provisions
Estimated consumables costs	$110,000	• Includes replacement of mechanical and electrical equipment due to wear and component failure
Total	$3,500,000/annum	

6.4 Cost for installation of shore power equipment at the WBCT site

The budget cost for the supply and installation of the shore power equipment, obtained from Siemens, ABB and Schneider, is $10–$12m.

This does not include the Cable Connection System from the shore power equipment to the dock. The budget cost for the Cable Connection System, depending on the complexity of the system chosen, is $2–$3m.

The table below summarises the total cost for the complete shore power facility for the landside component.

Table 4 – Summary of Overall Costs for the shore power facility at the WBCT

Item	Budget Cost	Comments
Ausgrid Design Costs	$200,000	
Design of 33kV cable connection from the Ausgrid nominated connection point to the WBCT Site	$400,000	At this stage no upgrading of Rozelle Substation appears to be necessary for this project.
Cost for the supply and installation of the 33kV cable	$5m–7m	Installation to Ausgrid Network Standard NS168. The Cost covers the following design and installation items. • Supply of 2.5–3.5 km of underground rated 33kV cable, dependant on route selection.
Cost for the design and installation of the shore power equipment at Site	$10–$12m	Budget prices from Siemens, ABB and Schneider.
Cost for the design and installation of the ship to shore Cable Connection System	$2–$3m	Budget prices from Siemens and Schneider.
Project Management	$2.9m	Preparation of specification, contract award and project management.
Project contingency	10%	Typical for a project of this nature.
Total Budget cost[1]	$23m– $28m	Suggest a +30%/–10% margin (refer note 2 below).

Note 1: The above budget cost is based on an exchange rate of 1 Australian Dollar being equivalent to 72 cents US Dollar.

Note 2: The +30/–10 margin suggested above is based on the following:

(a) The amount of $200,000 quoted by Ausgrid has been made on the basis that no modifications to Rozelle Substation will be required.

(b) The amount of $400,000 for the design of the cable connection from the Ausgrid connection point to the site by the ASP 3 designer is based on normal expected soil conditions and the expected absence of other buried infrastructure in the vicinity of the proposed cable route. Although not anticipated, any such anomalies could have a significant impact on the design cost.

(c) The cost for the supply of the 33kV cable is known with a relatively high degree of accuracy but any unusual soil conditions, particularly requiring excavation in rock would substantially increase the installation cost.

(d) The cost for the design and installation of the shore power equipment quoted by the various suppliers was on the basis that the quote was not accurate or binding. They all quoted similar figures for the shore power equipment, and for the Cable Connection System, but it was on the understanding that they had not even visited the site and had not carried out any detailed studies into the system they would be offering to suit the WBCT site.

7. Project Risk

The major risks to the project are outlined in table 5 below

Table 5 Risk Matrix

ID	Hazard	Risk - including Consequence(s)	Possible Cause(s)	Organisation Affected	Control Measures
1 Scope					
1.01	Major scope changes	Delay overall project and increase of cost	Change of requirements	Construction company, Ausgrid, Port Authority	Well-defined scope, appropriate contracting strategy, qualified owner's engineer
2 Schedule					
2.01	Unforeseen construction delays	Delay overall project	Equipment delivery delays, latent conditions	Construction Company, Port Authority	Allow float in program, site survey, environmental assessment
2.02	Ausgrid connection delays	Delay overall project	Connection availability	Construction Company, Port Authority	Allow float in program, project manage Ausgrid
2.03	Delay in completion of Ausgrid new Leichhardt Zone Substation	Delay overall project	Construction delay	Construction Company, Port Authority	Allow float in program, project manage Ausgrid
3 Budget					
3.01	Overspend budget	Not enough capital to complete project	Scope change, site delays	Port Authority	Allow for contingency, well defined scope, good site management by owner's engineer
3.02	Unforeseen construction delays	Delay overall project	Equipment delivery delays, latent conditions	Construction Company, Port Authority	Allow float in program, site survey, environmental assessment
3.03	Ausgrid connection delays	Delay overall project	Connection availability	Construction Company, Port Authority	Allow float in program, project manage Ausgrid

4 Design					
4.01	Design does not capture all the requirements	The final product does not satisfy requirements	Miscommunication between supplier and client	Supplier, Port Authority	Design Plan, Inspection and test Plans (ITPs), design manager, design reviews on regular basis i.e. 0%, 25%, Issued for Construction (IFC) stage, upfront design workshop with stakeholders
5 Construction					
5.01	Not built according to specification	Plant does not meet intended purpose	Incorrect version of design documents, not following procedure, lack of site QA, inexperienced staff	Construction company, Port Authority	Correct design and construct procedures followed, use experienced site staff
6 Quality					
6.01	Poor design, poor construction, poor manufacture of components	Delay construction, equipment not operating correctly	Manufacturer error	Construction company, Port Authority	Use of approved erection procedures, FAT, design reviews, ITPs, approved sub-contractors
7 Operate and Maintain					
7.01	WBCT Shore to Ship power system equipment failure or mal operation	Downtime in operation of Shore to Ship power system	Fault in components, operator error, lack of maintenance, lack of expertise	Port Authority, Cruise line	FAT and SAT witnessed, locally sourced components as much as possible, operation and maintenance procedures, training by OEM contractor, spare strategy, maintenance plans
8 Safety					
8.01	High Voltage Power cables	Operator harmed during connecting shore power to cruise ship	Not implementing WHS plan, lack of training and procedures	Port Authority	All operators are adequately instructed and trained
8.02	Moving Components	Operator harmed during connecting	Not implementing WHS plan, lack of	Port Authority	All operators are adequately instructed and trained

		shore power to cruise ship	training and procedures		
8.03	Construction	LTI and harm to construction staff	Not implementing WHS plan, lack of training and procedures	Port Authority, construction company	Implementation of approved WHS plan by Contractor
9 Environmental					
9.01	Construction waste, noise pollution, air borne pollution, site water runoff	Harm to environment	Not following environmental management policy	Natural Environment , Local population	Implementation of approved Environmental Management Plan(EMP)

8. Program for Implementation of shore power System at WBCT

A gantt chart has been included as Attachment C in this report which shows the total time required to design, install and commission the whole of the shore power facility. It includes the following entries:

- Ausgrid Studies
- Design from Ausgrid connection point to WBCT Site by the ASP3 designer
- Supply and Installation of the 33kV cable – estimated time of 14 weeks from Olex Cables
- Design, supply and installation of shore power equipment, including the Cable Connection System – estimated at 52 weeks

9. Overseas Passenger Terminal in Sydney

The other location in Sydney Harbour where cruise ships dock regularly is the Overseas Passenger Terminal (OPT), located at Circular Quay. Due to its location in relation to Sydney Harbour Bridge, much larger cruise ships are able to dock compared to those that are able to dock at the WBCT. In future, as ship sizes increase, more and more ships will be required to dock at the OPT in lieu of the WBCT due to their inability to pass under the Harbour Bridge.

The OPT has a number of major differences compared to the WBCT, which makes it more difficult to install shore power. These are:

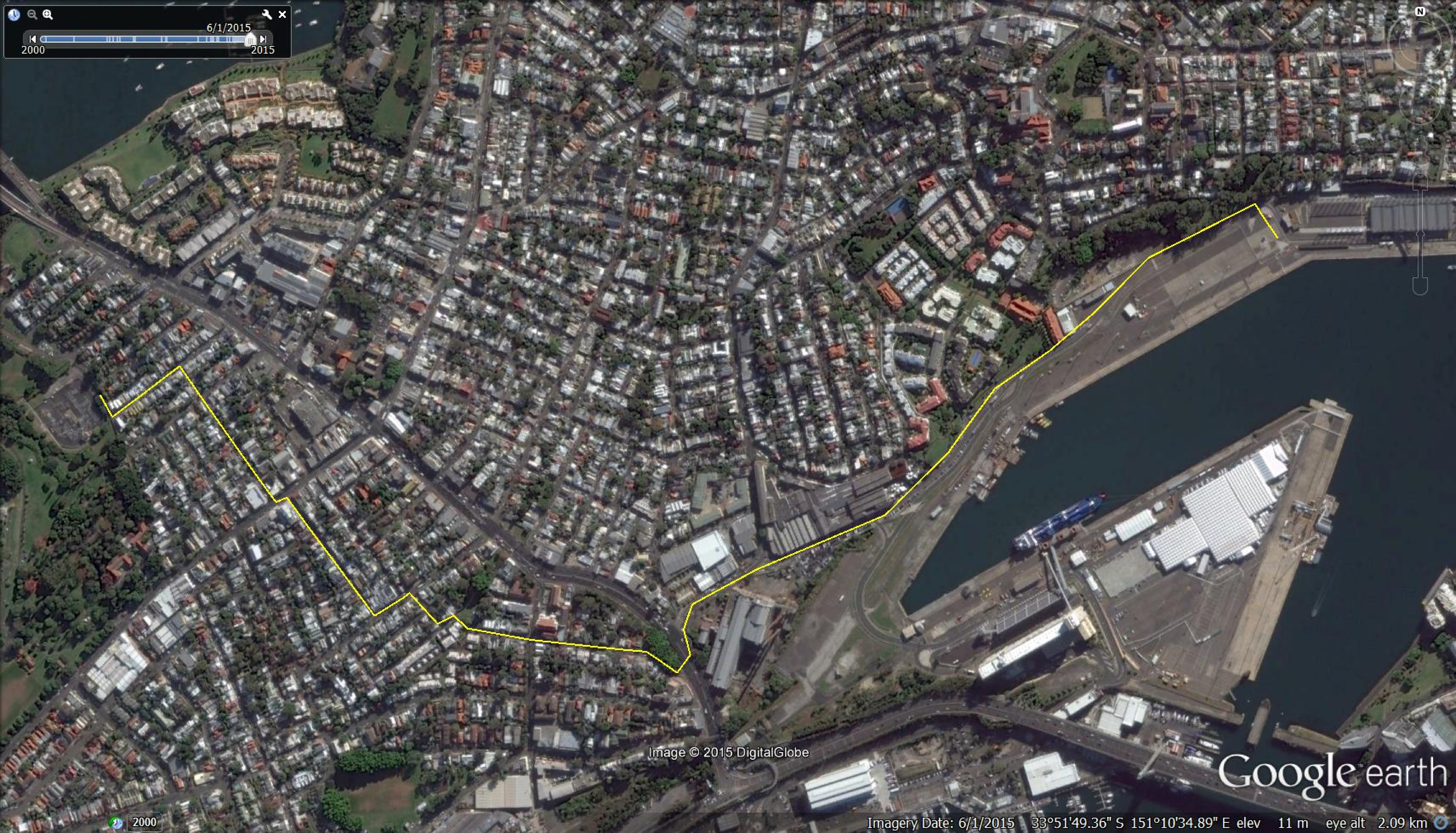
- The OPT has a number of commercial interests on the site, such as restaurants as well as public open space. This currently would limit the amount of space that could be made available to accommodate the shore power system.
- The OPT serves much larger cruise ships and could therefore potentially require a larger shore power System than that of the WBCT site.
- The OPT will be more difficult to be supplied with the required power from Ausgrid due to its location in the CBD of Sydney. Loads in the CBD are currently very high.

No further data has been collected concerning the OPT site and hence the present study is limited to the comments made above.

10. Reference List

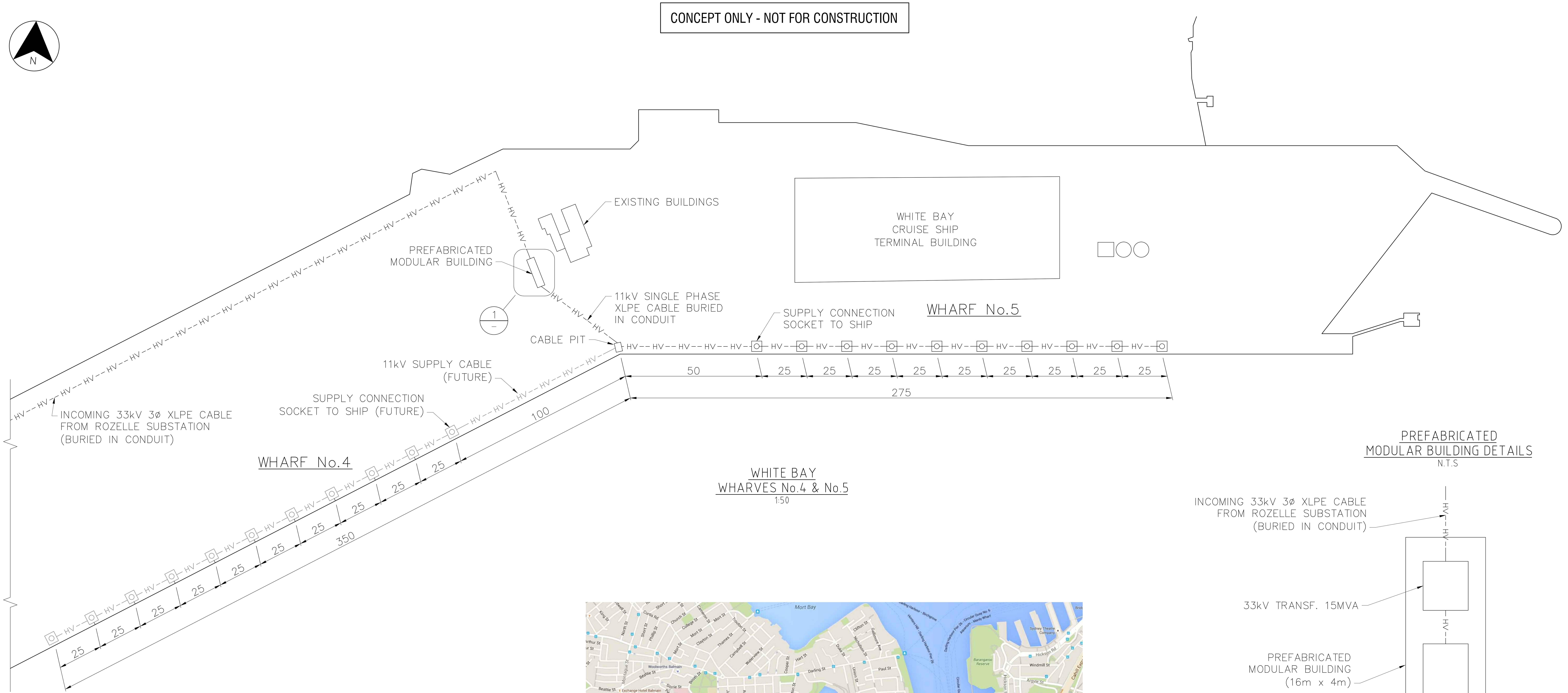
- White Bay Shore Power Pre-Feasibility Report by Lend Lease circa late 2014
- Ausgrid Customer connection advice report
- IEC/ISO/IEEE 80005-1 Ed. 1: Utility connections in port – Part 1: High Voltage Shore Connection (HVSC) Systems – General requirements
- IEC/ISO/IEEE 80005-3 Ed. 3: Utility connections in port – Part 3: Low Voltage Shore Connection (LVSC) Systems – General requirements
- IEC 62613-1: High-voltage plugs, sockets-outlets and ship couplers for high voltage shore connection systems (HVSC-systems) – Part 1: Dimensional compatibility and interchangeability requirements for accessories to be used by various types of ship
- IEC 62613-2: High-voltage plugs, socket-outlets and ship couplers for high-voltage shore connection systems (HVSC-systems) – Part 2: Dimensional compatibility and interchangeability requirements for accessories to be used by various types of ship
- IEC 61439-1: Low voltage equipment – Part 1: General rules
- IEC 61439-2: Low voltage equipment – Part 2: Power equipment
- IEC 60947-2: Low voltage equipment – Part 2: Circuit breakers
- IEC 60947-3: Low voltage equipment – Part 3: Switches, disconnectors, combined disconnector fuses
- IEC 60146-1-1, 2009, General rules – Part 1-1 : Basic specifications
- IEC 62271-202 High-voltage / low-voltage prefabricated substations

Attachment A: Google Earth map of possible 33kV cable route from Rozelle Subtransmission Substation to the WBCT site


6/1/2015
2000
2015
Image © 2015 DigitalGlobe
Google earth
2000
Imagery Date: 6/1/2015 33°51'49.36" S 151°10'34.89" E elev 11 m eye alt 2.09 km

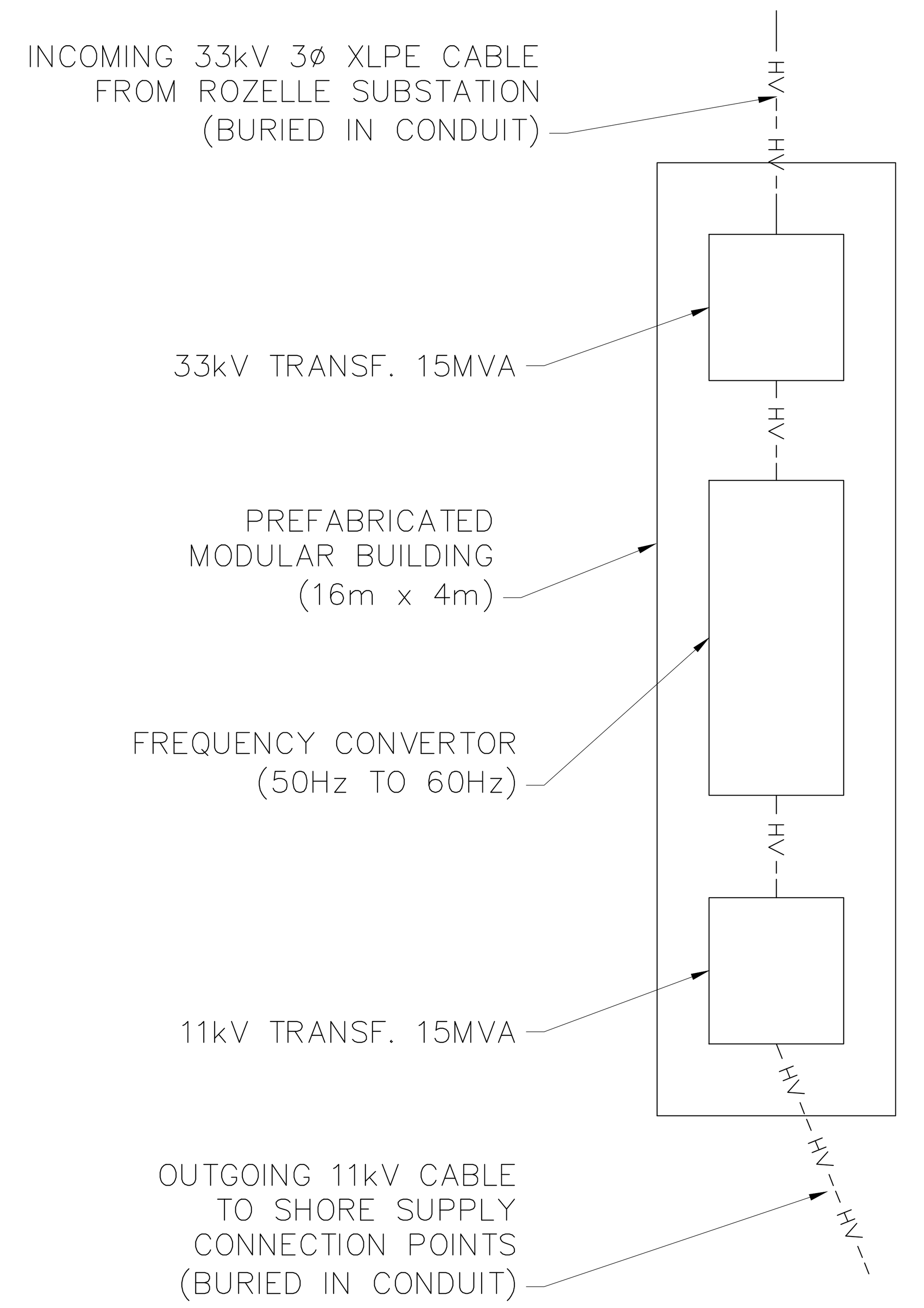
Attachment B: Proposed location of the shore power equipment at the WBCT Site, including the connections from the equipment to the dockside plug and socket connectors

CONCEPT ONLY - NOT FOR CONSTRUCTION

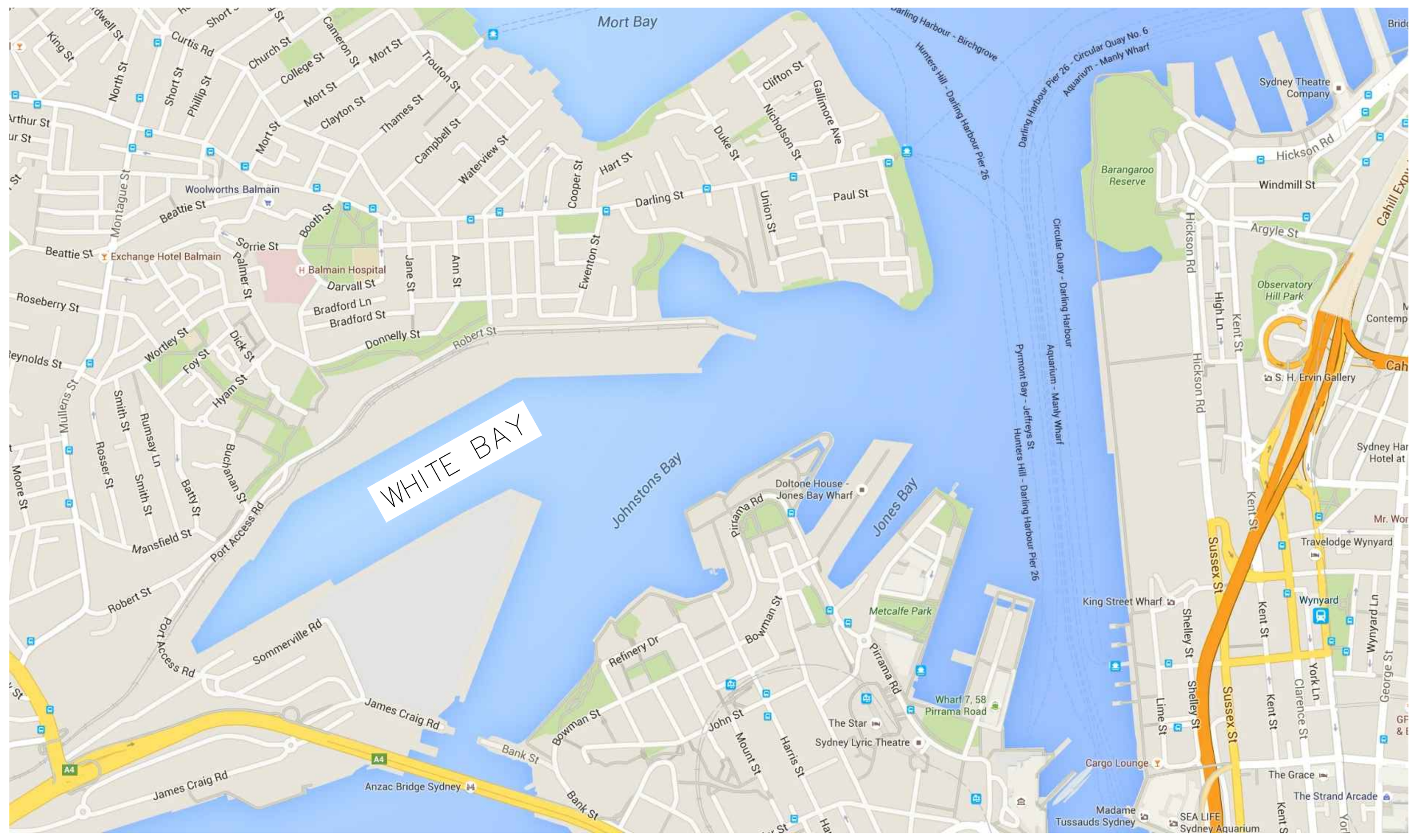


WHITE BAY
WHARVES No.4 & No.5
1:50

PREFABRICATED
MODULAR BUILDING DETAILS
N.T.S



DETAIL 1
SCALE N.T.S



KEY PLAN
WHITE BAY WHARVES No.4 & No.5
N.T.S

REV	BY	DATE	DESCRIPTION	APPD.
A	DC	30-09-15	ISSUED FOR CONCEPT DESIGN REVIEW	CF

A1 Original | Co-ordinate System: MGA Zone 56 | Height Datum: A.H.D. | Scale: AS SHOWN

DeskSite No. 1815962 Rev 5

0 10 50 100
METRES SCALE 1 TO 50 (ON A1 SHEET)

navari
Advisory, Design and Project Management

CLIENT

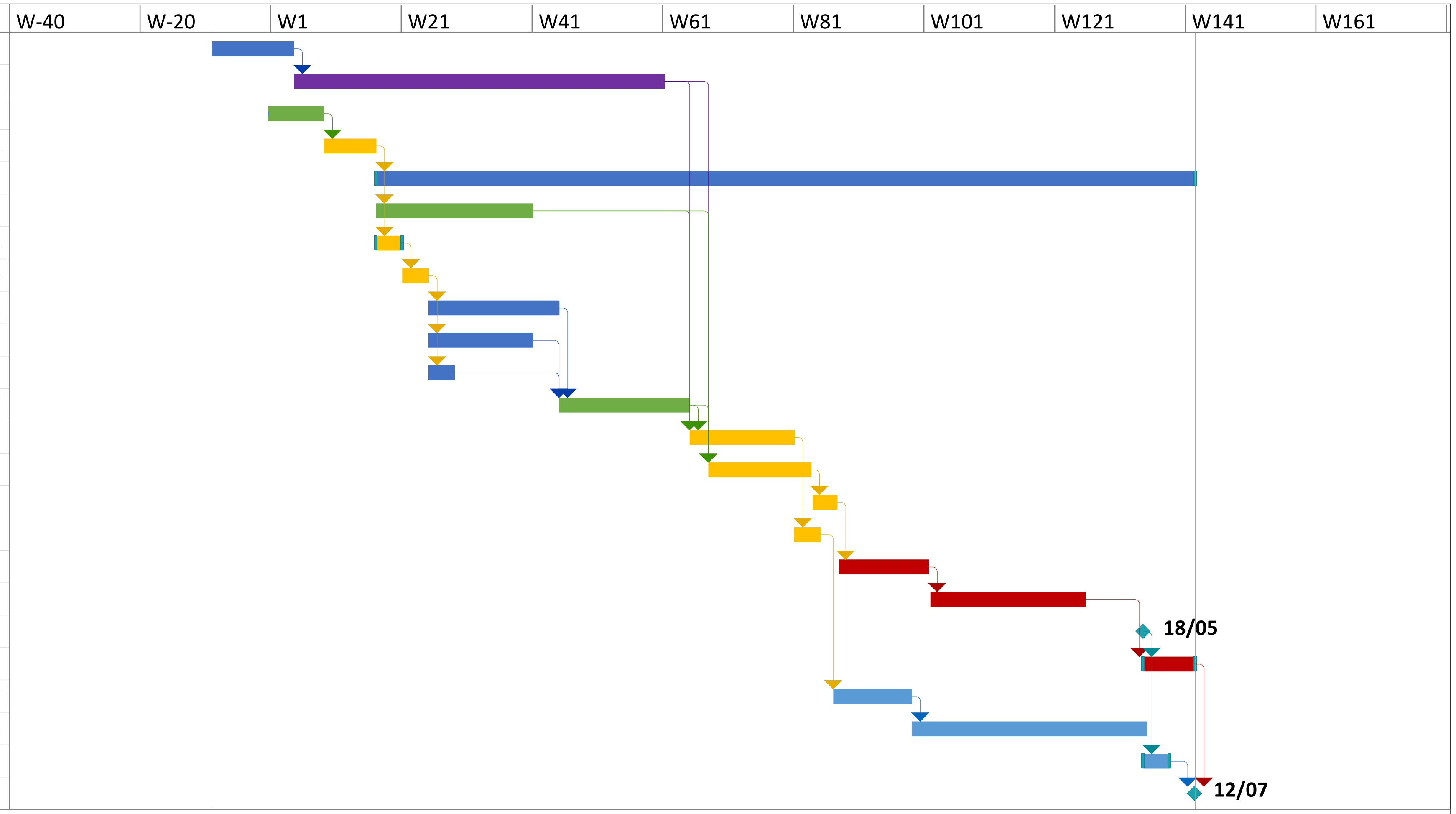
DRAWN	GLENN JOHNSON	DATE	30-09-15
DESIGNED	NIKITA SLINKO	DATE	30-09-15
DRG CHECK	MARC PHILIP	DATE	01-10-15
DESIGN CHECK	DON CUNNINGHAM	DATE	01-10-15
APPROVED	CON FELTRIN	DATE	01-10-15

WHITE BAY
SHORE POWER FACILITY
WHARVES No.4 & No.5
PROPOSED SITE LAYOUT

FILE No.
STATUS: PROPOSAL
SHEET: 1 OF 1 A1
DRG No. WHITE_BAY_PROPOSAL_A A
CAD FILE No.

Attachment C: Gantt chart of overall program

ID	Task Name	Duration	Start	Finish
1	Navari Feasibility Study Report	64 days	Mon 24/08/15	Thu 19/11/15
2	Ministerial Approval	14.15 mor	Fri 20/11/15	Tue 20/12/16
3	Customer Connection Report by Ausgrid	2.1 mons	Fri 23/10/15	Mon 21/12/15
4	Port Authority to choose most viable option	8 wks	Tue 22/12/15	Mon 15/02/16
5	Project Management	31.4 mons	Tue 16/02/16	Thu 12/07/18
6	Design Brief by Ausgrid	6 mons	Tue 16/02/16	Mon 1/08/16
7	Call for tender of ASP3 by Port Authority	1 mon	Tue 16/02/16	Mon 14/03/16
8	ASP3 Selection by Port Authority	4 wks	Tue 15/03/16	Mon 11/04/16
9	Ratings Study for sub-trans work by ASP3	5 mons	Tue 12/04/16	Mon 29/08/16
10	Council Approvals and Environmental Study by ASP3	4 mons	Tue 12/04/16	Mon 1/08/16
11	Thermal Resistivity Work by ASP3	1 mon	Tue 12/04/16	Mon 9/05/16
12	ASP3 Design approved by Ausgrid	5 mons	Tue 30/08/16	Mon 16/01/17
13	Call for tender for Shore Power work	4 mons	Tue 17/01/17	Mon 8/05/17
14	Call for tender for HV cable work	4 mons	Mon 6/02/17	Fri 26/05/17
15	Award contract for supply and installation of HV cable	1 mon	Mon 29/05/17	Fri 23/06/17
16	Award contract for supply and installation of Shore Equip	1 mon	Tue 9/05/17	Mon 5/06/17
17	Supply and delivery of HV Cable	14 wks	Mon 26/06/17	Fri 29/09/17
18	HV cable Installation and Verification to Ausgrid Requiren	6 mons	Mon 2/10/17	Fri 16/03/18
19	Rozelle Substation Ready for Connection	0 days	Fri 18/05/18	Fri 18/05/18
20	HV Connection to Rozelle Substation	2 mons	Fri 18/05/18	Thu 12/07/18
21	Shore Power Design by Equipment Supplier	3 mons	Tue 20/06/17	Mon 11/09/17
22	Shore Power Delivery, Installation	9 mons	Tue 12/09/17	Mon 21/05/18
23	Shore power Verification	1 mon	Fri 18/05/18	Thu 14/06/18
24	Project Completion	0 days	Thu 12/07/18	Thu 12/07/18



Project: WBCT Shore to Ship
Date: Thu 19/11/15

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	Manual Progress
Summary	Inactive Task	Duration-only	Finish-only	

Appendix 2 – Shore Power Analysis – Costs and Benefits Study (Starcrest)

WHITE BAY CRUISE TERMINAL SHORE POWER ANALYSIS

PORT AUTHORITY
OF NEW SOUTH WALES

Final Report

Prepared by:

STARCREST CONSULTING GROUP, LLC
ENVIRONMENTAL MANAGEMENT • AIR QUALITY • CLIMATE • SUSTAINABILITY

April 2017

White Bay Cruise Terminal Shore Power Analysis

Final Report

Prepared for:

PORT AUTHORITY
OF NEW SOUTH WALES

March 2016
(Updated April 2017)

Prepared by:

STARCREST CONSULTING GROUP, LLC
ENVIRONMENTAL MANAGEMENT
AIR QUALITY • CLIMATE • SUSTAINABILITY

Established 1997

Please note that there may be minor inconsistencies, due to rounding, associated with emission estimates, percent contribution, and other calculated numbers between the various sections, tables, and figures of this report. All estimates are calculated using more digits than presented in the various sections.

Contents

List of Tables

List of Figures

Executive Summary

The Port Authority of New South Wales (Port Authority) commissioned Starcrest Consulting Group, LLC (Starcrest) to analyse the potential emissions benefits and cost-effectiveness of shore power at White Bay Cruise Terminal (WBCT), along with four other scenarios. This study is part of a larger set of work the Port Authority is engaged in to fully analyse the feasibility of shore power as an emissions control strategy. The at-berth scenarios include:

- A baseline scenario prior to the implementation of any Australian fuel sulphur regulations (S1)
- The implementation of the (now inoperative) NSW 2015 Cruise Ship Regulation assuming low sulphur fuels are switched prior to arriving at-berth (S2)
- The implementation of the Australian Maritime Safety Authority (AMSA) Direction under subsection 246(1)(b) of the Navigation Act 2012 assuming fuels are switch after arriving at-berth (S2a)
- The implementation of an alternative compliant system using exhaust gas cleaning systems (EGCS) with a higher sulphur fuel (S3)
- The implementation of EGCS with two compliant fuels, (S4)
- The implementation of shore power in a similar manner as the California Air Resources Board's (CARB) program in California (S5) using the same fuels as S2

The analysis included comparing scenarios S2 through S5 with S1 to determine the relative incremental or additional emissions benefits of S5 provide beyond the AMSA Direction, from both a local and regional perspective. The emissions analysis was based on the Port Authority's 2015/16 cruise schedule and included local emissions from WBCT, whilst the regional analysis also incorporated the electricity generation emissions based on the 2008 EPA emissions inventory for NSW which were adjusted to an updated 2015 electrical generation portfolio based on available published literature. For the shore power cost-effectiveness calculations, information from the Port Authority's shore power feasibility and costing study and other sources were utilised.

For context, it is important to understand that there is no single 'silver bullet' in reducing cruise ship emissions while at-berth and that all ships have unique equipment and physical parameters that make emissions reduction strategies generally bespoke solutions. It should be noted that the use of cleaner fuels, such as required by the AMSA Direction is typically the primary strategy to reduce particulate matter (PM) and sulphur oxides (SO_x). EGCS and shore power represent significantly more complex and costly solutions that are typically implemented through the support of extensive publically funded grants or required by specific regulations. Currently there are no cruise ships regularly operating EGCS at White Bay and no cruise ships using shore power in Australia. There are significant initial costs and long lead implementation timelines associated with moving forward with either of these strategies. In the case of shore power, emissions at-berth are only reduced (not eliminated) for a portion of the total time the ship is at-berth (the time the ship is powered by the electricity grid). During this time, the ship's emissions are 'shifted' from the ship locally to the grid generation sources regionally. In addition, the auxiliary boilers, which are normally off while a cruise ship is at-berth, have to be turned on during shore power operations to provide an alternate source of heat.

The estimated emissions reductions of scenarios S2 through S5 compared to scenario S1 for PM (less than 2.5 and 10 microns), oxides of sulphur (SO_x), oxides of nitrogen (NO_x), volatile organic compounds (VOCs), and carbon dioxide (CO_2) are presented in Table ES.1.

Table ES.1: Scenario Emissions Reduction Comparisons to S1

Comparison	Condition		2015/16 Season Emissions Reductions					
			PM_{10}	$PM_{2.5}$	SOx	NOx	VOC	CO_2
Scenario 2 v 1	0.1% S		82.7%	80.0%	95.93%	6.1%	0.0%	5.0%
Scenario 2 v 1	0.001% S		85.0%	83.0%	99.96%	6.1%	0.0%	5.0%
Scenario 2a v 1	0.1% S/1.35%S		71.2%	69.1%	87.42%	5.0%	0.0%	4.1%
Scenario 2a v 1	0.001% S/1.35%S		73.1%	71.5%	90.70%	5.0%	0.0%	4.1%
Scenario 3 v 1	EGCS & 2.7% S		80.0%	80.0%	98.00%	10.0%	0.0%	-2.0%
Scenario 4 v 1	EGCS & 0.1% S		96.5%	96.0%	99.92%	15.5%	0.0%	3.1%
Scenario 4 v 1	EGCS & 0.001% S		97.0%	96.6%	99.999%	15.5%	0.0%	3.1%
Scenario 5 v 1	0.1%, 1.35%, 2.7% S fuels	Local	80.1%	79.5%	87.18%	64.3%	62.5%	na
	& Shore Power	Regional	77.0%	77.3%	74.52%	56.7%	57.7%	-12.1%
Scenario 5 v 1	0.1%, 1.35%, 2.7% S fuels	Local	80.6%	80.1%	88.33%	64.3%	62.5%	na
	& Shore Power	Regional	77.5%	78.0%	75.66%	56.7%	57.7%	-12.1%

Note: a negative reduction represents an increase in emissions

From a cost-effectiveness standpoint, shore power is significantly above (estimated to range from 2 to over 7.8 times) the CARB threshold level for cost-effective emissions reduction strategies, and would therefore be deemed not cost-effective.

Several other strategies are highlighted as potential alternatives to be considered if further emissions reductions beyond the AMSA Direction are warranted and include: engine and boiler technologies, after treatment technologies, alternatively fuelled on-board energy generation, alternatively generated power systems, operational efficiency improvements, and offsets from emissions reductions associated with other sources.

1. Introduction

The Port Authority of New South Wales (Port Authority) commissioned Starcrest Consulting Group, LLC (Starcrest) to analyse the potential benefits and cost-effectiveness of shore power at White Bay Cruise Terminal (WBCT) and four other scenarios. Starcrest has over 18 years of experience working on port-related air emissions quantification and reduction strategies in North America, Asia, Europe, and Central America. This study is part of a larger set of work the Port Authority is engaged in to fully analyse the feasibility of shore power as an emissions control strategy. The goals of this study are to:

1. Provide context and background materials relating to cruise ship emissions associated with WBCT, the fuels used by ships, strategies for reducing emissions from cruise ships at-berth, shore power fundamentals, relative emissions rates for the grid servicing WBCT, and other key elements needed to broadly understand the related issues with shore power and alternative emissions reduction strategies.
2. Provide context to where shore power relating to cruise ships started, and the ports that currently have cruise shore power programs.
3. Provide context to how cruise lines calling at WBCT view shore power as an emission reduction strategy.
4. Provide baseline emissions estimates for the 2015/16 WBCT cruise season and apply various control strategies to determine and compare the emissions reductions for each scenario.
5. Develop a cost-effectiveness analysis to help determine where shore power and the other scenarios emissions reductions stand from a cost-effectiveness viewpoint.

In addition to this study, the Port Authority is conducting an Engineering Feasibility Study, investigating noise impacts of shore power, and other supporting materials. For the cost-effectiveness analysis, findings from the Engineering Feasibility Study were incorporated.

2. Background

2.1 Cruise Ship Emissions At-Berth

Modern cruise ships typically have a diesel-electric (DE) configuration, in which propulsion as well as all non-propulsion energy demands are serviced by auxiliary (aux) engines (in a diesel-electric generator configuration). The ship does not have a dedicated propulsion engine; instead the electric propulsion motors are powered by the auxiliary engines. Common emissions sources for DE cruise ships include the auxiliary engines and auxiliary boilers. Auxiliary boilers are used to heat residual fuel and to provide hot water, steam, and space heat, and are fuelled by the same fuels consumed in the engines.

Typically DE cruise ships have 3-5 auxiliary engines on-board and they are used in various configurations depending on the ship's mode of operation. Typically, while at-berth, DE cruise ships have one auxiliary engine in operation. When the ship is in a manoeuvring mode, such as manoeuvring through Sydney Harbour, the ship will typically have multiple auxiliary engines operating due to additional loads required by the ship's thrusters and for safety reasons.

While at-berth, cruise ships generate on-board electricity through the use of their auxiliary engines, which services all the ship's electrical demands including: lighting, air conditioning, entertainment, refrigeration, laundry equipment, cooking and food prep, computers, communication systems, elevators, etc. Typically, the auxiliary engines are the only emissions source at-berth, as the auxiliary boilers are not needed due to the use of waste heat recovery systems on the generators, typically called 'economisers'. In cases where auxiliary engines are switched off (as occurs during connection to shore power) the auxiliary boilers must be turned on to produce the heat no longer provided by the economisers.

Conventional cruise ships that have dedicated propulsion engines, auxiliary engines, and auxiliary boilers, basically have the same operational configuration while at-berth, with auxiliary engines operating to provide the ship's power needs and boilers are typically off due to the use of economisers.

2.2 Cruise Ship Emissions in Sydney Harbour

Cruise ship emissions are generated from the following operations: transit from open water through Sydney Harbour, manoeuvring to and from berth, and while the ship is at-berth. Shore power only reduces emissions while a compatible ship is plugged in at-berth. Looking at a typical DE cruise ship call from the Sydney Heads to WBCT, with a swing (180 degree turn prior to docking), the total round trip transit time task is approximately 2.25 hours on average, while the average anticipated at-berth time for the 2015/16 Season is 11.8 hours. This means that of the total call emissions, typically 80% will occur at-berth and 20% will occur during the transit. Therefore, strategies that only target at-berth emissions will target a maximum of 80% of total emissions from a cruise ship's entire call to Sydney Harbour. See Annex 1 for more information on the estimates.

2.3 Marine Fuel Descriptions

The main types of marine fuels are as follows:

- Residual Oil (RO) is the heaviest fraction of the distillation of crude oil. RO is also known as Heavy Fuel Oil (HFO). Because of its high viscosity, heating is necessary for the fuel to flow properly. It tends to have high concentrations of pollutants, including sulphur, and may produce dark smoke when burned. It is also the cheapest liquid fuel on the market.
- Intermediate Fuel Oil (IFO) is a mixture of residual and distillate oils. IFO 180 is a mix of 98% of residual oil and 2% of distillate oil. IFO 380 is a mix of 88% of residual oil and 12% of distillate oil. Because of its higher distillate oil content, IFO 380 is more expensive than IFO 180.
- Distillate Oils are the lighter fractions of the distillation of crude oil. Marine distillate fuels are generally defined in ISO 8217 (2012). Distillate oils are further divided in the following two types:
    1. Marine Diesel Oil (MDO) consists of distillate oil with a trace of residual oil. MDO has lower sulphur content than residual oil, IFO 180, or IFO 380 but has higher sulphur content than MGO. MDO is available in several grades (including DMB and DMC). These grades have higher sulphur content and higher viscosity than MGO.
    2. Marine Gas Oil (MGO) is pure distillate oil and has the lowest sulphur content. MGO is available in several grades (including DMX and DMA). DMX fuel is used primarily for lifeboats, not for a ship's engines (due to its low flashpoint).
- Low-sulphur MGO (LSMGO) is MGO with sulphur content less than 0.1% S. LSMGO is also specified for use within EU community ports and anchorages in accordance with EU Sulphur Directive 2005/33/EC, and within the North American Emissions Control Area starting in 2015.

It should be noted that ultra-low sulphur diesel (ULSD), which typically has a fuel sulphur content of 10 parts-per-million or 0.001% S, is used predominately in land-based diesel-fuelled engines and in domestic vessels in numerous countries. ULSD is not considered a typical ocean-going vessel marine fuel, as the cost of USLD is significantly higher than the mainstream marine fuels and therefore nearly all ships operate on non-ULSD fuels. Due to the Australian Maritime Safety Administration (AMSA) Direction under subsection 246(1)(b) of the Navigation Act 2012 (see Section 2.5), cruise ships that call at Sydney cruise terminals, including WBCT, will need to take bunkers at WBCT or have compliant fuels on board prior to arrival. It is understood from some of the shipping lines that compliant LSMGO is not available for bunker, so ships bunkering (fuelling) at WBCT will be purchasing and using ULSD.

2.4 Reducing At-Berth Ship Emissions

There are several strategies for reducing ship-generated emissions at-berth including: switching to cleaner fuels, exhaust gas cleaning, shore power, engine technologies, increases in efficiencies, etc. Each of these various strategies have strengths, limitations, and costs that all vary by targeted pollutants or greenhouse gases, by vessel type, by vessel age, by vessel configuration, by application, by berth, and by port. There is ***no*** 'silver bullet' for reducing at-berth emissions.

Typically, the first ship emissions reduction strategy considered by both government and industry is the use of cleaner fuels, given that ships have historically used petroleum residual fuels. HFO is very viscous and typically needs to be heated for storage and use in ships' engines. HFO is the primary fuel used by ships due to its relative low costs compared to more refined fuels. MDO and MGO are more refined fuels that typically have the lowest sulphur content of marine fuels, ranging from less than 1% to less than 0.1% S, with that latter typically being referred to low sulphur marine fuels. By switching to cleaner fuels, the primary emissions that are reduced are sulphur oxides (SO_x) and particulate matter (PM). There is also a slight reduction in oxides of nitrogen (NO_x).

Fuel switching has been used as both a voluntary and mandatory emissions strategy. Fuel switching has been voluntarily adopted by shipping lines in particular instances.[1] It has also been incentivised at the port level,[2] mandated by states/regions,[3] and mandated at the international level through the International Maritime Organisation (IMO).

Shore power is another emissions reduction strategy that has been implemented on a limited basis at various ports around world. However due to the complexities and costs, shore power implementation has been typically associated only with cruise, container, and refrigerated cargo ships. Shore power is further discussed in Section 2.6 below.

Other alternative strategies for reducing at-berth emissions are further discussed in Section 8 of this report.

2.5 Fuel Sulphur Regulations

The IMO is responsible for setting fuel oil sulphur standards globally for international shipping, which is currently set at 3.5% S. At the 70th Marine Environmental Protection Committee (MEPC 70) in October 2016, the IMO agreed to set the global fuel oil sulphur limit to 0.5% S starting 1 January 2020.[4]

In September 2015, the New South Wales (NSW) Environment Protection Authority (EPA) promulgated the Protection of the Environment Operations (Clean Air) Amendment (Cruise Ships) Regulation 2015 (2015 Cruise Regulation),[5] and this is further discussed in Section 2.5. The EPA's 2015 Cruise Regulation started 1 October 2015 and required cruise ships to switch to low sulphur fuels (0.1% S or less) while at-berth. Starting in July 2016, the regulation additionally required cruise ships to switch to low sulphur fuels prior to transiting Sydney Harbour. Via discussions with the Port Authority and cruise lines, it is understood that cruise ships home-based outside Australia will most likely have 0.1%S fuel on-board from purchases in other countries, while cruise ships home-based in NSW will most likely have 0.001% S fuel (on-road ultra-low sulphur diesel or USLD) on-board as blending is not anticipated to be available for fuels purchased in Australia. Therefore, a range of fuels from 0.1% to 0.001% S will be utilized by the cruise fleet. From an emissions analysis perspective, 0.1% S represents

[1] Hong Kong Fair Winds Charter, container ships, 2010-2015 *www.hksoa.org/news_events/newsletter/2014/PR%20extending%20FWC2013.pdf*, accessed October 2015*;* Maersk Line container ships voluntary fuel switch at Port of Los Angeles, 2007-2010

[2] Port of Seattle, At-Berth Clean Fuels Incentive Program, *www.portseattle.org/Environmental/Air/Seaport-Air-Quality/Pages/ABC-Fuels.aspx*; Port Authority of New York & New Jersey (PANYNJ), Low Sulfur Fuel Incentive Program, *www.panynj.gov/about/low-sulfur-fuel.html*; PANYNJ Clean Vessel Program, *www.panynj.gov/about/clean-vessel-incentive-program.html*; Port of Amsterdam, Environmental Ship Index Incentive Program, *www.portofamsterdam.com/Eng/shipping/harbour-dues/Environmental-Ship-Index.html*; etc.; accessed October 2015

[3] California Air Resources Board (CARB), Ocean-Going Vessel Marine Fuel Rule, *www.arb.ca.gov/ports/marinevess/ogv.htm*; Canada and United States Environmental Control Area (ECA), *www.ec.gc.ca/energie-energy/default.asp?lang=En&n=1764584F-1*; and *www3.epa.gov/otaq/documents/oceanvessels/420b14097.pdf*, accessed October 2015

[4] IMO, *www.imo.org/en/mediacentre/pressbriefings/pages/mepc-70-2020sulphur.aspx*, accessed January 2017

[5] EPA, *www.epa.nsw.gov.au/air/air-ports-sub.htm*, accessed October 2015

the highest sulphur fuel (representing the least emissions reductions) allowed by the regulation while 0.001% S represents the lowest sulphur fuel (representing the maximum emissions reductions). The regulation provided for alternative methods to fuel switching, as long as these methods achieve emissions reductions of sulphur oxides and particulate matter at a level equal or below the levels that would be achieved by fuel switching. Alternative compliance strategies were required to be submitted to and approved by EPA. This regulation primarily reduced sulphur oxide emissions and particulate matter emissions initially at-berth and after June 2016 to the entire Sydney Harbour.

In May 2016, EPA became aware that the Commonwealth Government introduced amendments to the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* into Parliament in September 2015 which were assented to in December 2015, and resulted in the 2015 Cruise Regulation being inoperative from January 2016.

In December 2016 the Commonwealth announced a new direction to protect Sydney Harbour from harmful ship emissions. The AMSA Direction as outlined in the Marine Notice 21/2016,[6] authorized under Subsection 246(1)(b) of the *Navigation Act 2012*[7] which became effective in December 2016, directs cruise vessels to limit sulphur emissions while at-berth in Sydney Harbour. This directive is applicable to cruise ships capable of accommodating more than 100 passengers and requires the use either one or a combination of the following options: 0.1% S fuels, certified exhaust gas cleaning systems (EGCS), and/or shore power. The AMSA Direction allows for one hour after arrival and one hour prior to departure for ships to switch their fuels from IMO compliant fuels to 0.1% S or allows IMO compliant fuels to be burned during the same time frame to connect to and disconnect from the grid if shore power is used. The limit on sulphur emissions applies from one hour after the vessel's arrival at-berth until one hour before the vessel's departure. It should be noted that this direction is valid through 31 December 2018 unless withdrawn earlier.

In the interim between the EPA regulation being inoperative (January 2016) and the start of the AMSA Direction (December 2016), EPA was able to obtain agreement with both Carnival Australia and Royal Caribbean to ***voluntarily*** continue to comply with the at-berth requirements of the 2015 Cruise Regulation.[8]

2.6 Shore Power Fundamentals

Shore power is one of many emission control strategies that have been used to reduce ship emissions at-berth. Shore power typically shifts a ship's on-board electrical generation to the local landside power grid servicing the terminal. Instead of the ship generating its own electricity, the grid supplies the ship through a sophisticated system of cables, circuit breakers, transformers, and control circuits.[9] There are international standards for high voltage shore connection systems for both ship- and shore-side equipment related to shore power.[10] From an implementation perspective, shore power is not a 'quick fix' in that the strategy requires significant infrastructure improvements on both the ship and shore sides. The infrastructure improvements need to be engineered, approved, equipment ordered, installed, and commissioned, both on the ship- and shore-side. Currently, there are a limited number of

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[6] AMSA, *https://apps.amsa.gov.au/MOReview/MarineNoticeExternal.html*, accessed January 2017
[7] Federal Register of Regulation, *https://www.legislation.gov.au/Series/C2012A00128*, accessed January 2017
[8] EPA, *www.epa.nsw.gov.au/MediaInformation/white-bay.htm*, accessed January 2017
[9] International Association of Ports and Harbors (IAPH), World Ports Climate Initiative (WPCI), *wpci.iaphworldports.org/onshore-power-supply/index.html*, accessed October 2015
[10] ISO, *http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=53588*, accessed October 2015

ships calling at WBCT that have the required shipside equipment to utilise shore power. This is discussed in Section 5.5.

It is important to note that shore power ***does not*** reduce ship emissions to zero. First the ship is not connected to the landside power grid instantaneously when it arrives, nor disconnected instantaneously when it departs. A complex sequence of events needs to take place before the ship can shut down or restart its engines, which typically takes approximately an hour upon arrival and an up to hour prior to departure. While the ship is connected, shore power ***shifts locally generated*** emissions from the ship's engines (typically auxiliary engines) ***to regionally generated*** emissions associated with the power grid servicing the terminal. In addition to the auxiliary engines operating prior to connecting and disconnecting to the grid, shore power ***does not*** eliminate all at-berth (locally) generated emissions. When a cruise ship is connected to and operating on shore power, the waste heat from the diesel-electric generators drops (because the engines are off) and the auxiliary boilers must be turned on to service hot water and steam needs for the ship.

From a regional perspective, shore power emissions reduction effectiveness from a SO_x, PM, and carbon dioxide (CO_2) is dependent on the regional power grid's generation portfolio, the distance from the electrical generation station(s) to the terminal, and the condition of the grid (relating to energy losses).

2.7 NSW Grid

Since shore power creates additional regional emissions from the electrical power grid servicing the at-berth ship electrical loads, emissions rates for the Greater Metropolitan Region in NSW electric power grid were estimated from Technical Report No. 5, Air Emissions Inventory for the Greater Metropolitan Region in New South Wales 2008, from EPA. As presented in Table 2.1, the electrical generation sources for the grid in 2008 were dominated by coal with a small percentage from gas.

Table 2.1: 2008 Greater Metropolitan Region, NSW Grid Generation Emissions

Generation Source	Electrical Generation GWh/year	Estimated 2008 Grid Emissions			
		PM_{10} kg/year	$PM_{2.5}$ kg/year	SOx kg/year	CO_2 kg/year
Coal	68,999	6,520,000	3,340,000	251,000,000	65,100,000,000
Gas	3,033	84,900	84,900	17,800	1,080,000,000
Non Coal/Gas	84	2,040	2,010	10,900	50,000,000
Total	72,116	6,606,940	3,426,910	251,028,700	66,230,000,000

Note: kg – kilogram, GWh – gigawatt-hour, kWh – kilowatt-hour

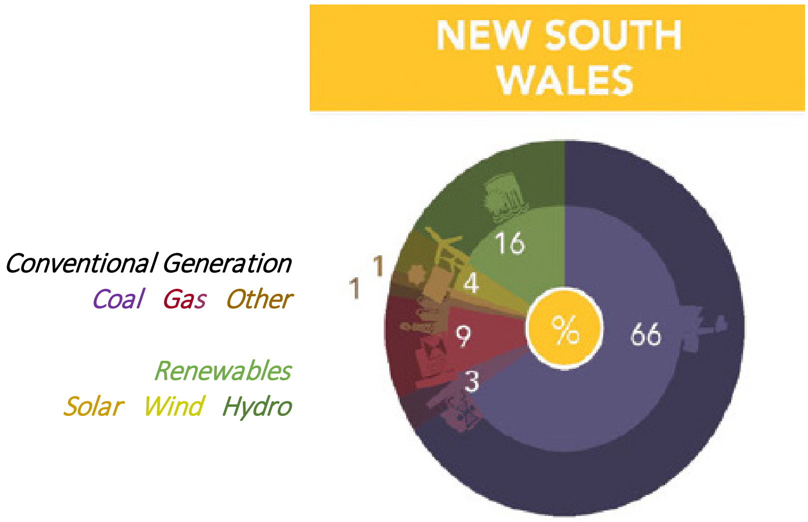
In 2008, 96% of electrical generation was coal-based, approximately 4% gas-based, and less than 1% non-coal/gas based. This was based on the Greater Metropolitan Region and represents the most up to date estimates for NSW prepared by the EPA. For 2015, the NSW grid generation sources have been estimated based on the August 2015 Australian Energy Market Operator (AEMO) Energy Update.[11] It should be noted that the estimates are for the entire NSW state and therefore the estimates of renewable sources is much higher. In 2015, the grid generation is 66% coal, 21% renewables, 12% gas, and 1% other. For the purposes of this study the 2015 NSW grid estimates represent a more conservative basis for assessing the

[11] AEMO, *www.aemo.com.au/About-the-Industry/Resources/Industry-Newsletter-Energy-Update/Energy-Update-April-2015*, accessed November 2015

impacts of shore power compared to using the published 2008 emissions estimates for power generation.

The air quality implications from the grid related composite emissions rates and shore power are further discussed in Section 6.

August 2015 - Australian Energy Market Operator Energy Update
Update to Grid Related Generation Sources



3. International Context for Cruise Terminals

Shore power, specifically provided to cruise ships, is considered high-voltage (typically running at 6.6 kilovolts or 11 kV). The first shore power service for cruise ships started in Juneau Alaska in 2001. The primary drivers for mandating shore power in Juneau were emissions and opacity issues from the increasing number of cruise ships visiting Alaska. Since 2001, the deployment of high voltage shore power specifically for cruise ships has broadened due to various drivers, as presented in Table 3.1

Table 3.1: Cruise Ship Shore Power Installations and Drivers

Year of Introduction	Port	Berths Equipped with Shore Power	Key Drivers for Installation
2001	Juneau, Alaska	1 of 7 berths + 4 anchorages	Visual & Community – haze from ship exhaust
2005	Seattle, Washington	2 of 3 berths	Community
2009	Vancouver, Canada	2 of 3 berths	Environmental & Community – demonstrate leadership
2010	San Diego, California	1 of 2 berths	Regulatory – Californian requirements
2010	San Francisco, California	1 of 3 berths	Regulatory & Community – Californian requirements
2011	Los Angeles, California	2 of 3 berths	Regulatory & Community – significant regional air quality concerns for LA area
2011	Long Beach, California	1 of 1 berth	Regulatory & Community – significant regional air quality concerns for LA area
2014	Halifax, Canada	2 of 5 berths	Environmental – demonstrate leadership
2015	Hamburg, Germany	4 of 5 berths (3 using LNG power barge)	Environmental – demonstrate leadership
2016	Brooklyn, New York	1 of 5 berths	Environmental – demonstrate leadership
2016	Auckland, New Zealand	Feasibility Study	Environmental – demonstrate leadership and reduce carbon

It should be noted that it is uncommon for all the berths at a terminal or port to be equipped with shore power due to costs and operational flexibility. From communications to date with these ports, several key findings are worth noting, as follows:

- For the North American ports of Juneau, Vancouver, Seattle and San Francisco a key consideration was that there was an excess of clean, renewable and cheap power (hydroelectric) with necessary infrastructure already located close to the berths, which reduced overall costs considerably.
- In Seattle and Vancouver, where shore power has been available for 10 and 6 years respectively, only 40-45% of all cruise ship calls are connecting to shore power. This is not expected to increase, as additional ships home porting or transiting these ports are not being retrofitted or built with shore power capability. Vancouver has been offering up to 47% discounts on harbour fees as an incentive but this has not increased shore power usage.
- California is the only jurisdiction world-wide that currently mandates that vessels connect to shore power (California Air Resource Board's [CARB] Shore Power Regulation, from January 2014),[12] requiring that an increasing percentage of fleets calling at Californian ports either connect to shore power whilst at-berth, increasing to 80+% from 2020 (including container ships, passenger ships, refrigerated cargo ships), or use alternative control techniques that achieve equivalent emission reductions. The regulation only applies to passenger ships that cumulatively make five or more visits annually to a single port.
- Halifax expects 17% of vessel visits to connect to shore power in 2015, its first season with shore power.
- The Brooklyn Cruise Terminal installation, by the Port Authority of New York and New Jersey, was designed specifically targeting only three cruise ships (*Queen Marry II*, *Regal Princess*, and *Caribbean Princess*) that frequently use this terminal, all of which are shore power equipped. The final cost of the shore-side installation was $21 million USD and the ships are charged 12 cents (USD) per kilowatt-hour while the New York Power Authority and the New York City Economic Development Corporation will split the remainder electricity costs which range from 12 cents per kilowatt-hour to market rate. The US EPA provided $2.9 million USD in grant funding.
- All shore power installations, except perhaps for Long Beach which is a Carnival-owned facility, have involved a consortium of parties contributing to the cost, including several levels of government, the cruise industry and the port. It should be noted that the cruise terminal in Long Beach is leased from the City of Long Beach to Carnival, and is not part of the Port of Long Beach.
- Victoria is Canada's busiest cruise port of call. The Greater Victoria Harbour Authority had considered shore power in 2014, but decided not to pursue shore power and identified scrubber technology as the preferred option for the mitigation of air quality impacts from cruise ships. Cruise ships are also required to use 0.1% sulphur fuel (or equivalent technologies) in Victoria as it is within the North American Emission Control Area, designated through the International Maritime Organisation (IMO). Together, these initiatives are seen as ensuring the continuity of good air quality while ships are within the vicinity of Victoria Harbour, not just at-berth. In June 2016, the port reopened[13] its review of shore power related to home-ported cruise ships, however no decision has been published.
- Hong Kong recently (May 2015) announced that it would not pursue shore power due to it being a costly system that few cruise ships would use. A government report found that only 35 international cruise ships would be equipped with shore power systems by end 2015,

[12] CARB, Shore Power for Ocean-Going Vessels, *www.arb.ca.gov/ports/shorepower/shorepower.htm*, accessed October 2015

[13] CBC News, *www.cbc.ca/news/canada/british-columbia/victoria-harbour-cruise-power-1.3644808*, accessed April 2017

representing only 16% of all international cruise ships. Most of these equipped ships cruise the North American west coast routes rather than Asian routes. The system was anticipated to cost nearly $55 million AUD for construction and nearly $2.5 million per year to operate, and the Hong Kong Environmental Protection Department said the facility would be 'significantly underutilized.' [14]

- Charleston, South Carolina has had significant community concerns regarding cruise ship impacts, including on air quality. The Port has not been able to justify installing shore power and they note that their air quality monitoring is 'not showing any concerns.'
- Florida, the cruise capital of the world with five cruise ship ports and in excess of 20 cruise berths, has not implemented shore power.
- The Port of Auckland has recently commissioned a feasibility study to look at the potential implementation of shore power and alternative strategies to reduce emissions from visiting cruise ships. The study is anticipated to be released during the second quarter of 2017.

As stated above, CARB is the only regulatory agency in the world that has a broad shore power-based regulation, and even the CARB regulation limits the anticipated use (up to 80%) due to the complexities of the strategy and the maritime industry. In addition, CARB provided over $100 million AUD in grant funding for 35 berths spread across the ports of Long Beach, Los Angeles, Oakland, and Hueneme.[15] This funding did not fully offset the costs of the projects.

One of the significant facilitators of the expansion of shore power was the development of international standards for ship and shore-based equipment.[16] The primary challenge to further adoption of the strategy is with the significant costs for both the ship- and shore-side infrastructure, the costs of operations, and the limited number of cruise ships equipped to take shore power.

Similar to Australia, the European Union (EU) does not have an established shore power program and only recently had its first high voltage cruise ship berth commissioned. The Hamburg Port Authority (HPA) just started operations in the summer of 2015 at its Altona cruise terminal (one berth),[17] which is the EU's first high voltage shore power berth. The Port of Amsterdam has moved forward with a study relating to shore power (also called on shore power supply or OPS), stating:

> "The sector has acknowledged that the only way to realize on shore power supply for sea cruise ships is to use a European approach. On shore power supply will only be feasible if a certain critical mass is reached. A large investment is needed in on-board connectors by cruise lines. This investment will only be made, if a significant amount of terminals along the usual sailing routes will offer on shore power supply. Therefore, the port of Amsterdam as major European cruise port, in close cooperation with Cruise Europe, ports in North and Western Europe and cruise lines sailing in Europe has taken the lead to realize a European project for on shore power supply: OPS Sea Cruise Europe."[18]

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[14] South China Morning Post, *www.scmp.com/news/hong-kong/health-environment/article/1810888/hong-kong-pulls-plug-shore-power-supply-cruise*, accessed October 2015

[15] Jonathan Foster, CARB, At-Berth Regulation Presentation, for US EPA Region 2 workshop, 16 June 2015

[16] Utility connections in port -- Part 1: High Voltage Shore Connection (HVSC) Systems, IEC/IEEE NP 80005-1, *www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=64717*, accessed October 2015

[17] Hamburg News, *www.hamburg-news.hamburg/en/cluster/port-logistics/shore-power-altonas-cruise-terminal/*, accessed October 2015

[18] Port of Rotterdam, *www.portofamsterdam.com/Eng/shipping/sea-shipping-and-sea-cruise/OPS-Sea-Cruise-Europe-sustainable-on-shore-power-supply-for-Sea-Cruise-Ships.html*, accessed October 2015

The ultimate goal of the OPS Sea Cruise Europe project is to build four OPS facilities in Europe based on the projects findings.

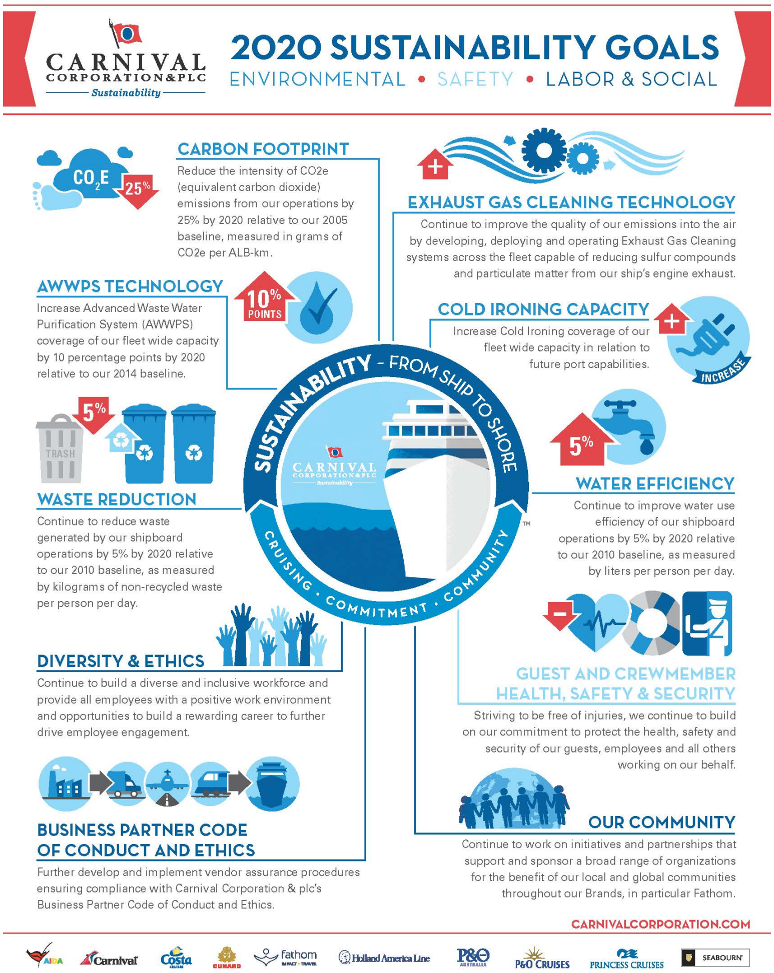
Most recently, the United States Environmental Protection Agency (USEPA) published a *Shore Power Technology Assessment at U.S. Ports.*[19] This document was compiled based on review of numerous and sometimes dated sources and is to provide a method of assessing shore power for ports throughout the US and not just those that already have it. There are some significant issues with the document in that it does not address auxiliary boilers, uses antiquated CARB approaches for determining auxiliary engine loads (which CARB has abandoned), doesn't take into account the time ships take to connect to and disconnect from grid power sources, heavily cites pre-2011 outdated sources and methods, among other issues. Unfortunately this document will inject confusion into the public domain until it is recalled or revised.[20]

[19] USEPA, *https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports*, accessed April 2017

[20] The view stated on the USEPA shore power report is that of Starcrest Consulting Group, LLC and does not represent an official view of the study by PANSW.

4. Cruise Industry Context

Based on information from a Cruise Lines International Association (CLIA) Australia submission to the EPA in May 2015 regarding shore power capability, 10 of 54 cruise ships scheduled to come to Sydney from 2015-2017 are equipped for shore power, representing 19% of vessels. CLIA also indicated that none of its members, representing 97% of calls to Sydney (between July 2015 and June 2017), have indicated any plans to install shore power as part of their IMO MARPOL Annex VI[21] compliance program.



From the cruise industry perspective, Carnival Corporation (Carnival Corp.), which makes up 87% of the calls at WBCT (see Section 5), is the dominant owner of shore power equipped cruise ships. Carnival Corp. recently released its 2015 Sustainability Report,[22] which included its 2020 Sustainability Goals, including shore power as a strategy. Shore power is only one of many other options the cruise lines are evaluating and implementing to meet their company's sustainability goals and to meet applicable local and international regulations. The primary upcoming challenge, relating to all of shipping, is the IMO's MARPOL Annex VI global world marine fuel sulphur standard that sets the maximum sulphur content for marine fuels at 0.5%. This is a watershed event that is scheduled to become effective at the beginning of 2020. This regulation will impact all ship operational modes (ocean transit, manoeuvring, at-berth, etc.) and therefore the cruise lines are looking for solutions that work across all operational modes. Carnival Corp.'s primary strategy associated with the IMO marine fuel regulation is the use of exhaust gas cleaning systems (EGCS) across its fleet. Carnival Corp. has publically announced a $400 million investment for the initial phase of 40 ships with EGCS installations,[23] which has been expanded to 70 ships. Carnival Corp. has also

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[21] International Convention for the Prevention of Pollutions from Ships, 1973, as modified by the Protocol of 1978 (MARPOL Convention)

[22] Carnival Corp., *phx.corporate-ir.net/phoenix.zhtml?c=200767&p=irol-newsArticle&ID=2087885*, accessed October 2015

[23] PR Newswire, *www.prnewswire.com/news-releases/carnival-corporation-significantly-increases-installations-of-industry-first-exhaust-gas-cleaning-technology-expands-to-more-than-70-percent-of-fleet-260213871.html*, accessed October 2015

publically announced four new ships will be powered by natural gas stored on-board as liquefied natural gas (LNG).[24]

In its submission to the NSW Parliamentary Inquiry into the performance of the EPA, Carnival Australia indicated it would be installing scrubber technology on all of its vessels in Australia from 2017 to 2019, during the ships' scheduled dry docks. Another key strategy is reducing the fleet's carbon footprint, which includes identifying and maximising efficiency improvements.

As part of Carnival Corps.' 2020 Sustainability goals, shore power is indicated as an increasing component. To put this into context, some of the cruise lines under the Carnival Corp. umbrella, most notably Princess Cruises, have installed a significant portion of their fleet with shore power capabilities. Other cruise lines under Carnival Corp. are incorporating space for shore power retrofits in new builds; however the electrical equipment and related engine room equipment/computers are not being installed at this point in time. This slightly reduces the cost if a ship needs to be converted in the future. P&O Australia has no shore power capable ships at this time.

Royal Caribbean Cruise Line (RCCL), which also calls at WBCT, and has only one ship in its fleet with shore power capabilities, is implementing a similar strategy as Carnival Corp. in response to the IMO fuel sulphur standards; installing scrubbing systems across their fleet starting in 2015 during scheduled dry docking, with four ships already operating scrubbers.[25]

[24] Carnival Corp., *phx.corporate-ir.net/phoenix.zhtml?c=200767&p=irol-newsArticle&ID=2059101*, accessed October 2015

[25] Port Authority of NSW email correspondence with Sheldon Thompson, Worldwide Port Operations and Product Operations Manager, RCCL Cruises Ltd, 27 March 2015

5. Emissions Reduction Scenarios

This study analyses a baseline scenario and four other scenarios at WBCT to illustrate how various potential emissions reduction strategies perform compared to the pre-Fuel Sulphur Regulation scenario and compared to each other, on both local and regional scales. The scenarios are applied to the 2015/16 WBCT cruise season from October 2015 to September 2016 (2015/16 Season). The analysis of emissions reduction scenarios against the 2015/16 fleet provides the relative outcomes for the current season and consideration is given to key elements relating to the 2016/2017 season, where applicable. It's important to note that with each cruise season, ships may be moved in or out of service at WBCT depending on market conditions, company deployment strategies, and other key considerations. These changes can have either positive or negative effects on the potential effectiveness of some emissions reduction strategies; these are noted as applicable within each scenario.

The Port Authority provided the anticipated cruise ship schedule for the 2015/16 Season. For the season, 24 different cruise ships will make 132 calls at WBCT (Table 5.1).[26] Some ships will only make one call during the season. Five ships will make more than 10 calls. There are six ships that currently have shore power capabilities calling at WBCT, as noted in Table 5.1, making a total of 29 calls (22% of total calls for the season). In addition to calls, total anticipated time at-berth is provided by ship.

[26] Based on Port Authority of NSW schedule data, September 2015

Table 5.1: Anticipated 2015/16 Season Cruise Ships and Number of Calls

Vessel	Operator	IMO	Passenger Capacity	Calls	Total At-Berth (hours)	Shore Power Capable?
Albatros	Phoenix Seereisen	7304314	1,000	1	62	No
Amsterdam	Holland-America	9188037	1,738	1	34	Yes
Artania	Phoenix Seereisen	8201480	1,323	1	36	No
Astor	CMV	8506373	656	1	11	No
Azamara Quest	Azamara Club Cruises	9210218	702	2	62	No
Black Watch	FOCL	7108930	807	1	38	No
Crystal Serenity	Crystal Cruises	9243667	1,140	1	41	Yes
Dawn Princess	Princess Cruises	9103996	2,342	14	126	Yes
Europa	Hapag Lloyd Kreuzfahrten	9183855	408	1	37	No
MS Marina	Oceania - Cruises	9438066	1,252	1	24	No
Noordam	Holland-America	9230115	1,918	4	36	Yes
Pacific Aria	P&O Cruises Australia	8919269	1,512	14	172	No
Pacific Eden	P&O Cruises Australia	8919245	1,512	14	119	No
Pacific Jewel	P&O Cruises Australia	8521220	1,912	37	331	No
Pacific Pearl	P&O Cruises Australia	8611398	1,856	22	189	No
Pacific Princess	P&O Cruises Australia	9187887	702	1	15	No
Pacific Venus	Japan Cruise Line	9160011	696	1	28	No
Sea Princess	Princess Cruises	9150913	2,342	4	37	Yes
Seabourn Odyssey	Seabourn Cruises	9417086	450	1	35	No
Silver Shadow	Silversea Cruises	9192167	388	1	13	No
Silver Whisper	Silversea Cruises	9192179	388	2	39	No
Sun Princess	Princess Cruises	9000259	2,272	5	45	Yes
Superstar Virgo	Star Cruises	9141077	3,350	1	22	No
Volendam	Holland-America	9156515	1,824	1	11	No

It should be noted that Carnival Corp owns Holland-America, Princess Cruises, P&O Cruises Australia, and Seabourn Cruises, which make up 115 of the anticipated 132 calls (87%). In addition, all the ships calling during the 2015/16 season have passenger capacities greater than 100, therefore would be required to follow the AMSA Direction.

The potential emissions reduction scenarios are detailed and key assumptions listed in the following subsections.

5.1 S1 – Baseline Conditions/Pre-2015 Cruise Regulation

Scenario 1 (S1) provides context to emissions levels prior to the implementation of 2015 Cruise Regulation and assumes that all ships use an average of 2.7% S HFO while at-berth, which is the highest global annual fuel sulphur content for HFO in the last five years.[27] No additional emissions reduction strategies are applied in this scenario. This 'baseline scenario' provides context to the other scenarios and is used to illustrate the potential magnitude of reductions that each scenario can potentially achieve.

[27] IMO, MEPC 69.5.7 *Sulphur Monitoring for 2015*, 4 February 2016

5.2 S2 – Compliance with EPA and AMSA Fuel Sulphur Regulations: 0.1%/0.001% S Fuels

Scenario 2 (S2) analyses the benefits from the intention of the EPA 2015 Cruise Regulation. This scenario assumes that all ship calls will be in compliance with the required fuel and assumes that switchover to the required fuel has be completed prior to arriving at-berth, thus maximizing the effectiveness of the Regulation. S2 represents the intention of Stage 2 of the Regulation, that beginning 1 July 2016, compliant fuel would be used while transiting Sydney Harbour, and therefore the same fuel would be assumed for the entire time at-berth, applied over the entire cruise season. Beyond the assumption listed above, the following key assumptions are related to S2:

i. Under this Scenario, all cruise ship calls will utilise either 0.1% S or 0.001% S fuels during their entire berthing period at-berth to provide an estimate of the maximum range of the potential benefits.
ii. No additional emissions controls applied for this scenario.

Scenario 2a (S2a) analyses the benefits from the implementation of the AMSA Direction with the 2015/16 cruise season. Emissions estimates for this scenario are based on the following assumptions:

i. Ships will transition from 2.7% S HFO to 0.1% S or 0.001% S during the first hour at-berth and transition back to 2.7% S HFO the last hour at-berth, as allowed by the directive. Due to blending during the switching period, the fuel average for the two one-hour periods will be assumed to be 1.35% S. The remainder time at-berth, defined as the berthing period in the AMSA Directive, the auxiliary engines will be assumed to operate on 0.1% S or 0.001% S fuels.
ii. No additional emissions controls applied for this scenario.

It should be noted that switching from HFO to MGO fuels reduces NO_x by 6%.[28]

[28] Port of Long Beach, *www.polb.com/environment/air/emissions.asp*; Port of Los Angles, *www.portoflosangeles.org/environment/studies_reports.asp*, accessed October 2015

5.3 S3 – Alternative Compliance with Fuel Sulphur Regulations: 2.7% S with EGCS

Scenario 3 (S3) analyses the benefits from a combination of exhaust gas cleaning systems (EGCS), otherwise known as scrubbers, and 2.7% S fuels as an alternative compliance option to the S2 Fuel Sulphur Regulations. This scenario estimates emissions assuming that ships calling at WBCT that are scheduled to have an EGCS installed in the future actually have the systems on-board and operational for the 2015/16 Season. As detailed in Section 4 above, Carnival is currently implementing a strategy that will install EGCS across its fleet. This means that when the systems are installed, 13 of 24 ships would have EGCS, representing 115 calls or 87% of the calls when put in context of the 2015/16 Season. This scenario represents an estimated future-case maximum benefit, based on the 2015/16 fleet for reference. Emissions are estimated based on the following assumptions:

i. All EGCS equipped ships use EGCS while at-berth
ii. EGCS equipped ships use 2.7% S fuel for the duration of their calls
iii. EGCS emissions reduction efficiencies of:[29]
    - 98% reduction of SO_x
    - 80% reduction of PM
    - 10% reduction of NO_x
iv. No additional emissions controls applied for this scenario

5.4 S4 – Alternative Compliance with Fuel Sulphur Regulations: 0.1%/0.001% S with EGCS

Scenario 4 (S4) is similar to S3, however the fuel used with the EGCS is assumed to be compliant with the S2 Fuel Sulphur Regulations at either 0.1% or 0.001% S fuels during the entire stay at-berth. This would represent an 'above and beyond' approach in that a cleaner fuel would still be switched over and the on-board EGCS system engaged whilst at-berth. This scenario nullifies the economic benefit to the ship operator for installing an EGCS (the operator would be paying both for higher priced fuels and for installation of emissions reduction equipment that would save them from needing to switch fuels in the first place).

[29] Starcrest correspondence with Thomas Dow, Vice President Public Affairs, Carnival Corp, Washington D.C., US, 1 October 2015. Starcrest contacted and confirmed with Don Greggory, Director, Exhaust Gas Cleaning System Association (EGCSA) to confirm that the values provided were within anticipated ranges for EGCS, October 2015.

5.5 S5 – Shore Power

Scenario 5 (S5), similar to S3, represents a future-case maximum benefit analysis that assumes a certain percentage of ship calls of the 2015/16 season are shore powered, as described below. Emissions are estimated based on the following assumptions:

i. Assumes a regulatory requirement that cruise companies calling more than 20 times would need to reduce emissions by 80% via shore power, in addition all ships with shore power capabilities will have to plug in; similar to CARB's shore power regulation scheme:
   - 116 calls out of 132 shore powered
   - 10 ships with shore power infrastructure

ii. All shore powered cruise ship calls are assumed to need an average of one hour after being tied up at-berth for connection to the grid and shut down of the auxiliary engines, and one hour prior to departure to start up the auxiliary engines and disconnect from the grid. Total auxiliary engine run time per call during the connection to and disconnection from the grid is assumed to be an average of two hours with the engines operating on 2.7% S fuels as allowed under the AMSA Direction.

iii. Boilers for these ships will assume to comply with the AMSA Direction and will operate 2 hours on 1.35% S fuel oil, to allow for fuel switching from 2.7% S fuels and the rest of the time (defined as the berthing period in the AMSA Direction) on either 0.1% or 001% S fuels.

iv. All cruise ships not shore powered are assumed to comply with the AMSA Direction (S2a).

v. At-berth electrical demand from the ship's on-board electrical consumers is fully provided by the landside electrical power grid during the connection period.

vi. In estimating grid emissions related to power generation to cover the at-berth electrical demand, no losses were assumed across the landside grid (from grid generation location to ship). Average loads per call, per ship are provided in Section 6.

vii. Grid emission rates were based on aggregated power production and associated emissions rates as published in Technical Report No. 5, Air Emissions Inventory for the Greater Metropolitan Region in NSW, 2008[30] and adjusted for 2015 based on the 2015 electrical generation make up (see Section 2.7) and normalized emissions rates from the 2008 Air Emissions Inventory.

It should be noted that while this scenario does look at the future-case maximum benefit, the reality is that currently only 6 of 24 cruise ships are shore power-ready, and those ships make 29 of 132 calls or 22%. For the anticipated 2016/17 season, currently 6 of 29 ships are shore power-ready, and make up 55 of 215 calls or 25%.

[30] EPA, *http://www.epa.nsw.gov.au/air/airinventory2008.htm*, accessed November 2015

6. Emissions Benefits Analysis by Scenario

The methods for analysing the above scenarios are based on methods used by the California Air Resources Board (CARB), numerous ports in North America and Asia, and consistent with the 2014 Third IMO GHG Study.[31] Ship emissions at-berth are estimated based on engine or boiler load, in kW, multiplied by the time at that load, in hours, to get energy consumption, in kWh. Work is then multiplied by specific emission factor, g/kWh, to get grams of emissions, which are then converted to tonnes.

6.1 Scenario Energy Consumption Estimates

Energy consumption estimates, in kWh, were developed for each of the five scenarios. They are based on assumed auxiliary engine and boiler loads while at-berth, which are based on data collected from Starcrest's Vessel Boarding Program, information provide by cruise lines, and from emissions inventories conducted at the Port of Los Angeles and Port of Long Beach, in California.[32] Energy consumption by emissions source for each scenario is then compiled, in kWh, on a per call basis and then multiplied by the total number of calls to get the total 2015/16 estimated power consumption. S1, S3, and S4 all have similar energy consumption profiles with the only consumer being the auxiliary engines. S2 also only has auxiliary engines as energy consumers and S2a includes both the fuel switching (FS) related energy and fully switched fuel related energy. S5 includes auxiliary engines prior to connection and after disconnecting to shore power, auxiliary boilers during fuel switching and shore power connection, and power provided to the ship by the landside power grid for shore power. Scenario energy consumption estimates are presented in Tables 6.1 and 6.2.

[31] IMO, *www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx*, accessed October 2015

[32] Port of Long Beach, *www.polb.com/environment/air/emissions.asp*; Port of Los Angles, *www.portoflosangeles.org/environment/studies_reports.asp*; accessed October 2015

Table 6.1: Scenario Energy Consumption/Generation per Call, by Emissions Source

2015/16 Cruise Season Vessel	Shore Powered?	Total Calls	Total Hours At-Berth	Average Hours per Call At-Berth	Aux Load kW	Boiler Load kW	S1, S2 S3, S4 Aux per Call kWh	S2a Aux Berth per Call kWh	S2a Aux FS Berth per Call kWh	S5 Aux Berth per Call kWh	S5 Aux FS Berth per Call kWh	S5 Grid per Call kWh	S5 Boilers per Call kWh	S5 Boilers FS Berth per Call kWh
Albatros	N	1	62	62.0	4,000	700	248,000	240,000	8,000	240,000	8,000	0	0	0
Amsterdam	Y	1	34	34.0	6,000	1,200	204,000	192,000	12,000	0	12,000	192,000	38,400	2,400
Artania	N	1	36	36.0	5,000	900	180,000	170,000	10,000	170,000	10,000	0	0	0
Astor	N	1	11	11.0	2,500	500	27,500	22,500	5,000	22,500	5,000	0	0	0
Azamara Quest	N	2	62	31.0	2,500	500	77,500	72,500	5,000	72,500	5,000	0	0	0
Black Watch	N	1	38	38.0	2,500	600	95,000	90,000	5,000	90,000	5,000	0	0	0
Crystal Serenity	Y	1	41	41.0	4,500	800	184,500	175,500	9,000	0	9,000	175,500	31,200	1,600
Dawn Princess	Y	14	126	9.0	7,500	1,600	67,500	52,500	15,000	0	15,000	52,500	11,200	3,200
Europa	N	1	37	37.0	1,000	300	37,000	35,000	2,000	35,000	2,000	0	0	0
MS Marina	N	1	24	24.0	5,000	900	120,000	110,000	10,000	110,000	10,000	0	0	0
Noordam	Y	4	36	9.0	6,500	1,300	58,500	45,500	13,000	0	13,000	45,500	9,100	2,600
Pacific Aria	Y	14	172	12.3	5,000	1,100	61,500	51,500	10,000	0	10,000	51,500	11,330	2,200
Pacific Eden	Y	14	119	8.5	5,000	1,100	42,500	32,500	10,000	0	10,000	32,500	7,150	2,200
Pacific Jewel	Y	37	331	8.9	6,500	1,300	57,850	44,850	13,000	0	13,000	44,850	8,970	2,600
Pacific Pearl	Y	22	189	8.6	6,500	1,300	55,900	42,900	13,000	0	13,000	42,900	8,580	2,600
Pacific Princess	N	1	15	15.0	2,500	500	37,500	32,500	5,000	32,500	5,000	0	0	0
Pacific Venus	N	1	28	28.0	2,500	500	70,000	65,000	5,000	65,000	5,000	0	0	0
Sea Princess	Y	4	37	9.3	7,500	1,600	69,750	54,750	15,000	0	15,000	54,750	11,680	3,200
Seabourn Odyssey	N	1	35	35.0	2,000	300	70,000	66,000	4,000	66,000	4,000	0	0	0
Silver Shadow	N	1	13	13.0	2,750	300	35,750	30,250	5,500	30,250	5,500	0	0	0
Silver Whisper	N	2	39	19.5	2,750	300	53,625	48,125	5,500	48,125	5,500	0	0	0
Sun Princess	Y	5	45	9.0	6,500	1,600	58,500	45,500	13,000	0	13,000	45,500	11,200	3,200
Superstar Virgo	N	1	22	22.0	12,000	2,300	264,000	240,000	24,000	240,000	24,000	0	0	0
Volendam	N	1	11	11.0	7,000	1,300	77,000	63,000	14,000	63,000	14,000	0	0	0
		132	**1,563**				**2,253,375**	**2,022,375**	**231,000**	**1,284,875**	**231,000**	**737,500**	**148,810**	**25,800**

Table 6.2: Scenario Energy Consumption/Generation 2015/16 Season, by Emissions Source

2015/16 Cruise Season Vessel	Shore Powered?	Total Calls	Total Hours At-Berth	Average Hours per Call At-Berth	Aux Load kW	Boiler Load kW	S1, S2 S3, S4 Aux Seasonal kWh	S2a Aux Berth Seasonal kWh	S2a Aux FS Berth Seasonal kWh	S5 Aux Berth Seasonal kWh	S5 Aux FS Berth Seasonal kWh	S5 Grid Seasonal kWh	S5 Boilers Berth Seasonal kWh	S5 Boilers FS Berth Seasonal kWh
Albatros	N	1	62	62.0	4,000	700	248,000	240,000	8,000	240,000	8,000	0	0	0
Amsterdam	Y	1	34	34.0	6,000	1,200	204,000	192,000	12,000	0	12,000	192,000	36,000	2,400
Artania	N	1	36	36.0	5,000	900	180,000	170,000	10,000	170,000	10,000	0	0	0
Astor	N	1	11	11.0	2,500	500	27,500	22,500	5,000	22,500	5,000	0	0	0
Azamara Quest	N	2	62	31.0	2,500	500	155,000	145,000	10,000	145,000	10,000	0	0	0
Black Watch	N	1	38	38.0	2,500	600	95,000	90,000	5,000	90,000	5,000	0	0	0
Crystal Serenity	Y	1	41	41.0	4,500	800	184,500	175,500	9,000	0	9,000	175,500	29,600	1,600
Dawn Princess	Y	14	126	9.0	7,500	1,600	945,000	735,000	210,000	0	210,000	735,000	112,000	44,800
Europa	N	1	37	37.0	1,000	300	37,000	35,000	2,000	35,000	2,000	0	0	0
MS Marina	N	1	24	24.0	5,000	900	120,000	110,000	10,000	110,000	10,000	0	0	0
Noordam	Y	4	36	9.0	6,500	1,300	234,000	182,000	52,000	0	52,000	182,000	26,000	10,400
Pacific Aria	Y	14	172	12.3	5,000	1,100	861,000	721,000	140,000	0	140,000	721,000	127,820	30,800
Pacific Eden	Y	14	119	8.5	5,000	1,100	595,000	455,000	140,000	0	140,000	455,000	69,300	30,800
Pacific Jewel	Y	37	331	8.9	6,500	1,300	2,140,450	1,659,450	481,000	0	481,000	1,659,450	235,690	96,200
Pacific Pearl	Y	22	189	8.6	6,500	1,300	1,229,800	943,800	286,000	0	286,000	943,800	131,560	57,200
Pacific Princess	N	1	15	15.0	2,500	500	37,500	32,500	5,000	32,500	5,000	0	0	0
Pacific Venus	N	1	28	28.0	2,500	500	70,000	65,000	5,000	65,000	5,000	0	0	0
Sea Princess	Y	4	37	9.3	7,500	1,600	279,000	219,000	60,000	0	60,000	219,000	33,920	12,800
Seabourn Odyssey	N	1	35	35.0	2,000	300	70,000	66,000	4,000	66,000	4,000	0	0	0
Silver Shadow	N	1	13	13.0	2,750	300	35,750	30,250	5,500	30,250	5,500	0	0	0
Silver Whisper	N	2	39	19.5	2,750	300	107,250	96,250	11,000	96,250	11,000	0	0	0
Sun Princess	Y	5	45	9.0	6,500	1,600	292,500	227,500	65,000	0	65,000	227,500	40,000	16,000
Superstar Virgo	N	1	22	22.0	12,000	2,300	264,000	240,000	24,000	240,000	24,000	0	0	0
Volendam	N	1	11	11.0	7,000	1,300	77,000	63,000	14,000	63,000	14,000	0	0	0
		132	**1,563**				**8,489,250**	**6,915,750**	**1,573,500**	**1,405,500**	**1,573,500**	**5,510,250**	**841,890**	**303,000**

It should be noted that for S3 and S4, an additional 2% kWh for use of EGCS is applied during the emissions estimates. This increase in kWh is due to the power requirements associated with the systems.

6.2 Emissions Factors

Typically, when estimating emissions from ships in the port area there are several specific pollutants and greenhouse gases (GHGs) that are included. The list of pollutants and GHGs for each port may vary depending on what air quality issues the local region is concerned about, like health risk, ozone, acid rain, etc.

Ship engines and boilers produce pollutants during operation, such as:

- Particulate Matter (PM_{10} and $PM_{2.5}$) refers to tiny, discrete solid or aerosol particles in the air. Dust, dirt, soot, and smoke are considered particulate matter (PM). Two types of PM are included in this emissions inventory: PM_{10}, which consists of particles measuring up to 10 micrometres in diameter; and $PM_{2.5}$, which consists of fine particles measuring 2.5 micrometres in diameter or smaller.
- Sulphur oxides (SO_x) are colourless, corrosive gases produced by the burning of fuel containing sulphur, like coal and oil, and by industrial processes such as smelters, paper mills, power plants and steel manufacturing plants. Sulphur dioxide (SO_2) is one form of SO_x.

- Nitrogen oxides (NO_x) is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts. Most NO_x are colourless and odourless. NO_x is made up of varying concentrations of nitrogen oxide (NO) and nitrogen dioxide (NO_2). NO_2 plays an essential role in the photochemical reactions that produce ozone, the major component in smog. NO_x is typically estimated for regions that have ozone-related air quality issues.
- Volatile organic compounds (VOCs) are comprised of various volatile fragments, including formaldehyde, both human-made and naturally occurring. In the context of diesel engine operations, benzene, toluene, ethylbenzene, and xylene (BTEX) are the VOCs mostly associated with more refined fuels like ULSD. The fractions of VOCs for BTEX constituents for pre-2007 model year land-based diesel engines running on ULSD are: [33]
    - Benzene 0.007835
    - Toluene 0.00433
    - Ethylbenzene 0.002655
    - Xylene 0.003784

  BTEX is typically not calculated nor associated with ship emissions. Additional research would be needed to obtain more specific breakouts to the engines anticipated to be used on-board cruise ships calling at WBCT in order to estimate BTEX emissions at the cruise terminal with full confidence; however, for the magnitude of their emission, the above factors are sufficient. BTEX and VOCs are anticipated to be marginally controlled with scrubbers, however there is no testing data to derive an efficiency factor, and therefore no reduction was taken in S3 and S4.
- Carbon dioxide (CO_2) is the dominant GHG produced by ship engines and boilers. Diesel Cycle engines are some of the most efficient engines and create relatively low CO_2 emissions compared to other engine types, such as spark-ignited engines. Other important GHGs emitted are: nitrous oxide (N_2O) and methane (CH_4). These have equivalent global warming potentials compared to CO_2 of 298 and 25 respectively. However, even with these relatively high global warming potentials, N_2O at-berth is typically less than 2% of CO_2 and CH_4 is significantly less than 1% of CO_2.[34]
- Diesel Particulate Matter (DPM) is a significant component of PM. Diesel exhaust also includes more than 40 substances that are listed as hazardous pollutants. DPM is considered a surrogate for the effects of both the PM and gaseous component of diesel exhaust. For ships, DPM is typically slightly less than $PM_{2.5}$ due to the fact that auxiliary boilers do not produced DPM. For scenarios that don't involve boilers, the DPM emissions will typically be similar to the $PM_{2.5}$ levels.
- Carbon monoxide (CO) is a colourless, odourless, toxic gas commonly formed when carbon-containing fuel is not burned completely. Motor vehicles are typically the predominant source of carbon monoxide in urban regions.
- Hydrocarbons (HC) emissions are fragments of fuel molecules that are only partially burned in the fuel combustion process. HC in the air react with NO_x and sunlight to contribute to the formation of ground-level ozone and greenhouse gases. On a mass basis, HC generated from cruise ships burning low sulphur fuels is approximately 1.6 times the mass of PM_{10} emissions for the same activity levels.[35]

[33] USEPA, *Air Toxics Emissions from On-Road Vehicles in MOVES2014*, EPA-420-R-14-021, December 2014
[34] Port of Long Beach, *2013 Air Emissions Inventory,* Starcrest, July 2014 [POLB 2013], Table 2.23
[35] Port of Long Beach, *2014 Air Emissions Inventory*, Starcrest, September 2015 [POLB 2014], Table 2.1

For this analysis, PM_{10}, $PM_{2.5}$, SO_x, NO_x, VOC, and CO_2 emissions were estimated as they were indicated as the primary pollutants of concern in NSW, and CO_2 was the only GHG estimated from the landside power grid for comparison.

For auxiliary engines, specific emissions factors are used for Diesel Cycle medium speed engines (speeds between 130 – 2,000 revolutions per minute [rpm]) based on the fuel they are using. Similarly for boilers, specific emissions factors are used for auxiliary boilers based on the fuel they are using. The emissions factors,[36] in grams (g)/kWh, used for this study are presented in Table 6.3.

Table 6.3: Scenario Energy Consumption/Generation 2015/16 Season, by Emissions Source

Engine	IMO Tier	PM_{10}	$PM_{2.5}$	NOx	SOx	VOC	CO_2
HFO 2.7% Sulfur							
Medium speed diesel	Tier 0	1.50	1.200	14.7	12.3	0.408	722
Medium speed diesel	Tier 1	1.50	1.200	13.0	12.3	0.408	722
HFO 1.35% Sulfur							
Medium speed diesel	Tier 0	1.19	0.948	14.7	6.15	0.408	722
Medium speed diesel	Tier 1	1.19	0.948	13.0	6.15	0.408	722
MDO/MGO 0.1% Sulfur							
Medium speed diesel	Tier 0	0.26	0.240	13.8	0.50	0.408	686
Medium speed diesel	Tier 1	0.26	0.240	12.2	0.50	0.408	686
ULSD 0.001% Sulfur							
Medium speed diesel	Tier 0	0.23	0.204	13.8	0.01	0.408	686
Medium speed diesel	Tier 1	0.23	0.204	12.2	0.01	0.408	686
Auxiliary Boiler Emission Factors (g/kWh)							
Engine	IMO Tier	PM_{10}	$PM_{2.5}$	NOx	SOx	VOC	CO_2
Boiler 1.35% S	na	0.63	0.506	2.10	8.25	0.10	970
Boiler 0.1% S	na	0.14	0.130	2.00	0.60	0.10	922
Boiler 0.001% S	na	0.12	0.109	2.00	0.01	0.10	921

For regional electric power grid-related emissions, specific emissions factors were generated based on the electrical generation sources supplying the grid, and the EPA estimated emissions from those sources in 2008. Emissions factors were composited and converted to g/kWh for both 2008 and 2015 based on the electrical generation mix (see Section 2.7), and are presented in Table 6.4. The composite emissions factors for 2015 were used in the evaluation for S5.

[36] POLB 2013; Port of Los Angeles, *2014 Inventory of Air Emissions*, Starcrest, September 2015

Table 6.4: Composite Emissions Factors for Greater Metropolitan Region Grid, NSW

Electricity Generation Source	Electricity Generation 2008 GWh/year	PM_{10} 2008 kg/year	$PM_{2.5}$ 2008 kg/year	SOx 2008 kg/year	NOx 2008 kg/year	VOC 2008 kg/year	CO_2 2008 kg/year
Coal	68,999	6,520,000	3,340,000	251,000,000	166,000,000	904,000	65,100,000,000
Gas	3,033	84,900	84,900	17,800	2,360,000	411,000	1,080,000,000
Non Coal/Gas	84	2,040	2,010	10,900	130,000	34,500	50,000,000
Total	**72,116**	**6,606,940**	**3,426,910**	**251,028,700**	**168,490,000**	**1,349,500**	**66,230,000,000**
Composite EF 2008 kg/GWh		92	48	3,481	2,336	19	918,381
Composite 2008 g/kWh		0.09	0.05	3.48	2.34	0.02	918.38
Composite 2015 g/kWh		**0.07**	**0.04**	**2.40**	**1.70**	**0.03**	**671.39**

The following key observations can be made from Tables 6.3 and 6.4:

i. Auxiliary boilers vs. auxiliary engine using 0.1% sulphur marine gas oil (MGO), from an emissions standpoint (for the same amount of kWh):
   - PM: an auxiliary engine emits nearly double the PM as an auxiliary boiler
   - SO_x: an auxiliary boiler emits slightly greater SO_x than an auxiliary engine
   - NO_x: an auxiliary boiler emits over 6 time less NO_x than an auxiliary engine
   - CO_2: an auxiliary boiler emits significantly greater CO_2 than an auxiliary engine

ii. Auxiliary boiler and auxiliary engine using 0.1% sulphur MGO vs NSW grid (2015 adjusted), from an emissions standpoint (for the same amount of kWh):
   - PM: NSW grid emits nearly double the PM as an auxiliary boiler and slightly less than an auxiliary engine
   - SO_x: NSW grid emits over 4 times greater SO_x than an auxiliary engine or auxiliary boiler
   - NO_x: NSW grid emissions over 7 times less than an auxiliary engine and slightly less than an auxiliary boiler
   - CO_2: NSW grid emits slightly less CO_2 than an auxiliary engine and about the a third of an auxiliary boiler (excluding grid losses)

6.3 Scenario Emissions Estimates

Emissions estimates are developed by applying the appropriate emissions factors to the estimated energy consumption, by source, under each scenario. Summaries of each scenario's emissions estimates are presented in Table 6.5. Emissions that occur at WBCT include auxiliary engines and boilers, while grid emissions (S5) occur regionally.

It is important to note that the emissions estimates in this analysis provide a relative magnitude in emissions levels that can be used to compare each scenario against each other and provide perspective against other emissions sources in the Greater Metropolitan Region. The comparisons between the scenarios and the resulting differences are the most important aspect of the emissions analysis; the precise estimated masses are much less important.

One tonne of $PM_{2.5}$ emissions is equivalent to over 55,500 heavy-duty diesel trucks operating for an average workday.

One tonne of SO_x emission is equivalent to over 380,000 heavy-duty diesel trucks operating for an average workday.

One tonne of CO_2 emission is equivalent to nearly 4 heavy-duty diesel trucks operating for an average workday.

Table 6.5: Scenarios Summary of Total Emissions Estimates

Scenario	Condition	Emission Source	2015/16 Season Emissions Estimates, tonnes PM_{10}	$PM_{2.5}$	SOx	NOx	VOC	CO_2
S1	Baseline 2.7%S	Aux Engines	**12.73**	**10.19**	**104.42**	**123.3**	**3.46**	**6,129**
S2 (NSW)	0.1% S	Aux Engines	**2.21**	**2.04**	**4.24**	**115.8**	**3.46**	**5,823**
	0.001% S	Aux Engines	**1.91**	**1.73**	**0.04**	**115.8**	**3.46**	**5,823**
S2a (AMSA)	0.1% S/1.35%S	Aux Engines	**3.66**	**3.15**	**13.13**	**117.2**	**3.46**	**5,880**
	0.001% S/1.35%S	Aux Engines	**3.42**	**2.90**	**9.71**	**117.2**	**3.46**	**5,880**
S3	EGCS & 2.7% S	Aux Engines	**2.55**	**2.04**	**2.09**	**111.0**	**3.46**	**6,252**
S4	EGCS & 0.1% S	Aux Engines	**0.44**	**0.41**	**0.08**	**104.2**	**3.46**	**5,939**
S4	EGCS & 0.001% S	Aux Engines	**0.38**	**0.35**	**0.001**	**104.2**	**3.46**	**5,939**
S5	0.1%, 1.35%, 2.7% S fuels	Aux Engines	2.23	1.83	10.38	41.7	1.2	2,100
	& Shore Power	Boilers	0.31	0.26	3.00	2.3	0.1	1,070
		Grid	0.39	0.22	13.22	9.4	0.2	3,700
			2.93	**2.31**	**26.61**	**53.4**	**1.5**	**6,869**
S5	0.1%, 1.35%, 2.7% S fuels	Aux Engines	2.18	1.78	9.68	41.7	1.2	2,100
	& Shore Power	Boilers	0.29	0.24	2.50	2.3	0.1	1,070
		Grid	0.39	0.22	13.22	9.4	0.2	3,700
			2.86	**2.24**	**25.41**	**53.4**	**1.5**	**6,869**

For context of the estimated emissions magnitudes for WBCT above, the baseline emissions are compared to the 2008 Sydney and Greater Metropolitan Region (GMR) EPA emissions inventory

Source	PM_{10} tonnes	$PM_{2.5}$ tonnes	SOx tonnes	NOx tonnes	VOC tonnes
WBCT Baseline	13	10	104	123	3
Sydney 2008	20,443	11,728	10,798	74,722	131,356
GMR 2008	123,458	39,083	289,237	319,156	306,595

Comparing Scenario 2 through Scenario 5 against Scenario 1 (representing baseline) shows the relative reductions from the pre-regulation condition, as presented in Table 6.6.

Table 6.6: Scenario Reduction Comparisons to S1

			2015/16 Season Emissions Reductions					
Comparison	Condition		PM_{10}	$PM_{2.5}$	SOx	NOx	VOC	CO_2
Scenario 2 v 1	0.1% S		82.7%	80.0%	95.93%	6.1%	0.0%	5.0%
Scenario 2 v 1	0.001% S		85.0%	83.0%	99.96%	6.1%	0.0%	5.0%
Scenario 2a v 1	0.1% S/1.35%S		71.2%	69.1%	87.42%	5.0%	0.0%	4.1%
Scenario 2a v 1	0.001% S/1.35%S		73.1%	71.5%	90.70%	5.0%	0.0%	4.1%
Scenario 3 v 1	EGCS & 2.7% S		80.0%	80.0%	98.00%	10.0%	0.0%	-2.0%
Scenario 4 v 1	EGCS & 0.1% S		96.5%	96.0%	99.92%	15.5%	0.0%	3.1%
Scenario 4 v 1	EGCS & 0.001% S		97.0%	96.6%	99.999%	15.5%	0.0%	3.1%
Scenario 5 v 1	0.1%, 1.35%, 2.7% S fuels	Local	80.1%	79.5%	87.18%	64.3%	62.5%	na
	& Shore Power	Regional	77.0%	77.3%	74.52%	56.7%	57.7%	-12.1%
Scenario 5 v 1	0.1%, 1.35%, 2.7% S fuels	Local	80.6%	80.1%	88.33%	64.3%	62.5%	na
	& Shore Power	Regional	77.5%	78.0%	75.66%	56.7%	57.7%	-12.1%

Note: a negative reduction represents an increase in emissions

From a local emissions perspective, all the emissions reduction scenarios provide a range of reductions in PM_{10}, $PM_{2.5}$, and SO_x from 69% to nearly 100%, which is a ***significant*** improvement over the pre-2015 emissions. NO_x is reduced from 5% to nearly 65% locally depending on the strategy, with Scenario 5 having the most significant improvements. Fuel switching alone based on the AMSA Direction (Scenario 2a), provides better than 69% reduction in PM and between 87% and 90% reduction in SO_x. Scenario 2a also has a slight reduction in NO_x and no impact on VOC emissions. Scenario 4 and Scenario 5 provide locally greater than a 95% reduction in PM_{10}, $PM_{2.5}$, and SO_x, while regionally Scenario 5 is anticipated to perform poorer, relative to the same pollutants, as the grid servicing WBCT and has relatively high PM and SO_x emissions rates. Scenario 5 performs better for NO_x and VOC than Scenario 4 and all other scenarios. Scenario 3 reduces PM_{10}, $PM_{2.5}$, and SO_x from 80% to nearly 98%, which is nearly as effective as Scenario 5 regionally, with significantly less CO_2 penalty.

Scenario 5 is the only scenario that has a significant (12%) increase in CO_2 due to the composition of grid-generated power (even with updated 2015 electrical generation mix which incorporates renewables in the generation portfolio [see Section 2.7]). In addition, regional emissions are increased relative to the added energy that would be required from the ships connecting to the grid. This finding presents opportunities to incorporate and source dedicated renewable energy for shore power; however addressing dedicated renewable energy sources and associated costs were not evaluated in these scenarios as they were beyond the scope of this analysis.

Table 6.7 presents the associated mass emissions reductions, as modelled, for each scenario as compared to Scenario 1.

Table 6.7: Scenario Mass Emissions Reduction Comparisons to S1

			2015/16 Season Emissions Reduced, tonnes					
Comparison	Condition		PM_{10}	$PM_{2.5}$	SOx	NOx	VOC	CO_2
Scenario 2 v 1	0.1% S		10.5	8.1	100.2	7.6	0.0	306
Scenario 2 v 1	0.001% S		10.8	8.5	104.4	7.6	0.0	306
Scenario 2a v 1	0.1% S/1.35%S		9.1	7.0	91.3	6.1	0.0	250
Scenario 2a v 1	0.001% S/1.35%S		9.3	7.3	94.7	6.1	0.0	250
Scenario 3 v 1	EGCS & 2.7% S		10.2	8.1	102.3	12.3	0.0	-123
Scenario 4 v 1	EGCS & 0.1% S		12.3	9.8	104.3	19.1	0.0	190
Scenario 4 v 1	EGCS & 0.001% S		12.4	9.8	104.4	19.1	0.0	190
Scenario 5 v 1	0.1%, 1.35%, 2.7% S fuels	Local	10.2	8.1	91.0	79.3	2.2	na
	& Shore Power	Regional	9.8	7.9	77.8	69.9	2.0	-740
Scenario 5 v 1	0.1%, 1.35%, 2.7% S fuels	Local	10.3	8.2	92.2	79.3	2.2	na
	& Shore Power	Regional	9.9	7.9	79.0	69.9	2.0	-740

Note: a negative reduction represents an increase in emissions

For purposes of providing context to the magnitude of each scenario's relative remaining emissions, the emissions for each scenario's local emissions are illustrated in Figures 6.1 through 6.3 and regional emissions are illustrated in Figures 6.4 through 6.7. VOCs are not shown due to the relatively low mass emitted (less than 4 tonnes). It should be noted that CO_2 is unlike air pollutants in that its impact is the same whether it is emitted locally or regionally; therefore there is not a local comparison figure for CO_2.

Figure 6.1: Local PM Emissions Comparisons, by Scenario

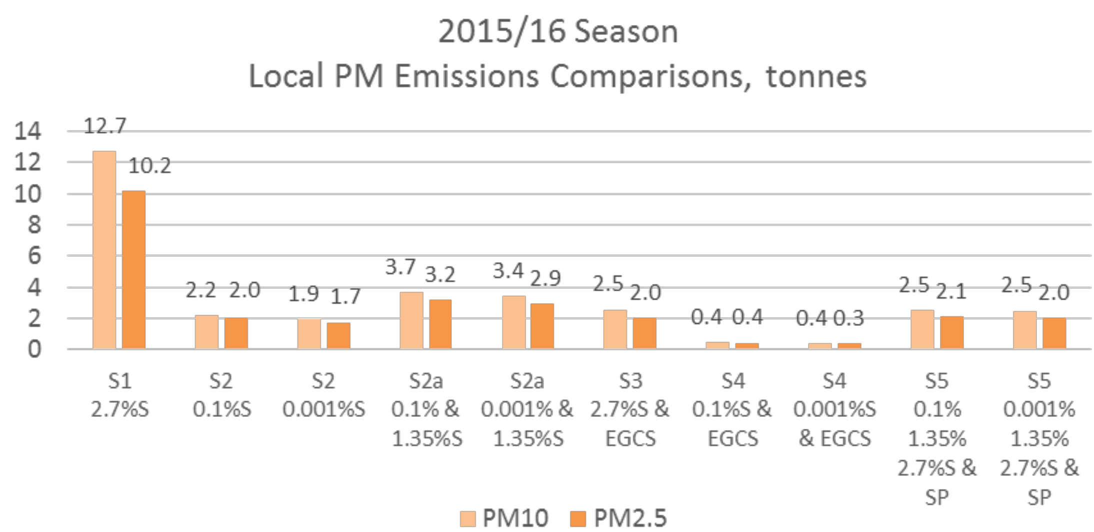


Figure 6.2: Local SO_x Emissions Comparisons, by Scenario

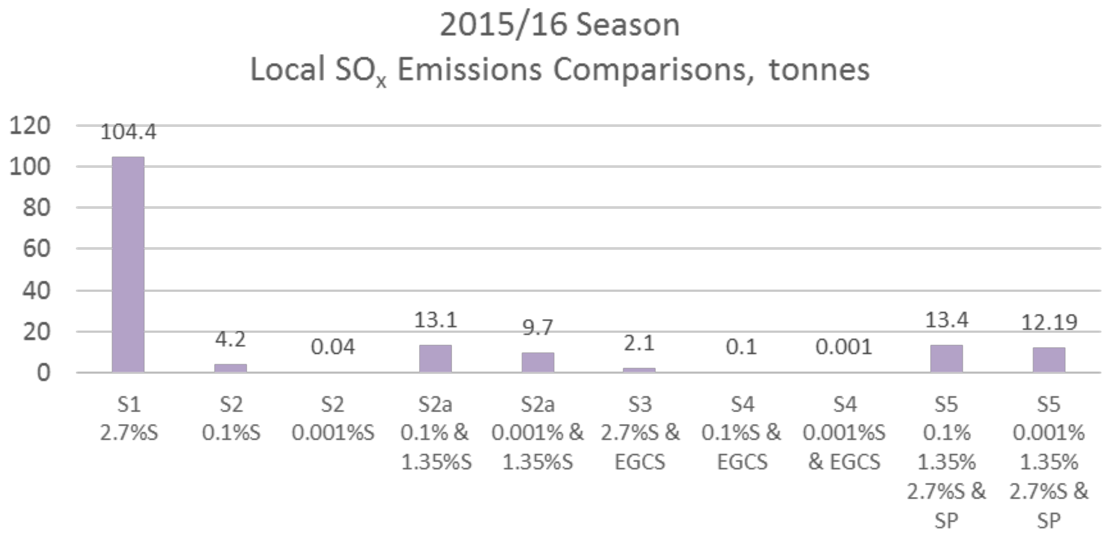


Figure 6.3: Local NO_x Emissions Comparisons, by Scenario

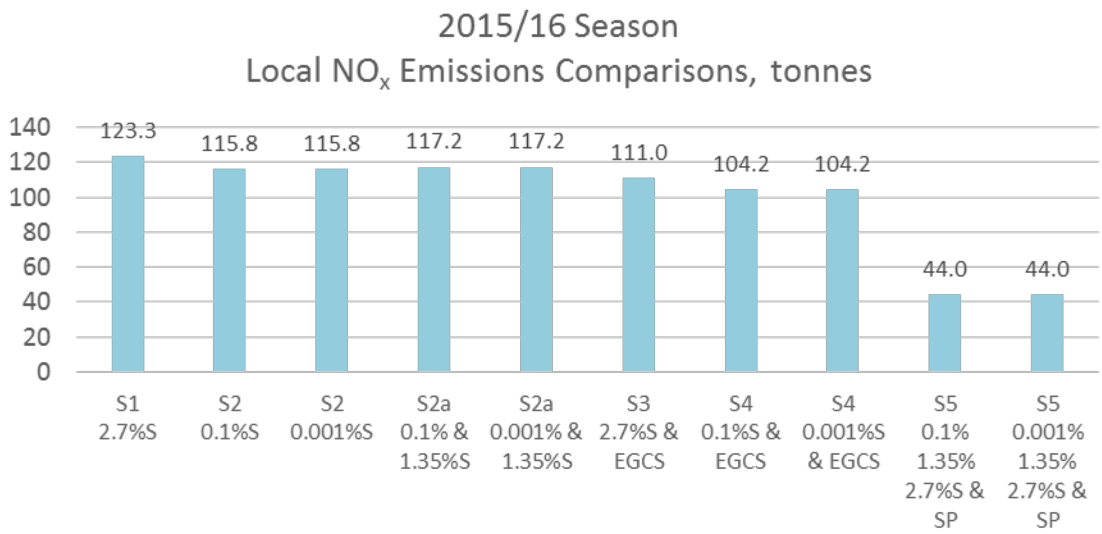


Figure 6.4: Regional PM Emissions Comparisons, by Scenario

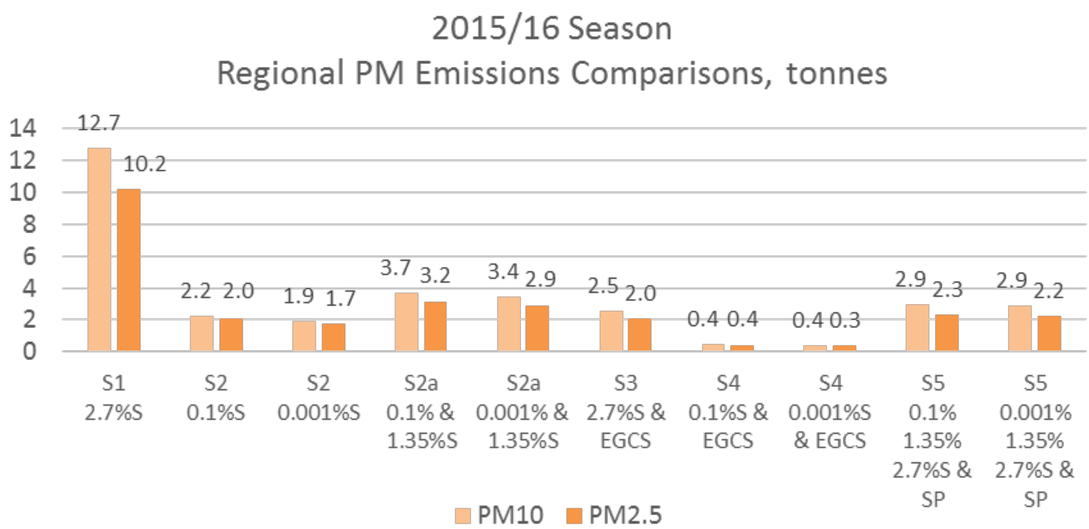


Figure 6.5: Regional SO_x Emissions Comparisons, by Scenario

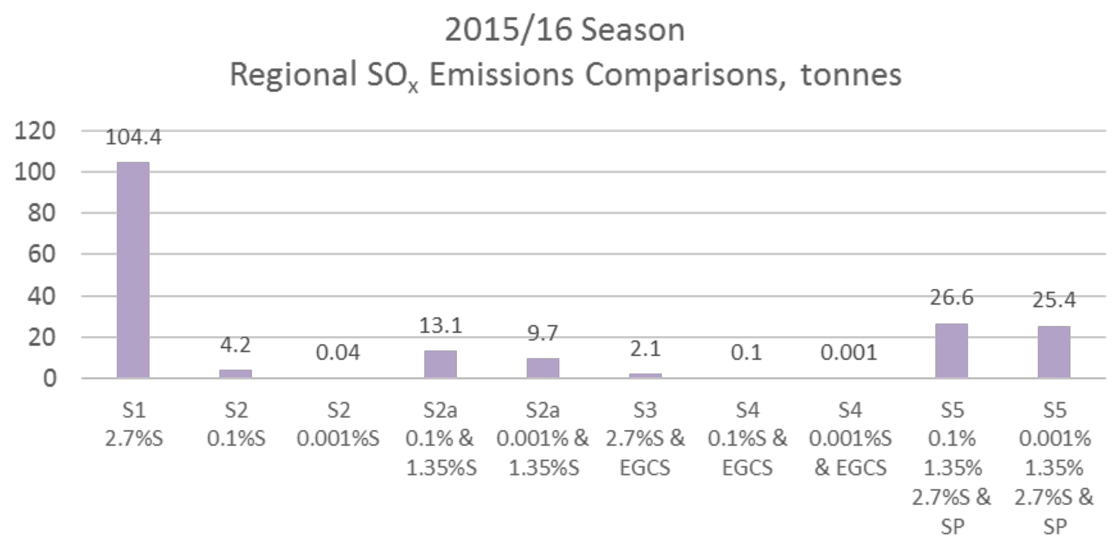


Figure 6.6: Regional NO_x Emissions Comparisons, by Scenario

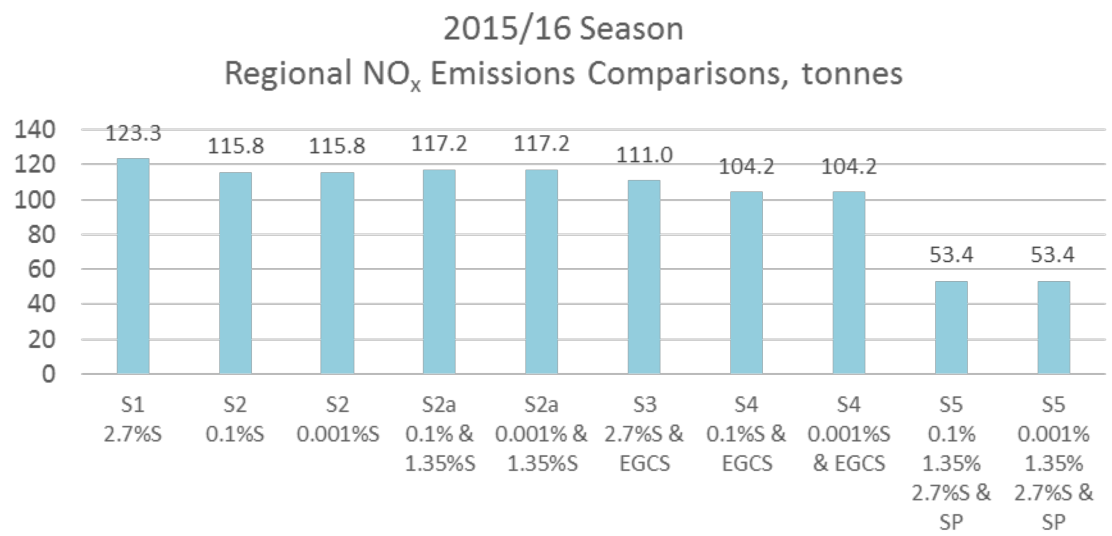
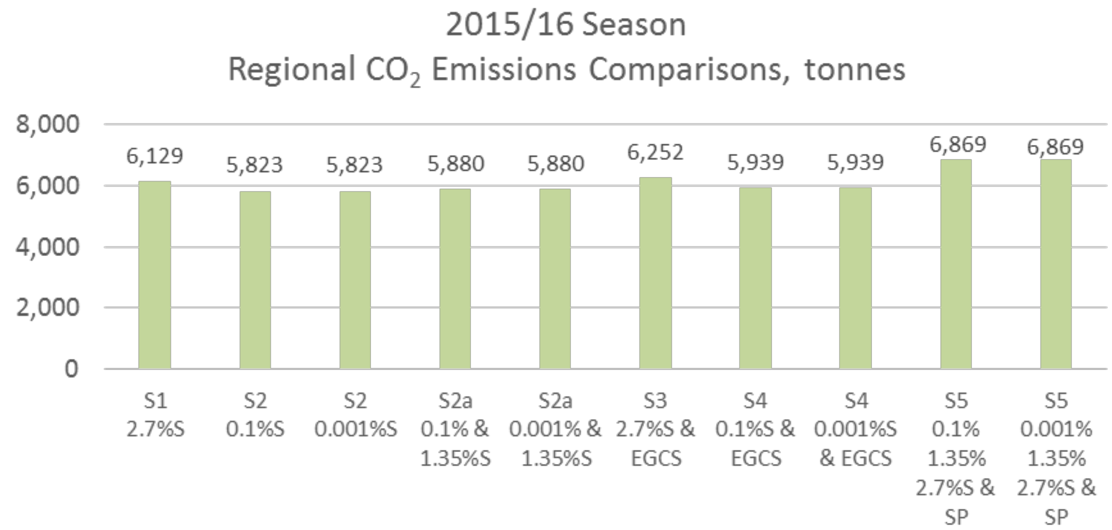


Figure 6.7: Regional CO_2 Emissions Comparisons, by Scenario



Emission estimates by ship for each scenario are presented in Tables 6.8 through 6.13.

Table 6.8: S1 Emissions Estimates, by Ship

2015/16 Cruise Season						S1 Baseline 2.7%S					
Vessel	S5 Shore Powered?	S3/S4 EGCS?	Calls	Total Hours At-Berth	Average hours per Call At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes
Albatros	N	Y	1	62	62.0	0.37	0.30	3.05	3.22	0.10	179
Amsterdam	Y	Y	1	34	34.0	0.31	0.24	2.51	3.00	0.08	147
Artania	N	Y	1	36	36.0	0.27	0.22	2.21	2.65	0.07	130
Astor	N	Y	1	11	11.0	0.04	0.03	0.34	0.40	0.01	20
Azamara Quest	N	Y	2	62	31.0	0.23	0.19	1.91	2.28	0.06	112
Black Watch	N	Y	1	38	38.0	0.14	0.11	1.17	1.40	0.04	69
Crystal Serenity	Y	Y	1	41	41.0	0.28	0.22	2.27	2.40	0.08	133
Dawn Princess	Y	Y	14	126	9.0	1.42	1.13	11.62	13.89	0.39	682
Europa	N	Y	1	37	37.0	0.06	0.04	0.46	0.54	0.02	27
MS Marina	N	Y	1	24	24.0	0.18	0.14	1.48	1.56	0.05	87
Noordam	Y	Y	4	36	9.0	0.35	0.28	2.88	3.04	0.10	169
Pacific Aria	Y	Y	14	172	12.3	1.29	1.03	10.59	12.66	0.35	622
Pacific Eden	Y	Y	14	119	8.5	0.89	0.71	7.32	8.75	0.24	430
Pacific Jewel	Y	Y	37	331	8.9	3.21	2.57	26.33	31.46	0.87	1,545
Pacific Pearl	Y	Y	22	189	8.6	1.84	1.48	15.13	18.08	0.50	888
Pacific Princess	N	Y	1	15	15.0	0.06	0.05	0.46	0.55	0.02	27
Pacific Venus	N	Y	1	28	28.0	0.11	0.08	0.86	1.03	0.03	51
Sea Princess	Y	Y	4	37	9.3	0.42	0.33	3.43	4.10	0.11	201
Seabourn Odyssey	N	Y	1	35	35.0	0.11	0.08	0.86	0.91	0.03	51
Silver Shadow	N	Y	1	13	13.0	0.05	0.04	0.44	0.53	0.01	26
Silver Whisper	N	Y	2	39	19.5	0.16	0.13	1.32	1.58	0.04	77
Sun Princess	Y	Y	5	45	9.0	0.44	0.35	3.60	4.30	0.12	211
Superstar Virgo	N	Y	1	22	22.0	0.40	0.32	3.25	3.88	0.11	191
Volendam	N	Y	1	11	11.0	0.12	0.09	0.95	1.13	0.03	56
			132	**1,563**		**12.73**	**10.19**	**104.42**	**123.34**	**3.46**	**6,129**

Table 6.9: S2 Emissions Estimates, by Ship

						S2 0.1% S						S2 0.001% S					
2015/16 Cruise Season Vessel	S5 Shore Powered?	S3/S4 EGCS?	Calls	Total Hours At-Berth	Average hours per Call At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes
Albatros	N	Y	1	62	62.0	0.06	0.06	0.12	3.03	0.10	170	0.06	0.05	0.0012	3.03	0.10	170
Amsterdam	Y	Y	1	34	34.0	0.05	0.05	0.10	2.82	0.08	140	0.05	0.04	0.0010	2.82	0.08	140
Artania	N	Y	1	36	36.0	0.05	0.04	0.09	2.48	0.07	123	0.04	0.04	0.0009	2.48	0.07	123
Astor	N	Y	1	11	11.0	0.01	0.01	0.01	0.38	0.01	19	0.01	0.01	0.0001	0.38	0.01	19
Azamara Quest	N	Y	2	62	31.0	0.04	0.04	0.08	2.14	0.06	106	0.03	0.03	0.0008	2.14	0.06	106
Black Watch	N	Y	1	38	38.0	0.02	0.02	0.05	1.31	0.04	65	0.02	0.02	0.0005	1.31	0.04	65
Crystal Serenity	Y	Y	1	41	41.0	0.05	0.04	0.09	2.25	0.08	127	0.04	0.04	0.0009	2.25	0.08	127
Dawn Princess	Y	Y	14	126	9.0	0.25	0.23	0.47	13.04	0.39	648	0.21	0.19	0.0047	13.04	0.39	648
Europa	N	Y	1	37	37.0	0.01	0.01	0.02	0.51	0.02	25	0.01	0.01	0.0002	0.51	0.02	25
MS Marina	N	Y	1	24	24.0	0.03	0.03	0.06	1.46	0.05	82	0.03	0.02	0.0006	1.46	0.05	82
Noordam	Y	Y	4	36	9.0	0.06	0.06	0.12	2.85	0.10	161	0.05	0.05	0.0012	2.85	0.10	161
Pacific Aria	Y	Y	14	172	12.3	0.22	0.21	0.43	11.88	0.35	591	0.19	0.18	0.0043	11.88	0.35	591
Pacific Eden	Y	Y	14	119	8.5	0.15	0.14	0.30	8.21	0.24	408	0.13	0.12	0.0030	8.21	0.24	408
Pacific Jewel	Y	Y	37	331	8.9	0.56	0.51	1.07	29.54	0.87	1,468	0.48	0.44	0.0107	29.54	0.87	1,468
Pacific Pearl	Y	Y	22	189	8.6	0.32	0.30	0.61	16.97	0.50	844	0.28	0.25	0.0061	16.97	0.50	844
Pacific Princess	N	Y	1	15	15.0	0.01	0.01	0.02	0.52	0.02	26	0.01	0.01	0.0002	0.52	0.02	26
Pacific Venus	N	Y	1	28	28.0	0.02	0.02	0.04	0.97	0.03	48	0.02	0.01	0.0004	0.97	0.03	48
Sea Princess	Y	Y	4	37	9.3	0.07	0.07	0.14	3.85	0.11	191	0.06	0.06	0.0014	3.85	0.11	191
Seabourn Odyssey	N	Y	1	35	35.0	0.02	0.02	0.04	0.85	0.03	48	0.02	0.01	0.0004	0.85	0.03	48
Silver Shadow	N	Y	1	13	13.0	0.01	0.01	0.02	0.49	0.01	25	0.01	0.01	0.0002	0.49	0.01	25
Silver Whisper	N	Y	2	39	19.5	0.03	0.03	0.05	1.48	0.04	74	0.02	0.02	0.0005	1.48	0.04	74
Sun Princess	Y	Y	5	45	9.0	0.08	0.07	0.15	4.04	0.12	201	0.07	0.06	0.0015	4.04	0.12	201
Superstar Virgo	N	Y	1	22	22.0	0.07	0.06	0.13	3.64	0.11	181	0.06	0.05	0.0013	3.64	0.11	181
Volendam	N	Y	1	11	11.0	0.02	0.02	0.04	1.06	0.03	53	0.02	0.02	0.0004	1.06	0.03	53
			132	**1,563**		**2.21**	**2.04**	**4.24**	**115.78**	**3.46**	**5,823**	**1.91**	**1.73**	**0.0424**	**115.78**	**3.46**	**5,823**

Table 6.10: S2a Emissions Estimates, by Ship

					S2a 0.1% S w/1.35% during fuel switch at berth							S2a 0.001% S w/1.35% during fuel switch at berth						
2015/16 Cruise Season Vessel	S5 Shore Powered?	Calls	Total Hours At-Berth	Average hours per Call At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux NO_2 Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes	Aux PM10 Seasonal tonnes	Aux PM2.5 Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux NO2 Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO2 Seasonal tonnes
Albatros	N	1	62	62.0	0.07	0.07	0.17	3.03	3.03	0.10	170	0.063	0.057	0.050	3.03	3.03	0.10	170
Amsterdam	Y	1	34	34.0	0.06	0.06	0.17	2.83	2.83	0.08	140	0.057	0.051	0.075	2.83	2.83	0.08	140
Artania	N	1	36	36.0	0.06	0.05	0.15	2.49	2.49	0.07	124	0.050	0.044	0.062	2.49	2.49	0.07	124
Astor	N	1	11	11.0	0.01	0.01	0.04	0.38	0.38	0.01	19	0.011	0.009	0.031	0.38	0.38	0.01	19
Azamara Quest	N	2	62	31.0	0.05	0.04	0.13	2.15	2.15	0.06	107	0.044	0.039	0.062	2.15	2.15	0.06	107
Black Watch	N	1	38	38.0	0.03	0.03	0.08	1.32	1.32	0.04	65	0.026	0.023	0.031	1.32	1.32	0.04	65
Crystal Serenity	Y	1	41	41.0	0.06	0.05	0.14	2.26	2.26	0.08	127	0.050	0.044	0.056	2.26	2.26	0.08	127
Dawn Princess	Y	14	126	9.0	0.44	0.38	1.66	13.23	13.23	0.39	656	0.414	0.349	1.295	13.23	13.23	0.39	656
Europa	N	1	37	37.0	0.01	0.01	0.03	0.51	0.51	0.02	25	0.010	0.009	0.012	0.51	0.51	0.02	25
MS Marina	N	1	24	24.0	0.04	0.04	0.12	1.47	1.47	0.05	83	0.037	0.032	0.062	1.47	1.47	0.05	83
Noordam	Y	4	36	9.0	0.11	0.09	0.41	2.90	2.90	0.10	162	0.103	0.086	0.321	2.90	2.90	0.10	162
Pacific Aria	Y	14	172	12.3	0.35	0.31	1.22	12.01	12.01	0.35	596	0.328	0.280	0.865	12.01	12.01	0.35	596
Pacific Eden	Y	14	119	8.5	0.28	0.24	1.09	8.34	8.34	0.24	413	0.268	0.226	0.863	8.34	8.34	0.24	413
Pacific Jewel	Y	37	331	8.9	1.00	0.85	3.79	29.97	29.97	0.87	1,486	0.943	0.795	2.966	29.97	29.97	0.87	1,486
Pacific Pearl	Y	22	189	8.6	0.58	0.50	2.23	17.23	17.23	0.50	854	0.551	0.464	1.764	17.23	17.23	0.50	854
Pacific Princess	N	1	15	15.0	0.01	0.01	0.05	0.52	0.52	0.02	26	0.013	0.011	0.031	0.52	0.52	0.02	26
Pacific Venus	N	1	28	28.0	0.02	0.02	0.06	0.97	0.97	0.03	48	0.021	0.018	0.031	0.97	0.97	0.03	48
Sea Princess	Y	4	37	9.3	0.13	0.11	0.48	3.90	3.90	0.11	194	0.120	0.102	0.370	3.90	3.90	0.11	194
Seabourn Odyssey	N	1	35	35.0	0.02	0.02	0.06	0.86	0.86	0.03	48	0.020	0.017	0.025	0.86	0.86	0.03	48
Silver Shadow	N	1	13	13.0	0.01	0.01	0.05	0.50	0.50	0.01	25	0.013	0.011	0.034	0.50	0.50	0.01	25
Silver Whisper	N	2	39	19.5	0.04	0.03	0.12	1.49	1.49	0.04	74	0.035	0.030	0.068	1.49	1.49	0.04	74
Sun Princess	Y	5	45	9.0	0.14	0.12	0.51	4.10	4.10	0.12	203	0.128	0.108	0.401	4.10	4.10	0.12	203
Superstar Virgo	N	1	22	22.0	0.09	0.08	0.27	3.66	3.66	0.11	182	0.082	0.072	0.149	3.66	3.66	0.11	182
Volendam	N	1	11	11.0	0.03	0.03	0.12	1.08	1.08	0.03	53	0.031	0.026	0.086	1.08	1.08	0.03	53
		132	**1,563**		**3.66**	**3.15**	**13.13**	**117.19**	**117.19**	**3.46**	**5,880**	**3.421**	**2.903**	**9.712**	**117.19**	**117.19**	**3.46**	**5,880**

Table 6.11: S3 Emissions Estimates, by Ship

2015/16 Cruise Season						S3 EGCS 2.7% S					
Vessel	S5 Shore Powered?	S3/S4 EGCS?	Calls	Total Hours At-Berth	Average hours per Call At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes
Albatros	N	Y	1	62	62.0	0.07	0.06	0.06	2.90	0.10	183
Amsterdam	Y	Y	1	34	34.0	0.06	0.05	0.05	2.70	0.08	150
Artania	N	Y	1	36	36.0	0.05	0.04	0.04	2.38	0.07	133
Astor	N	Y	1	11	11.0	0.01	0.01	0.01	0.36	0.01	20
Azamara Quest	N	Y	2	62	31.0	0.05	0.04	0.04	2.05	0.06	114
Black Watch	N	Y	1	38	38.0	0.03	0.02	0.02	1.26	0.04	70
Crystal Serenity	Y	Y	1	41	41.0	0.06	0.04	0.05	2.16	0.08	136
Dawn Princess	Y	Y	14	126	9.0	0.28	0.23	0.23	12.50	0.39	696
Europa	N	Y	1	37	37.0	0.01	0.01	0.01	0.49	0.02	27
MS Marina	N	Y	1	24	24.0	0.04	0.03	0.03	1.40	0.05	88
Noordam	Y	Y	4	36	9.0	0.07	0.06	0.06	2.74	0.10	172
Pacific Aria	Y	Y	14	172	12.3	0.26	0.21	0.21	11.39	0.35	634
Pacific Eden	Y	Y	14	119	8.5	0.18	0.14	0.15	7.87	0.24	438
Pacific Jewel	Y	Y	37	331	8.9	0.64	0.51	0.53	28.32	0.87	1,576
Pacific Pearl	Y	Y	22	189	8.6	0.37	0.30	0.30	16.27	0.50	906
Pacific Princess	N	Y	1	15	15.0	0.01	0.01	0.01	0.50	0.02	28
Pacific Venus	N	Y	1	28	28.0	0.02	0.02	0.02	0.93	0.03	52
Sea Princess	Y	Y	4	37	9.3	0.08	0.07	0.07	3.69	0.11	205
Seabourn Odyssey	N	Y	1	35	35.0	0.02	0.02	0.02	0.82	0.03	52
Silver Shadow	N	Y	1	13	13.0	0.01	0.01	0.01	0.47	0.01	26
Silver Whisper	N	Y	2	39	19.5	0.03	0.03	0.03	1.42	0.04	79
Sun Princess	Y	Y	5	45	9.0	0.09	0.07	0.07	3.87	0.12	215
Superstar Virgo	N	Y	1	22	22.0	0.08	0.06	0.06	3.49	0.11	194
Volendam	N	Y	1	11	11.0	0.02	0.02	0.02	1.02	0.03	57
			132	**1,563**		**2.55**	**2.04**	**2.09**	**111.00**	**3.46**	**6,252**

Table 6.12: S4 Emissions Estimates, by Ship

2015/16 Cruise Season						S4 EGCS 0.1% S						S4 EGCS 0.001% S					
Vessel	S5 Shore Powered?	S3/S4 EGCS?	Calls	Total Hours At-Berth	Average hours per Call At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux NO_2 Seasonal tonnes	Aux CO_2 Seasonal tonnes
Albatros	N	Y	1	62	62.0	0.013	0.012	0.0025	2.72	0.10	174	0.011	0.010	0.000025	2.73	2.73	174
Amsterdam	Y	Y	1	34	34.0	0.011	0.010	0.0020	2.53	0.08	143	0.009	0.008	0.000020	2.53	2.53	143
Artania	N	Y	1	36	36.0	0.009	0.009	0.0018	2.24	0.07	126	0.008	0.007	0.000018	2.24	2.24	126
Astor	N	Y	1	11	11.0	0.001	0.001	0.0003	0.34	0.01	19	0.001	0.001	0.000003	0.34	0.34	19
Azamara Quest	N	Y	2	62	31.0	0.008	0.007	0.0016	1.93	0.06	108	0.007	0.006	0.000016	1.93	1.93	108
Black Watch	N	Y	1	38	38.0	0.005	0.005	0.0010	1.18	0.04	66	0.004	0.004	0.000010	1.18	1.18	66
Crystal Serenity	Y	Y	1	41	41.0	0.010	0.009	0.0018	2.03	0.08	129	0.008	0.008	0.000018	2.03	2.03	129
Dawn Princess	Y	Y	14	126	9.0	0.049	0.045	0.0095	11.74	0.39	661	0.043	0.039	0.000095	11.74	11.74	661
Europa	N	Y	1	37	37.0	0.002	0.002	0.0004	0.46	0.02	26	0.002	0.002	0.000004	0.46	0.46	26
MS Marina	N	Y	1	24	24.0	0.006	0.006	0.0012	1.32	0.05	84	0.005	0.005	0.000012	1.32	1.32	84
Noordam	Y	Y	4	36	9.0	0.012	0.011	0.0023	2.57	0.10	164	0.011	0.010	0.000023	2.57	2.57	164
Pacific Aria	Y	Y	14	172	12.3	0.045	0.041	0.0086	10.69	0.35	602	0.039	0.035	0.000086	10.69	10.69	602
Pacific Eden	Y	Y	14	119	8.5	0.031	0.029	0.0060	7.39	0.24	416	0.027	0.024	0.000060	7.39	7.39	416
Pacific Jewel	Y	Y	37	331	8.9	0.111	0.103	0.0214	26.58	0.87	1,498	0.096	0.087	0.000214	26.58	26.58	1,498
Pacific Pearl	Y	Y	22	189	8.6	0.064	0.059	0.0123	15.27	0.50	860	0.055	0.050	0.000123	15.27	15.27	860
Pacific Princess	N	Y	1	15	15.0	0.002	0.002	0.0004	0.47	0.02	26	0.002	0.002	0.000004	0.47	0.47	26
Pacific Venus	N	Y	1	28	28.0	0.004	0.003	0.0007	0.87	0.03	49	0.003	0.003	0.000007	0.87	0.87	49
Sea Princess	Y	Y	4	37	9.3	0.015	0.013	0.0028	3.47	0.11	195	0.013	0.011	0.000028	3.47	3.47	195
Seabourn Odyssey	N	Y	1	35	35.0	0.004	0.003	0.0007	0.77	0.03	49	0.003	0.003	0.000007	0.77	0.77	49
Silver Shadow	N	Y	1	13	13.0	0.002	0.002	0.0004	0.44	0.01	25	0.002	0.001	0.000004	0.44	0.44	25
Silver Whisper	N	Y	2	39	19.5	0.006	0.005	0.0011	1.33	0.04	75	0.005	0.004	0.000011	1.33	1.33	75
Sun Princess	Y	Y	5	45	9.0	0.015	0.014	0.0029	3.63	0.12	205	0.013	0.012	0.000029	3.63	3.63	205
Superstar Virgo	N	Y	1	22	22.0	0.014	0.013	0.0026	3.28	0.11	185	0.012	0.011	0.000026	3.28	3.28	185
Volendam	N	Y	1	11	11.0	0.004	0.004	0.0008	0.96	0.03	54	0.003	0.003	0.000008	0.96	0.96	54
			132	**1,563**		**0.441**	**0.407**	**0.0849**	**104.20**	**3.46**	**5,939**	**0.382**	**0.346**	**0.000849**	**104.22**	**104.22**	**5,939**

Table 6.13: S5 Emissions Estimates, by Ship

2015/16 Cruise Season				S5 0.1% S & Shore Power w/1.35% S during boiler fuel switch & 2.7%S during connect/disconnect aux from grid																				
Vessel	S5 Shore Powered?	Calls	Total Hours At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux NO_2 Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes	Boilers PM_{10} Seasonal tonnes	Boilers $PM_{2.5}$ Seasonal tonnes	Boilers SOx Seasonal tonnes	Boilers NOx Seasonal tonnes	Boilers NO_2 Seasonal tonnes	Boilers VOCs Seasonal tonnes	Boilers CO_2 Seasonal tonnes	Grid PM_{10} Seasonal tonnes	Grid $PM_{2.5}$ Seasonal tonnes	Grid SOx Seasonal tonnes	Grid NOx Seasonal tonnes	Grid NO_2 Seasonal tonnes	Grid VOCs Seasonal tonnes	Grid CO_2 Seasonal tonnes
Albatros	N	1	62	0.07	0.07	0.17	3.03	3.03	0.101	170	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Amsterdam	Y	1	34	0.01	0.01	0.07	0.18	0.18	0.005	9	0.007	0.006	0.04	0.08	0.07	0.00	36	0.01	0.01	0.46	0.33	0.33	0.006	129
Artania	N	1	36	0.06	0.05	0.15	2.49	2.49	0.073	124	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Astor	N	1	11	0.01	0.01	0.04	0.38	0.38	0.011	19	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Azamara Quest	N	2	62	0.05	0.04	0.13	2.15	2.15	0.063	107	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Black Watch	N	1	38	0.03	0.03	0.08	1.32	1.32	0.039	65	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Crystal Serenity	Y	1	41	0.01	0.01	0.06	0.12	0.12	0.004	6	0.005	0.005	0.03	0.06	0.06	0.00	29	0.01	0.01	0.42	0.30	0.30	0.005	118
Dawn Princess	Y	14	126	0.25	0.20	1.29	3.09	3.09	0.086	152	0.044	0.037	0.44	0.32	0.22	0.01	147	0.05	0.03	1.76	1.25	1.25	0.022	493
Europa	N	1	37	0.01	0.01	0.03	0.51	0.51	0.015	25	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
MS Marina	N	1	24	0.04	0.04	0.12	1.47	1.47	0.049	83	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Noordam	Y	4	36	0.06	0.05	0.32	0.68	0.68	0.021	38	0.010	0.009	0.10	0.07	0.05	0.00	34	0.01	0.01	0.44	0.31	0.31	0.005	122
Pacific Aria	Y	14	172	0.17	0.13	0.86	2.06	2.06	0.057	101	0.037	0.032	0.33	0.32	0.26	0.01	148	0.05	0.03	1.73	1.23	1.23	0.022	484
Pacific Eden	Y	14	119	0.17	0.13	0.86	2.06	2.06	0.057	101	0.029	0.025	0.30	0.20	0.14	0.01	94	0.03	0.02	1.09	0.77	0.77	0.014	305
Pacific Jewel	Y	37	331	0.57	0.46	2.96	7.07	7.07	0.196	347	0.094	0.079	0.94	0.67	0.47	0.02	311	0.12	0.07	3.98	2.82	2.82	0.050	1,114
Pacific Pearl	Y	22	189	0.34	0.27	1.76	4.20	4.20	0.117	206	0.055	0.046	0.55	0.38	0.26	0.01	177	0.07	0.04	2.27	1.60	1.60	0.028	634
Pacific Princess	N	1	15	0.01	0.01	0.05	0.52	0.52	0.015	26	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Pacific Venus	N	1	28	0.02	0.02	0.06	0.97	0.97	0.029	48	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Sea Princess	Y	4	37	0.07	0.06	0.37	0.88	0.88	0.024	43	0.013	0.011	0.13	0.09	0.07	0.00	44	0.02	0.01	0.53	0.37	0.37	0.007	147
Seabourn Odyssey	N	1	35	0.02	0.02	0.06	0.86	0.86	0.029	48	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Silver Shadow	N	1	13	0.01	0.01	0.05	0.50	0.50	0.015	25	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Silver Whisper	N	2	39	0.04	0.03	0.12	1.49	1.49	0.044	74	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Sun Princess	Y	5	45	0.08	0.06	0.40	0.96	0.96	0.027	47	0.016	0.013	0.16	0.11	0.08	0.00	52	0.02	0.01	0.55	0.39	0.39	0.007	153
Superstar Virgo	N	1	22	0.09	0.08	0.27	3.66	3.66	0.108	182	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
Volendam	N	1	11	0.03	0.03	0.12	1.08	1.08	0.031	53	0.000	0.000	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.000	0
		132	**1,563**	**2.23**	**1.83**	**10.38**	**41.72**	**41.72**	**1.215**	**2,100**	**0.309**	**0.263**	**3.00**	**2.32**	**1.68**	**0.08**	**1,070**	**0.39**	**0.22**	**13.22**	**9.37**	**9.37**	**0.165**	**3,700**

Note: S5 assume shore power, based on a CARB-like approach for their at-berth regulations, applied to WBCT. Under CARB scheme, not all cruise ships would need to shore power, only the frequent callers.

Table 6.13: S5 Emissions Estimates, by Ship (continued)

2015/16 Cruise Season				S5 0.001% S & Shore Power w/1.35% S during boiler fuel switch & 2.7%S during connect/disconnect aux from grid																	
Vessel	S5 Shore Powered?	Calls	Total Hours At-Berth	Aux PM_{10} Seasonal tonnes	Aux $PM_{2.5}$ Seasonal tonnes	Aux SOx Seasonal tonnes	Aux NOx Seasonal tonnes	Aux VOCs Seasonal tonnes	Aux CO_2 Seasonal tonnes	Boilers PM_{10} Seasonal tonnes	Boilers $PM_{2.5}$ Seasonal tonnes	Boilers SOx Seasonal tonnes	Boilers NOx Seasonal tonnes	Boilers VOCs Seasonal tonnes	Boilers CO_2 Seasonal tonnes	Grid PM_{10} Seasonal tonnes	Grid $PM_{2.5}$ Seasonal tonnes	Grid SOx Seasonal tonnes	Grid NOx Seasonal tonnes	Grid VOCs Seasonal tonnes	Grid CO_2 Seasonal tonnes
Albatros	N	1	62	0.06	0.06	0.05	3.03	0.101	170	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Amsterdam	Y	1	34	0.01	0.01	0.07	0.18	0.005	9	0.006	0.005	0.02	0.08	0.00	36	0.01	0.01	0.46	0.33	0.006	129
Artania	N	1	36	0.05	0.04	0.06	2.49	0.073	124	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Astor	N	1	11	0.01	0.01	0.03	0.38	0.011	19	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Azamara Quest	N	2	62	0.04	0.04	0.06	2.15	0.063	107	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Black Watch	N	1	38	0.03	0.02	0.03	1.32	0.039	65	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Crystal Serenity	Y	1	41	0.01	0.01	0.06	0.12	0.004	6	0.005	0.004	0.01	0.06	0.00	29	0.01	0.01	0.42	0.30	0.005	118
Dawn Princess	Y	14	126	0.25	0.20	1.29	3.09	0.086	152	0.042	0.035	0.37	0.32	0.01	147	0.05	0.03	1.76	1.25	0.022	493
Europa	N	1	37	0.01	0.01	0.01	0.51	0.015	25	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
MS Marina	N	1	24	0.04	0.03	0.06	1.47	0.049	83	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Noordam	Y	4	36	0.06	0.05	0.32	0.68	0.021	38	0.010	0.008	0.09	0.07	0.00	34	0.01	0.01	0.44	0.31	0.005	122
Pacific Aria	Y	14	172	0.17	0.13	0.86	2.06	0.057	101	0.035	0.029	0.25	0.32	0.01	148	0.05	0.03	1.73	1.23	0.022	484
Pacific Eden	Y	14	119	0.17	0.13	0.86	2.06	0.057	101	0.028	0.023	0.25	0.20	0.01	94	0.03	0.02	1.09	0.77	0.014	305
Pacific Jewel	Y	37	331	0.57	0.46	2.96	7.07	0.196	347	0.089	0.074	0.80	0.67	0.02	311	0.12	0.07	3.98	2.82	0.050	1,114
Pacific Pearl	Y	22	189	0.34	0.27	1.76	4.20	0.117	206	0.052	0.043	0.47	0.38	0.01	177	0.07	0.04	2.27	1.60	0.028	634
Pacific Princess	N	1	15	0.01	0.01	0.03	0.52	0.015	26	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Pacific Venus	N	1	28	0.02	0.02	0.03	0.97	0.029	48	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Sea Princess	Y	4	37	0.07	0.06	0.37	0.88	0.024	43	0.012	0.010	0.11	0.09	0.00	44	0.02	0.01	0.53	0.37	0.007	147
Seabourn Odyssey	N	1	35	0.02	0.02	0.02	0.86	0.029	48	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Silver Shadow	N	1	13	0.01	0.01	0.03	0.50	0.015	25	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Silver Whisper	N	2	39	0.03	0.03	0.07	1.49	0.044	74	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Sun Princess	Y	5	45	0.08	0.06	0.40	0.96	0.027	47	0.015	0.012	0.13	0.11	0.00	52	0.02	0.01	0.55	0.39	0.007	153
Superstar Virgo	N	1	22	0.08	0.07	0.15	3.66	0.108	182	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
Volendam	N	1	11	0.03	0.03	0.09	1.08	0.031	53	0.000	0.000	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.000	0
		132	**1,563**	**2.18**	**1.78**	**9.68**	**41.72**	**1.215**	**2,100**	**0.293**	**0.245**	**2.50**	**2.32**	**0.08**	**1,070**	**0.39**	**0.22**	**13.22**	**9.37**	**0.165**	**3,700**

Note: S5 assume shore power, based on a CARB-like approach for their at-berth regulations, applied to WBCT. Under CARB scheme, not all cruise ships would need to shore power, only the frequent callers.

7. Cost-Effectiveness Analysis of Emission Reduction Scenarios

Below is a cost-effectiveness analysis for the implementation of shore power at WBCT. CARB's Carl Moyer Program is one of the preeminent government-funded grant programs in North America focused on reducing emissions to help meet air quality standards. The Carl Moyer Program, now in its 18th year, is a grant program using state monies that funds the incremental cost of cleaner-than-required engines, equipment, and other sources of air pollution. As such, the program has a well-documented cost-effectiveness criterion that is assessed for all applications and is also used by other entities to determine cost-effectiveness of air emissions reduction strategies and programs.[37] Cost-effectiveness is a measure of the dollars provided to a project for each tonne of resulting emissions reduced. The Carl Moyer Program's focus is the damaging impacts from PM (specifically PM_{10}, which is made up of 98% $PM_{2.5}$) and NO_x from diesel powered engines. It should be noted that the Carl Moyer Program cost-effectiveness calculation does not take into account SO_x nor CO_2, therefore this approach does not "penalise" the WBCT analysis due to the modelled CO_2 emissions increase from shore power. The program takes into account the toxicity of PM from diesel engines by applying a weighting factor of 20 to PM_{10} emissions; NO_x emissions reductions are not adjusted. The following factors are considered by the Carl Moyer Program in determining a project's cost-effectiveness:

1. Annual emissions reductions of PM_{10} and NO_x
2. Duration of the project (evaluation period)
3. Total project-related costs (infrastructure and operational & maintenance [O&M])
4. Discount rate to calculate the Capital Recovery Factor (CRF)

Two sets of variables were gathered from appropriate sources to establish the lower and upper bounds for estimating the project's cost-effectiveness using the Carl Moyer Program methods, for two evaluation periods. The resulting estimates create an upper and lower bound, with the project anticipated to fall somewhere between the two bounds. The following variables were used:

[37] CARB, Carl Moyer Program Guidelines, *www.arb.ca.gov/msprog/moyer/guidelines/current.htm*, accessed November 2015 [CARB CMP]

1. From Table 6.6, the annual reductions for S5 compared to S1 were used for both fuel types and both domains (regional and local)
2. Evaluation periods: [38] 10-years 20-years
3. The total project costs include:
   a. On-shore infrastructure[39]

		10-years	20-years
a. On-shore infrastructure[39]	low:	$20,700,000	$20,700,000
	high:	$36,400,000	$36,400,000
b. On-shore O&M[40]	low:	$931,500 per year	$931,500 per year
	high:	$1,638,000 per year	$1,638,000 per year
c. Cruise ship infrastructure retrofit costs[41]	# of ships:	10	20
	low:	$700,000 per ship	$700,000 per ship
	high:	$2,750,000 per ship	$2,750,000 per ship
4. Interest rate for CRF[42]:	low:	4.5%	4.5%
	high:	8.0%	8.0%
5. CRF (calculated):	low:	0.1264	0.0769
	high:	0.1490	0.1019

6. Exchange Rate: 0.76 AUD$: 1.00 US$
7. Energy costs for shore power supplied electricity were not considered due to the future uncertainty of fuel oil costs and future costs of energy supplied by the grid.

[38] The evaluation periods of 10 and 20 years were selected to provide a broad range of cost-effectiveness values and were based upon a hybrid approach between government funding of shore power infrastructure projects (typically evaluated for 20 years) and commercial ship retrofits (typically evaluated 10 or less years). The Carl Moyer Program allows for shore power projects (landside infrastructure) to have a maximum evaluation period of up to 20 years; applicants can choose the project life but cannot exceed the maximum evaluation period. Cruise ship lines typically have up to a 10 year payback period for vessel infrastructure improvements.

[39] Port Authority of New South Wales, *Engineering Feasibility Study, Report for Shore Power Feasibility Study for White Bay Cruise Terminal*, Navari Pty Ltd, December 2015; high and low estimates with +30% and -10% contingency respectively.

[40] Assumed to be 4.5% of on-shore infrastructure costs, consistent with Hong Kong estimates; Maritime Executive, *www.maritime-executive.com/article/shore-power-too-expensive-for-hong-kong*, accessed November 2015.

[41] Cruise ships are anticipated to operate on a maximum 10-year cycle then be moved to other markets globally. As Australia transitions from a second- to first-tier cruise market, the fleet changes are anticipated to intensify as the older ships will need to be replaced with newer ships having more amenities onboard, to remain competitive. For the 10-year evaluation period, assuming the same fleet as the 2015/2016 season, four additional ships would need to be retrofitted immediately and over the evaluation period, at least six new ships coming into WBCT service would need to be retrofitted for Scenario 5. For the 20-year evaluation period it is assumed that all 10 shore power capable ships from the 10-year period would be replaced by within the 20-year evaluation period due to the maximum cycle of 10-years. Range of estimated costs for high voltage systems for cruise ships from various interviews and sources, Starcrest; Letter from Pencarrow Marine to Port Authority, *Cost Estimate for Retrofitting Shore Power – Cruise Vessels*, November 2015.

[42] For low estimate, Port Authority borrow rate from NSW Treasury is 4.5%; for high estimate, Port Authority weighted average cost of capital (WACC) is 8%. Port Authority, January 2016.

In general, in setting up the cost-effectiveness analysis, the parameters chosen present shore power in the "best light" to maximise the cost-effectiveness results of the strategy. The following factors were not considered in the cost, which would generally have a negative impact on cost-effective findings: 1) differential energy costs over each evaluation period from fuel-oil generation on-board and costs associated with grid supplied power; 2) forecasting growth of both cruise ship groups (those applicable to a shore power regulation and those not) and associated ship/fleet turn over during the evaluation periods; and 3) time to install the land-side and ship-side infrastructure (assumes a mature shore power program could start during the 2015/2016 cruise season).

Using the emissions estimates for Scenario 5 (shore power), the cost-effectiveness analysis assumes the annual number of ships and the number of calls utilising shore power to be constant over both the 10-year and 20-year evaluation periods. This assumption reduces uncertainty associated with forecasting future trends relating to the number of calls by the non-applicable and applicable cruise fleets and minimises the number of ships that need to be equipped with shore power equipment (which helps improve the cost- effectiveness results). The scenario further assumes a "fully mature" CARB-type regulatory action requiring the use of shore power at-berth for cruise ships calling WBCT starting with the 2015/2016 cruise season. It should be noted that the CARB at-berth regulation does not result in 100% of ships calling at regulated port terminals to be connected to shore power; it requires 80% of regulated ships in its current final phase. This approach maximises the benefit of the shore power by mandating the use of the infrastructure installed land-side and on-board. Real-life cruise ship deployments and cruise ship fleet routing changes would most likely increase the number of cruise ships that would need to be retrofitted to operate on shore power, reduce the total 10 and 20 year benefits from individual ships retrofitted, and would result in negative impacts on cost-effectiveness findings.

As stated above, cost-effectiveness is calculated using annualised emissions reductions typically for PM_{10} and NO_x, with PM_{10} being weighted 20 times compared to NO_x due to its disproportionate health effects, using the equation below: [43]

Cost-Effectiveness (\$/weighted tonne) =
Total Project Costs x CRF / ((20 x PM_{10} annual reductions) + NO_x annual reductions)

[43] CARB CMP, adapted from Formulas C-1 and C-2, Appendix C.

Based on the CARB cost effectiveness method, the 10- and 20-years incremental cost-effectiveness results (using the high and low variables) for Scenario 5 being applied 'on top of' Scenario 2a, for both 0.1% and 0.001% S fuels and by local and regional domains is provided in Table 7.1.

Figure 7.1: S5 v S2a Incremental Cost-Effectiveness

Comparison	Condition		Annual Reductions, tonnes PM_{10}	$PM_{2.5}$	NOx	CO_2	On-shore Infrastructure	On-shore O&M	Ship Infrastructure	Total	Incremental Cost Eff. $/wgt tonne
Low - 10 year											
Scenario 5 v 2a	0.1% S & Shore power	Local	1.1	1.1	73.1	na	$20,700,000	$9,315,000	$7,000,000	$37,015,000	$48,924
		Regional	0.7	0.8	63.8	-990					$59,565
Scenario 5 v 2a	0.001% S & Shore power	Local	0.9	0.9	73.1	na	$20,700,000	$9,315,000	$7,000,000	$37,015,000	$50,794
		Regional	0.6	0.7	63.8	-990					$62,361
High - 10 year											
Scenario 5 v 2a	0.1% S & Shore power	Local	1.1	1.1	73.1	na	$36,400,000	$16,380,000	$27,500,000	$80,280,000	$125,126
		Regional	0.7	0.8	63.8	-990					$152,343
Scenario 5 v 2a	0.001% S & Shore power	Local	0.9	0.9	73.1	na	$36,400,000	$16,380,000	$27,500,000	$80,280,000	$129,910
		Regional	0.6	0.7	63.8	-990					$159,492
Low - 20 year											
Scenario 5 v 2a	0.1% S & Shore power	Local	1.1	1.1	73.1	na	$20,700,000	$18,630,000	$14,000,000	$53,330,000	$42,878
		Regional	0.7	0.8	63.8	-990					$52,204
Scenario 5 v 2a	0.001% S & Shore power	Local	1.1	1.1	73.1	na	$20,700,000	$18,630,000	$14,000,000	$53,330,000	$44,517
		Regional	0.7	0.8	63.8	-990					$54,654
High - 20 year											
Scenario 5 v 2a	0.1% S & Shore power	Local	1.1	1.1	73.1	na	$36,400,000	$32,760,000	$55,000,000	$124,160,000	$132,258
		Regional	0.7	0.8	63.8	-990					$161,025
Scenario 5 v 2a	0.001% S & Shore power	Local	1.1	1.1	73.1	na	$36,400,000	$32,760,000	$55,000,000	$124,160,000	$137,314
		Regional	0.7	0.8	63.8	-990					$168,582

The cost-effectiveness for the incremental benefits for shore power (S5) beyond the benefits from the AMSA Direction (S2a) range from over $42,000 to $168,000 AUD per weighted tonne across both time evaluation periods, local/regional benefits, and low/high scenarios. CARB sets a threshold limit of $21,522 AUD per weighted tonne ($18,030 USD/ton)[44] as a line above which projects are deemed not to be cost-effective for grant purposes. Shore power (Scenario 5), both on a local and regional level, ranges from 2 to over 7.8 times higher than the CARB cost-effectiveness limit and therefore would be considered very expensive and not cost-effective from a public funding standpoint. It's also important to note that CARB would consider only the regional domain, not the local domain, for Scenario 5.

To put the shore power cost-effectiveness analysis into perspective it is worth considering that since 1998, the Carl Moyer Program has provided over $980 million USD in State and local funds with an average state-wide cost-effectiveness of $10,000 USD/weighted ton. As an example, the Program has been used to replace over 46,000 engines from various land-based and marine-based mobile sources.[45]

[44] CARB CMP, Appendix G; assumes a 0.76 conversion rate from AUD to USD
[45] CARB, Update: Joint ARB & CAPCOA AB 8 Carl Moyer Program Evaluation, Board Hearing Presentation, December 18, 2014, *www.arb.ca.gov/board/books/2014/121814/14-10-6pres.pdf*, accessed January 2016

8. Alternative Emissions Reduction Strategies

It is important to remember that when assessing emissions reduction strategies, that an individual strategy might reduce some pollutants while increasing other pollutants. As was stated earlier in the report, there are neither 'silver bullets', nor 'one size fits all' solutions for ship emissions reductions. That said, there are a number of potential alternative emission reduction strategies for cruise ships at-berth to be considered, which can be grouped into the following categories:

1. Engine and boiler technologies
2. After treatment technologies
3. Alternatively fuelled on-board energy generation
4. Alternatively generated power systems
5. Operational efficiency improvements
6. Offsets from emissions reductions associated with other sources

It is also important to note that each of the potential alternative strategies needs to be assessed and evaluated on a case-by-case basis, as there are numerous variables for each specific application and vessel that can have significant impacts on whether a strategy will be feasible, effective, or both. A screening analysis of candidate strategies would need to be performed to determine if the strategy would most likely be effective and feasible. The goal of this section is not to provide an exhaustive look at alternative strategies,[46] but to discuss, at a high level, a few of the most applicable alternative strategies.

8.1 Engine and Boiler Technologies

Engine and boiler technologies reduce emissions and/or improve efficiencies associated with auxiliary engines and boilers on-board a ship and are integral with the workings of the engine or boiler. The key limitation of these technologies is that they typically require dry dock time, reclassification, and can be very expensive. Focusing on auxiliary engines, ship engines may have remanufacture kits available which might bring an engine into the next higher level IMO engine NO_x tier at the potential expense of PM. Some engines may have a 'low NO_x mode' setting, which again comes at the expense of PM, so when looking to reduce PM, these engines should not be operated in low NO_x mode. Replacement of existing turbo chargers with high efficiency turbochargers or two-stage turbochargers, while expensive, can reduce PM, NO_x, and CO_2, but could increase hydrocarbon (HC) emissions. Turbocharger cut-offs can reduce NO_x at the expense of PM. Continuous water injection, direct water injection, and humid air systems can reduce NO_x at that expense of PM and CO_2. Retrofitting existing engines with crankcase volatile organic compounds (VOC) recovery systems can reduce VOC emissions from the crankcase.

[46] For further reference materials, see IMO, *Study of Emission Control and Energy Efficiency Measures for Ships in the Port Area*, February 2015, B. Anderson, et-al [MEPC 68-INF.16]; NSW EPA, *Emissions from ships operating in the Greater Metropolitan Area*, DNV GL, October 2015; Ports of Los Angeles and Long Beach, *San Pedro Bay Ports Clean Air Action Plan Guide to OGV Emissions Control Strategies*, Starcrest, 2012

Boiler technologies are mostly limited to the replacement of existing boilers with high efficiency boilers, which can require significant dry-dock effort but reduces NO_x and CO_2 (PM effects yet to be determined). Advanced auxiliary engine waste heat recovery systems, can reduce NO_x and CO_2 (PM effects yet to be determined), but this strategy requires the ship's auxiliary engines to be operating in certain performance ranges in order for them to work.

8.2 After-Treatment Technologies

After-treatment technologies reduce auxiliary engine and boiler exhaust emissions, and unlike the strategies in 8.1, are not integral with the workings of the engine. Therefore these technologies can reside on-board or off the ship. Examples of the latter are the recently demonstrated barge-based systems that connect directly to a ship's exhaust stack where exhaust is treated by air control equipment mounted on a barge. These systems significantly reduce PM, SO_x, and NO_x; however they increase CO_2. Two systems have recently received approval from CARB[47] as alternative technologies to the CARB Shore Power rule, which is a significant step towards being a viable strategy. These systems include:

- The Marine Exhaust Treatment System-1 (METS-1), an alternative control technology that can be used for compliance with the airborne toxic control measure for Auxiliary Diesel Engines Operated on Ocean-going Vessels At-Berth in a California Port (At-Berth Regulation). The Executive Order (EO), AB-15-01, applies to Clean Air Engineering's METS-1 and allows the use of METS-1 by container ships for compliance with the At-Berth Regulation. The EO identifies the approved control efficiencies for METS-1, operating parameters, monitoring requirements, and recordkeeping requirements for METS-1.

- The Advanced Marine Emissions Control System (AMECS), an alternative control technology that can be used for compliance with the Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated Of Ocean-going Vessels At-Berth in a California Port (At-Berth Regulation). The EO, AB-15-02, applies to Advanced Cleanup Technologies' AMECS and allows the use of AMECS by container vessels for compliance with the At-Berth Regulation. The EO identifies the approved control efficiencies, operating parameters, monitoring requirements, and recordkeeping requirements for AMECS.

It's important to note that both these systems ***only*** have approval from CARB for ***container ships*** within ***specific auxiliary engine load ranges*** that are significantly lower than most cruise ships. Significant challenges need to be overcome prior to getting either system certified for the wide range of cruise ship loads and exhaust configurations. In addition, there is neither performance nor reliability data associated with these systems, which will need to be collected when they start operations. The business case for these systems currently relies on regulatory mandates for shore power, so it's unclear if the business case works for 'voluntary' programs. These and other issues will need to be resolved as the companies get to the task of implementing their business plans, but for now these systems, while promising, must be considered to be 'emerging.'

The other after-treatment technologies include selective catalytic reduction (SCR) and scrubbers. Scrubbers, as mentioned in Section 4, are being integrated into the Carnival Corp. and RCCL fleets ahead of the IMO fuel sulphur cap commencing in 2020, and are included in Scenario 3 and Scenario 4 in Section 6.

[47] CARB, *www.arb.ca.gov/ports/shorepower/shorepower.htm*, accessed October 2015

8.3 Alternatively Fuelled On-Board Energy Generation

This category of strategies generally focuses around the use of natural gas instead of fuel oil in auxiliary engines and boilers, with the gas stored in the form of liquefied natural gas (LNG). As stated in Section 4, Carnival Corp. has large new cruise ships that will use LNG, however, it's anticipated that they would not be in the WBCT market for quite some time nor be able to reach WBCT due to the height restriction of the Sydney Harbour Bridge. An alternative concept using LNG, which hasn't come to fruition at this time, is to convert one auxiliary engine to LNG service and then only run that engine while at port on LNG. Converted dual fuel engines do not provide a NO_x reduction (in fact NO_x can increase), but do provide significant reductions in PM (almost similar to a scrubber). Spark-ignited LNG dedicated engines are the only LNG engines that get the NO_x benefits. LNG supply, lack of infrastructure, and on-board storage are major challenges that have to be overcome in order to make LNG feasible. Water emulsified fuels have the potential to reduce both NO_x and PM, but requires supplying the ship with surfactant and typically installation of mixing equipment on-board.

8.4 Alternatively Generated Power Systems

Alternatively generated power systems, landside or waterside, are systems that use cleaner fuels than those used by the regional grid, like natural gas, hydrogen, etc. These systems, mostly conceptual at this time, can be installed within or adjacent to the terminal or use a barge for the equipment platform that provides flexibility in moving the power system relatively easily within a port area.

An example of a barge-based alternately generated power system is from Becker Marine Systems which has built an LNG Hybrid barge[48] system that generates electricity from LNG-fuelled engines in place of power generated from the landside grid, and which can be used by cruise ships. The system is completing its first year of operation at the Port of Hamburg Authority and the system can provide up to 7 MW of power, with designs of up to 10.5 MW. The system is currently used with Aida Cruise (Carnival Corp.) and the project was co-funded by an EU grant. This system requires terminal-side shore power infrastructure and equipment as well as cabling from the barge location to the terminal and on-board infrastructure for each ship using the system. The potential benefits from this approach include reduction in infrastructure costs with bringing sufficient power to a terminal (if applicable) and potentially cleaner emissions per unit energy than the grid.

Noise testing is being conducted in Hamburg and the findings have not been released at the date of this report, so it's unclear what the impacts of noise are from barge-based power systems compared to normal ship operations.

[48] Becker Marine, *www.becker-marine-systems.com*, accessed October 2015

8.5 Operational Efficiency Improvements

Ship operational efficiencies are improvements that reduce fuel consumption while at-berth. Operational improvements associated with lighting, air conditioning, refrigeration, amenities provided on-board for the passengers, and optimising performance of auxiliary engines and boilers, so that power demands are minimised, benefits both the operational costs associated with generating on-board power (versus controlling emissions) and ultimately reduces emissions. Cruise lines are working on efficiency improvements; however uncertainty lies with the magnitude of resulting improvements, and it is anticipated that these strategies would not reach the same levels of reductions as fuel switching, shore power, or other alternative strategies. Efficiency improvements can have synergistic effect when implemented with other strategies, but by category should not be thought of as a primary strategy.

8.6 Offsets from Emissions Reductions Associated with Other Sources

An important strategy that is used successfully in North America is the practice of emissions offsets from other sources than the target source. This is a common strategy used to maximize the more cost-effective opportunities from other ‘lower-hanging fruit’ or when the target source’s emission reduction cost-effectiveness is prohibitive. Emissions from the target source are offset by emissions reductions from other sources within the same geographical region/area as the target source. One of the most cost-effective approaches relating to the maritime and port sectors is re-powering domestic vessels (ferries, tug boats, push boats, etc.), trucks, and cargo handling equipment, with cleaner, more efficient engines. Other options are identified by evaluation emissions inventoried sources in and around the target emissions source(s) and region. Candidate emissions sources are evaluated on a cost-effective basis and ranked based on a hierarchy established by the funding agency. Since this approach does not directly reduce emissions from the target source, some in the community may not be satisfied with this approach.

9. Findings

The emissions benefit analysis conducted to compare various scenarios: S2 – NSW EPA Cruise Regulation 2015 using 0.1%/0.001% sulphur fuels; S2a – AMSA Direction using 0.1%/0.001% sulphur fuels; S3 – EGCS and 2.7% sulphur fuel, S4 – EGCS and 0.1%/0.001% sulphur fuels, and S5 – shore power and 0.1%/0.001%/2.7% sulphur fuels) against the baseline emissions (S1) [2.7% sulphur fuel], is a typical screening analysis to determine which of the potential strategies maximises emissions reductions while minimising costs. Ultimately, the issues associated with cruise ships calling at WBCT can be looked at from several perspectives including reducing acute health risk (related to PM/SO_x) and reducing ozone formation on both a local and regional level (related to NO_x), while taking into account the impacts on the WBCT carbon footprint.

Looking at acute health risk, CARB's focus is primarily on diesel particulate matter (which is primarily made up of PM and SO_x) as the key air toxic associated with diesel-fuel internal combustion engines. Significant reductions from 69–73% in PM and 87–91% reduction in SO_x will be achieved from the implementation of AMSA Direction requiring low sulphur fuel compared to S1, which is a low risk/low cost strategy now widely used in various regions of the world. Additional reductions beyond cleaner fuels can be achieved through the use of more complex and costly strategies such as S3, S4, and S5, with S4 being the maximum emission reduction strategy. The cost-effectiveness for a shore power program at WBCT compared to other possible strategies within a regional airshed is not favourable. This is validated by S5 having an incremental cost effectiveness over S2a ranging 2 to over 7.8 times higher than the CARB cost-effectiveness threshold.

Looking from an ozone formation standpoint, shore power does provide NO_x and VOC (which are precursors of ozone) reductions that are well beyond S2 through S4; however, shore power still is not considered cost-effective. From an experience perspective, there are most likely other opportunities within the greater Sydney airshed to reduce NO_x and VOC emissions at a significantly lower cost. In addition, it should be noted that S5 and S3 ***increase*** regional CO_2 generation from cruise ship calls at WBCT.

In areas like California that have been reducing emissions from all sources for over 50 years, strategies like S4 and S5 come to fruition (mandatory or voluntary) after efforts to introduce much more cost-effective strategies have been exhausted. In practice, regulated or voluntary shore power programs are less cost-effective in reducing health risk and carbon footprint related emissions at the local and regional level than other strategies. Based on the analysis, the incremental benefits from shore power beyond the AMSA Direction are not considered cost-effective. If additional reductions are desired, other strategies within the local and regional domains should be explored.

From a cost and experience point of view, installation of EGCS is already being implemented by Carnival Corp. and RCCL and this may present a win-win opportunity. If further reductions are warranted beyond the AMSA Direction, the use of EGCS at-berth/within port could be further explored, with possible next steps being to further evaluate the cruise lines' EGCS strategies to determine the time frames for availability of EGCS equipped ships, estimate potential future emissions reductions according to the actual schedules, and estimate cost-effectiveness for the scenarios requiring the higher priced low sulphur fuels combined with EGCS systems.

Annex 1: Estimate of Energy Consumption of Typical Cruise Call

This Annex provides the estimate of energy/emissions, by mode, of a DE cruise calling at WBCT. Emissions are equal to energy (in kWh) times an emissions factor (grams per kWh) for each pollutant or greenhouse gas emitted. Therefore, for DE cruise ships, energy is consumption is a direct indicator of emissions output. In conventional cruise ships, with a large 2-stroke engine, this is not the case for most pollutants.

The example presented in Section 2.2 was developed using information provided by the Port Authority NSW Harbour Master and Vessel Boarding Data (Starcrest), for a typical, large DE cruise ship transiting the Sydney Harbour, from the Heads to WBCT, time at-berth, and transit out from WBCT to the Heads.

Cruise Ship Variables

28000 kW propulsion motor(s) rated power
1400 kW average propulsion engine load during transit
13800 kW aux load during transit
21 knts - max rated ship speed
11500 kW aux load at-berth
11.8 weighted average time at-berth

Transit Variables

2.25 round trip manu time (1.25 hour inbound transit + swing & 1 hour outbound transit)
5.5 knts average transit speed
0.05 assumed average propulsion engine load factor during transit
0.02 calculated for direct transit, additional added for swing maneuver

Other Key Assumptions

Ship is assumed to be in a maneuvering state during entire transit
Assumes no shore powering during time at-berth
Assumes ship is diesel/electric
Propulsion load based on the Propeller Law
Ship parameters based on Starcrest Vessel Boarding Program

Total Call Energy Estiamte

34,200	kWh transit	20% of total call kWh
136,075	kWh at-berth	80% of total call kWh
170,275	kW total	

Appendix 3 – Air Quality Assessment (Jacobs)

White Bay Cruise Terminal

Port Authority of NSW

Air Quality Assessment

Document No. | 5

28 March 2017

Air Quality Assessment
Port Authority of NSW

Document history and status

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2	3 Dec 2015	WBCT Air Quality Assessment	M Davies	S Lakmaker	M Davies
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White Bay Cruise Terminal

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Contents

1. Introduction

1.1 General Introduction

The Port Authority of New South Wales (Port Authority) has commissioned Jacobs to undertake an air quality assessment of cruise ships operating at the White Bay Cruise Terminal (WBCT). Specifically, the purpose of the assessment was to:

- Review potential exposure of local residents and the general community in Balmain to cruise ship emissions from WBCT;
- Compare oxide of nitrogen (NO_X) emissions and exposure in areas of the Sydney Greater Metropolitan Region (GMR) that are not impacted by WBCT cruise ship emissions, to emissions in the Leichhardt / Balmain area which include cruise ship emissions; and
- Consider Sydney GMR regional NO_X emissions and the range of NO_X emissions abatement under consideration by NSW Government.

This Sydney GMR comparison is focussed on NO_x rather than other pollutants, such as sulphur dioxide (SO_2) and particulates (PM_{10} and $PM_{2.5}$), and the findings are intended to inform and be considered along with other investigations underway by the Port Authority, specifically assessment of shore power for ships berthed at the WBCT (Starcrest, 2017).

The potential reductions in NO_X offered by shore power are more substantial than for SO_2 and PM_{10}/$PM_{2.5}$ when the reductions in emissions for these pollutants already achieved by the requirement for cruise ships to use low sulphur fuel while berthed at WBCT is taken into consideration. Hence this assessment is focussed on NO_x emissions to provide information in regard to existing NO_x levels and the potential relative benefits of shore power compared to other alternatives, which have not already been addressed via the introduction of low sulphur fuel. These aspects are discussed further in Section 1.2.

It is noted that the Inner West Council was proclaimed on 12 May 2016. It is made up of the former local government areas (LGAs) of Ashfield, Leichhardt and Marrickville. References to the Leichhardt LGA throughout this report refer to the former Leichhardt LGA, which is now part of the Inner West LGA.

1.2 Background

Air emissions from cruise ships are generated from diesel engines used while the ships are in transit and manoeuvring into berth (propulsion engines) and while at berth (auxiliary engines). Modern cruise ships typically have a diesel-electric configuration, in which propulsion as well as all non-propulsion energy demands are serviced by the auxiliary engines (in a diesel-electric generator configuration). The main air quality pollutants of concern from the operation of these engines are sulphur dioxide, nitrogen dioxide, particulate matter, carbon monoxide, carbon dioxide and hydrocarbons.

In 2013 the WBCT was established in Balmain, NSW. During the project approval the air quality impacts from WBCT were assessed as part of the Environmental Assessment (EA) in 2010 (SKM, 2010). The project was assessed in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC, 2005) and the Director-General's Requirements issued for the environmental assessment of the project. The results of the dispersion modelling showed that the project was unlikely to cause exceedances of the air quality assessment criteria for nitrogen dioxide (NO_2), particulates less than 10 microns (PM_{10}) or sulphur dioxide (SO_2) at the nearest sensitive receptors in Balmain.

Port Authority commissioned campaign air quality monitoring of SO_2 and PM_{10} during 2013 and 2014, where ambient air quality in Balmain was monitored in two locations during cruise ship movements. No exceedances of the ground-level criteria were recorded during the monitoring. To provide further assurance to the community, a monitoring station was installed during 2015 to monitor SO_2 and particulates less than 2.5 microns ($PM_{2.5}$) continuously. The monitoring station results, meteorological conditions measured on site and ship location data are made available publically online to provide real-time information to the community about the air quality in Balmain. NO_X is not currently monitored.

Regulatory agencies in NSW have become involved in investigations to reduce air emissions from ships in the Sydney area.

In September 2015 the NSW government introduced regulatory requirements for the use of low sulphur fuel (0.1% or less) by cruise ships in Sydney Harbour. The requirements took effect for cruise ships berthed in Sydney Harbour from 1 October 2015, and for cruise ships operating in Sydney Harbour they were due to take effect from 1 July 2016.

In May 2016 the EPA became aware that the Commonwealth Government introduced amendments to the Protection of the Sea (Prevention of Pollution from Ships) Act 1983 into Parliament in September 2015 which were assented to in December 2015, which resulted in the NSW low sulphur fuel requirements being inoperative from January 2016.

In December 2016 the Commonwealth announced a new direction to protect Sydney Harbour from ship emissions. The Australian Maritime Safety Authority (AMSA) Direction as outlined in the Marine Notice 21/2016, authorised under Subsection 246(1)(b) of the Navigation Act 2012, which became effective in December 2016, directs cruise vessels to limit sulphur emissions while at-berth in Sydney Harbour. This directive is applicable to cruise ships capable of accommodating more than 100 passengers and requires the use either one or a combination of the following options: 0.1% sulphur fuels, certified exhaust gas cleaning systems (EGCS), and/or shore power. The limit on sulphur emissions applies from one hour after the vessel's arrival at-berth until one hour before the vessel's departure.

In the interim between the EPA regulation being inoperative (January 2016) and the start of the AMSA Marine Notice Direction 21/2016 (December 2016), EPA was able to obtain agreement with both Carnival Australia and Royal Caribbean to voluntarily continue to comply with the at-berth requirements of the 2015 Cruise Regulation.

The consideration of shore power has been assessed and reviewed in a recent study for WBCT to determine the context and technical feasibility, cost effectiveness and emission impacts of adopting this option as an emission reduction measure (Starcrest Consulting, 2017; Goldsworthy, 2015). The most recent iteration of the reports considers NO_X emissions for each emission reduction scenario (March 2017).

Five emission reduction scenarios have been assessed by Starcrest Consulting for emission reduction effectiveness. From a local perspective, all scenarios tested provided a range of reductions in particulates and sulphur dioxide. It was noted that for a regional perspective, the reliance of the NSW energy grid on coal sources effectively shifts the emission impacts. Feasibility of shore power from a cost-benefit estimates are that the implementation of shore power at WBCT for both local and regional emission reduction ranges from 2 to over 7 times higher than the cost effective limit adopted by California Air Resources Board (CARB), and is therefore deemed not cost effective.

Other potential emission reduction strategies were identified by Starcrest Consulting as: engine and boiler technologies; after-treatment technologies; alternatively fuelled on-board energy generation; alternatively generated power systems; operational efficiency improvements and offsets from emissions reductions associated with other sources.

1.3 Project Objectives

The objective of this air quality study is to consider cruise ship emission exposure within the Balmain (Leichhardt local government area) of Sydney, so as to assist with determining the need for air pollution control measures, specifically shore power, at the WBCT.

2. Local Air Quality Impacts

As outlined in Section 1.2, Port Authority is undertaking air quality monitoring in the Balmain area, with a focus on SO_2 and $PM_{2.5}$. There have been no exceedances of ambient air quality criteria set by the EPA since monitoring was commenced in 2013.

Other pollutants such as NO_X are not monitored in the Balmain area with the nearest EPA monitoring station located at Rozelle, and as such it is not possible to directly measure their impact in Balmain either from cruise ships or other sources e.g., motor vehicle transport, which is the dominant NO_X emission source in the Sydney GMR.

The impact of pollutants associated with cruise ship emissions operating within the WBCT were assessed as part of the Environmental Assessment (EA) for the project in 2010, and Starcrest Consulting has refined emission estimates based on scheduled cruise ship visits in 2015/16. These are discussed in the following sections.

2.1 2010 WBCT Air Quality Assessment

The 2010 WBCT air quality assessment used air dispersion modelling with the CALPUFF model to predict the impact of an array of pollutants from cruise ships on surrounding sensitive receivers, including residences in neighbouring Balmain. The modelling assessment considered cumulative impacts being the impact from cruise ships added to existing background air pollution levels as measured by the EPA in inner suburbs of Sydney.

Ship emission scenarios assessed were based on information provided by Sydney Ports Corporation (SPC, now Port Authority) and are as follows:

1) A large passenger ship at berth at Wharf No. 5 for 12 hours per day (6 am – 6 pm) for up to approximately 170 days per year, plus a medium passenger ship at Wharf No. 5 for 72 hours on 3 occasions per year (ships not at berth at the same time);
2) A large passenger ship at berth at Wharf No. 5 for 12 hours per day (6 am – 6 pm) for up to approximately 170 days per year, plus a medium passenger ship at berth at Wharf No. 4 for 12 hours (6 am – 6 pm) for 10 days per year (ships at berth concurrently); and
3) A large passenger ship at berth at Wharf No. 5 for 12 hours per day (6 am – 6 pm) for up to approximately 170 days per year, plus a large passenger ship at Wharf No. 5 for 72 hours on 3 occasions per year (ships not at berth at the same time).

In practice, the scenarios for modelling were identified as follows:

- Scenario 1: A large passenger ship at Wharf No. 5 with constant emissions from 6 am to 6 pm;
- Scenario 2: A medium passenger ship at Wharf No. 5 with constant emissions for 24 hours;
- Scenario 3: A large passenger ship at Wharf No. 5 plus a medium passenger ship at Wharf No. 4 with constant emissions from both ships between 6 am and 6 pm; and
- Scenario 4: A large passenger ship at Wharf No. 5 with constant emissions for 24 hours.

The *Pacific Dawn* was used as an example of a large passenger ship, and the *Nautica* was used for a medium passenger ship. Dimensions and operating parameters for these ships were obtained from Carnival Australia, Oceania Cruises and Lloyd’s Register.

Ship emissions for existing and future scenarios were determined using the National Pollutant Inventory Emission Estimation Technique Manual for Maritime Operations Version 2.0 (2008). Emissions were calculated using the emission factors in **Table 2-1**.

Table 2-1 Emission Factors for Ships at Berth

Pollutant	Auxiliary Engine Emission Factors (kg/kWh)*
NO_X	0.0145
PM_{10}	0.001
SO_2	0.0097
* Emission factors for weighted average fuel burn (Table 7 of NPI Emission Estimation Technique Manual for Maritime Operations Version 2.0) – to be used when fuel type unknown.	

The above emission factors relate to emissions from auxiliary engines. The ships modelled in the assessment, however, run a single main diesel electric engine while at berth. Emissions were estimated by multiplying the above emission factors by the engine power operating while at berth. Carnival Australia (Carnival) indicated that the *Pacific Dawn* operates one 9720 kW engine at 8000 kW while at berth. Oceania Cruises staff indicated that the *Nautica* also kept one engine in operation while the ship was at berth, but did not provide engine size or operating regime information. An internet search indicated that the *Nautica* engines were 3280 kW; due to their relatively small size, the ship was assumed to operate one engine at 100% while at berth.

Emissions of SO_2 are a function of the fuel sulphur content. The weighted average fuel burn emission factor assumes a sulphur content of 2.4%. This value was consistent with advice provided by Carnival, which indicated that the fuel used for refuelling in Sydney has a sulphur content of 2 + 0.5%. Further advice from Shell, who supplies fuel to cruise ships that are refuelled in Sydney Harbour, indicated that the sulphur content of its fuel is 2.36%, which is consistent with the 2.4% used in the SO_2 emissions estimation.

Table 2-2 outlines the estimated hourly air pollution emissions from ships berthed at the WBCT under each of the scenarios considered.

Table 2-2 Ship Emissions at Berth

Pollutants	Scenario 1	Scenario 2	Scenario 3		Scenario 4
	Large (*Pacific Dawn*)	**Medium (*Nautica*)**	**Large (*Pacific Dawn*)**	**Medium (*Nautica*)**	**Large (*Pacific Dawn*)**
Emission rates (kg/hour)					
NO_X	115.92	47.52	115.92	47.52	115.92
PM_{10}	7.92	3.24	7.92	3.24	7.92
SO_2	77.76	31.68	77.76	31.68	77.76

The modelling showed that Scenario 3 (concurrent berthing of a large and a medium-sized passenger ship between 6 am and 6 pm) generally resulted in the highest predicted ground-level pollutant concentrations for all pollutants over all averaging times. The exception is Scenario 4 where the 24-hour averages were predicted to be higher.

In terms of modelled impacts, the following was concluded for each of the assessed pollutants:

- **NO_X as NO_2:** The modelling showed no exceedances of the EPA 1-hour or annual NO_2 criteria. The highest concentration of 162 µg/m^3 was less than the 246 µg/m^3 1-hour criterion;
- **PM_{10}:** The results of modelling showed that Scenario 4 has the highest potential to cause an exceedance of the 50 µg/m^3 EPA criterion. This potential is observed by adding the maximum predicted incremental increase (22 µg/m^3) to the maximum assumed background level (35 µg/m^3), to give 57 µg/m^3. The probability of an exceedance was determined to be very low because:
    - Ships will not be at the berth every day of the year (approximately 170 ships ship year, say one ship every two days);
    - Scenario 4 is the least likely of all modelled scenarios;

  - Maximum increments from ship emissions would have to coincide with maximum background levels;
  - Annual average PM_{10} concentrations were predicted to be below the assessment criterion of 30 $\mu g/m^3$ at all locations even when a background level of around 20 $\mu g/m^3$ is included;
- **SO_2:** The results of modelling showed that cumulative SO_2 impacts complied with EPA 10-minute, 1-hour, 24-hour and annual criteria at all sensitive receiver locations.

With respect to SO_2 it is noted that the modelling scenario is based on emission estimates for fuel with a sulphur content of 2.4% which is much higher than the current fuel regulation of 0.1%. As such actual impacts from 2015 onwards will be much lower than those predicted in the 2010 air quality assessment.

2.2 Office of Environment and Heritage air quality monitoring

Acknowledging that the 2010 air quality assessment predicted cumulative impacts, including background air pollution concentrations at that that time, it is necessary to review the background air quality in the area now, to assess if any changes have occurred that may affect the ship emission impacts assessed back in 2010.

The NSW Office of Environment and Heritage (OEH) maintains an air quality monitoring network in the Sydney region. The closest OEH monitoring station is at Rozelle Hospital, approximately 1.5 km west of WBCT. The station measures ozone (O_3), oxides of nitrogen (NO, NO_2, NO_x), carbon monoxide (CO) and PM_{10}, and in March 2015 SO_2 and $PM_{2.5}$ monitoring systems were established.

The data from this monitoring station were used to inform the air quality assessment for the WBCT project approval, where data from 2001–06 were analysed for hourly and annual concentrations. To understand whether background air quality has changed near Balmain since the air quality assessment was completed in 2010, the data used for the assessment have been compared to the more recent measured data at Rozelle (sourced from OEH, 2015).

All available daily maximum 1-hour NO_2 data are shown in **Figure 2.1**. No significant changes in the NO_2 data are evident from 2001 – 2015 at this monitoring station. The air quality criteria for NO_2 in NSW is 12 parts-per-hundred-million (pphm) over a 1-hour average.

All available daily average PM_{10} data (averaged from 1 hourly data) from Rozelle OEH monitoring station are shown in **Figure 2.2**. No significant changes in the PM_{10} data are evident from 2001–15 at this monitoring station.

The annual average NO_2 (2001–14) and PM_{10} (2004–14) measured at Rozelle is shown in **Table 2-3**.

$PM_{2.5}$ monitoring was established in Rozelle during March 2015, so no long-term trends in this data are evident.

Hence the predicted cumulative impacts from the 2010 air quality assessment would not change as a result of currently available background air quality concentrations.

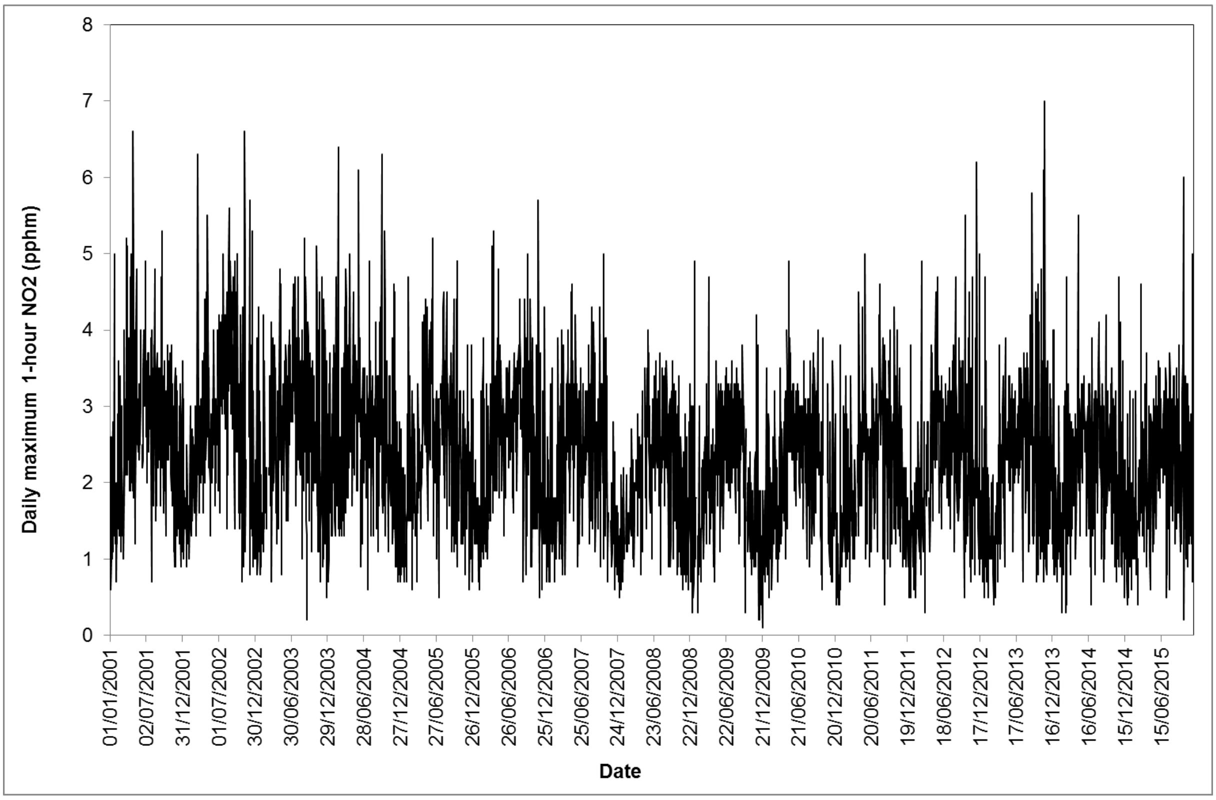


Figure 2.1 : Daily maximum 1-hour NO_2 (ppb) at Rozelle OEH Monitoring Station

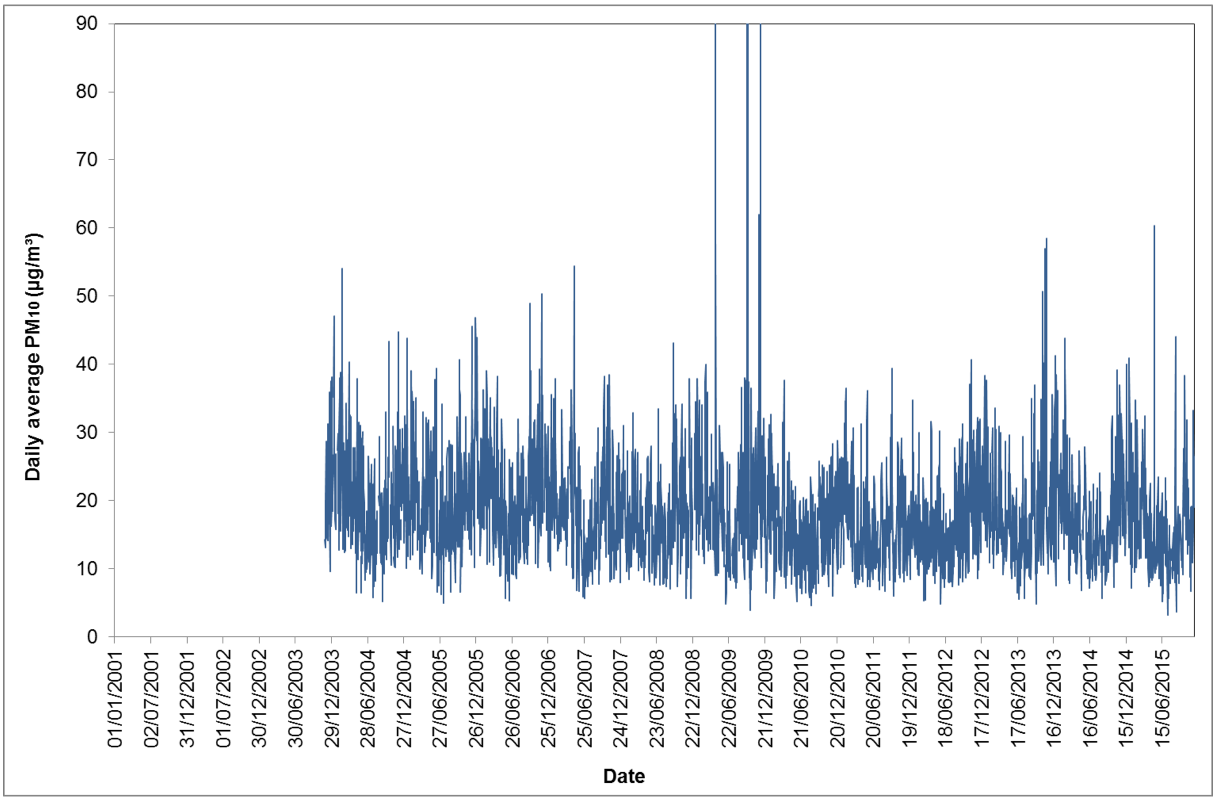


Figure 2.2 : Daily average PM_{10} (ug/m3) at Rozelle OEH Monitoring Station

Table 2-3 Annual average concentration of NO_2 and PM_{10} at Rozelle OEH monitoring station

Pollutant	Year	Annual average concentration (derived from 1 hour averages)
NO_2 (pphm)	2001	1.4
	2002	1.5
	2003	1.4
	2004	1.4
	2005	1.3
	2006	1.3
	2007	1.2
	2008	1.1
	2009	1.1
	2010	1.1
	2011	1.1
	2012	1.2
	2013	1.1
	2014	1.1
PM_{10} (µg/m^3)	2004	20.1
	2005	20.2
	2006	20.4
	2007	18.1
	2008	17.3
	2009	24.7
	2010	16.1
	2011	16.6
	2012	16.9
	2013	18.3
	2014	17.8

2.3 Starcrest Consulting 2017 Ship Emission Estimates

In order to assess if the air quality impacts as assessed by modelling in 2010 as part of the WBCT approvals process remain valid, a comparison has been made between the Starcrest Consulting emission estimates for the 2015/16 cruise year and the emissions estimated in the 2010 air quality assessment. The emission comparison assumes emissions rates associated with combustion of Marine Diesel Oil (MDO) that is prior to the introduction of the EPA's 2015 Cruise Regulation and the AMSA Marine Notice 21/2016 (December 2016).

Table 2-4 sets out the emission estimates by Starcrest Consulting for the 2015/16 cruise year for the same pollutants and scenarios assumed in the 2010 air quality assessment. It is noted that the *Pacific Dawn* as assessed in 2010 has been replaced by the Dawn Princess as the reference large ship and the *Nautica* has been replaced by the *Pacific Princess* as the reference medium ship (these ships were selected as the engine sizes are comparable). In addition to the NO_X, PM_{10} and SO_2 considered in the 2010 air quality assessment for the WBCT, Starcrest Consulting 2017 has considered other pollutant emissions, specifically VOCs as relevant to local and regional air quality. The total estimated VOCs for all cruise ships visiting the WBCT for the 2015/16 cruise season is 3.46 tonnes per annum. VOC emissions for the model scenarios included in the 2010 WBCT air quality assessment are also included in **Table 2-4** including a speciation for recognised toxic and odorous VOCs.

Table 2-4: Starcrest Consulting 2017 Emission Baseline Estimates (as applied to the 2010 model scenarios)

Pollutants	Scenario 1	Scenario 2	Scenario 3		Scenario 4
	Large (*Dawn Princess*)	**Medium (*Pacific Princess*)**	**Large (*Dawn Princess*)**	**Medium (*Pacific Princess*)**	**Large (*Dawn Princess*)**
Emission rates (kg/hour)					
NO_X	110.24	36.67	110.24	36.67	110.24
PM_{10}	11.27	4.00	11.27	4.00	11.27
SO_2	92.22	30.67	92.22	30.67	92.22
VOCs[1]	3.02	1.33	3.02	1.33	3.02
Benzene	0.0236	0.0104	0.0236	0.0104	0.0236
Toluene	0.0131	0.0058	0.0131	0.0058	0.0131
Ethylbenzene	0.0080	0.0035	0.0080	0.0035	0.0080
Xylene	0.0114	0.0050	0.0114	0.0050	0.0114

It can be seen that the Starcrest Consulting 2017 emission estimates (refer to **Table 2-4**) compare well with the 2010 modelling estimates for NO_X, PM_{10} and SO_2 (refer to **Table 2-2**) with the material differences being:

- SO_2 emission for large ships estimated at 77.66 kg/hour in 2010 and 92.22 kg/hour in 2015. The difference is explained by the 2010 air quality assessment adopting a fuel sulphur content of 2.34% compared with 2.7% by Starcrest Consulting in 2017. In terms of actual air quality impacts the result is of no consequence as the actual sulphur content of fuel used by ships while at berth is now a maximum of 0.1%, which would result in significantly lower concentrations at the receivers.
- In terms of PM_{10}, for large ships this was estimated at 7.92 kg/hour in 2010 and 11.27 kg/hour in 2015, suggesting a 42% increase by Starcrest, 2017, compared with SKM, 2010. It is noted that Starcrest use a PM_{10} emission factor of 0.0015 kg/hour for MDO (from CARB, 2007) whereas SKM, 2010 uses an emission factor of 0.001 kg/hour consistent with the NPI Emission Estimate Technique Manual for Maritime Operations, which is 50% higher than the Starcrest estimate, explaining the difference in PM_{10} emissions. As for SO_2, in terms of actual air quality impacts the result is of no consequence as the actual sulphur content of fuel used by ships while at berth is now a maximum of 0.1% and the corresponding PM_{10} emission factor for this fuel is 0.00026 kg/hour (Starcrest, 2017). This is approximately 4 times lower than the 0.001 kg/hour PM_{10} emission factor used by the SKM, 2010 study, and would result in PM_{10} concentrations at receivers lower than those assessed in 2010.

[1] **Ref: Starcrest Consulting (2017):** Volatile organic compounds (VOCs) are comprised of various volatile fragments both human-made and naturally occurring. In the context of diesel engine operations, benzene, toluene, ethylbenzene, and xylene (BTEX) are the VOCs mostly associated with more refined fuels like ULSD. The fractions of VOCs for BTEX constituents for pre-2007 model year land-based diesel engines running on ULSD are:

- Benzene 0.007835
- Toluene 0.00433
- Ethylbenzene 0.002655
- Xylene 0.003784.

BTEX is typically not calculated nor associated with ship emissions. Additional research would be needed to obtain more specific breakouts to the engines anticipated to be used on-board cruise ships calling at WBCT in order to estimate BTEX emissions at the cruise terminal with full confidence; however, for the magnitude of their emission, the above factors are sufficient. BTEX and VOCs are anticipated to be marginally controlled with scrubbers, however there is no testing data to derive an efficiency factor, and therefore no reduction was taken.

2.4 Summary of Local Air Quality Impacts

In summary, the cumulative air quality impacts of SO_2, NO_2 and PM_{10} from the WBCT as assessed in 2010 remain valid acknowledging that actual ship emission estimates by Starcrest Consulting, 2017 are comparable with those from SKM, 2010 and there has been no material change in background air quality. As such the predicted SO_2, NO_2 and PM_{10} impacts from the 2010 air quality study which showed compliance with EPA criteria are considered to provide an accurate and conservative representation of current impacts. It is noted that the introduction of low sulphur fuel requirement results in lower SO_2, and PM_{10} emissions than those assessed in 2010 and correspondingly lower impacts would be expected.

With respect to BTEX these were not assessed as part of the 2010 WBCT air quality assessment. It is however possible to comment on the likely extent of impacts in Balmain from these pollutants from the WBCT by comparing their emission concentrations with that of SO_2 (for example), and then estimating (scaling) their impact using the predicted SO_2 impacts. This analysis is presented in **Table 2-5** for Scenario 3 which presented the highest impacts in the 2010 assessment.

Table 2-5 Estimated WBCT VOC (speciated) Impacts in Balmain

Pollutants	Scenario 3 Emission Sources (kg/hour)		Scenario 3 Max. 1 hour impacts (WBCT only)	EPA Criteria (1 hour) (µg/m³)
	Large (*Dawn Princess*)	**Medium (*Pacific Princess*)**	**Highest result at residential receivers**	
SO_2	92.22	30.67	414	570
VOCs	3.02	1.33	14.7	-
Benzene	0.0236	0.0104	0.11	29
Toluene	0.0131	0.0058	0.064	360
Ethylbenzene	0.0080	0.0035	0.038	8000
Xylene	0.0114	0.0050	0.055	190

It can be seen that estimated worst-case BTEX impacts are well below EPA criteria. It is noted that these results are for the WBCT only and exclusive of background levels, however, noting that highest result is for benzene, with an estimated impact of 0.11 µg/m^3 compared with a criterion of 29 µg/m^3 (based on this analysis) it is not expected that BTEX emissions from ship emissions operating at the WBCT would significantly contribute to any adverse cumulative impacts.

It is noted that the scaling approach used for this analysis has some limitations when applied to multiple sources of pollution emissions. However, as there are only two sources (i.e. two vessels) and emissions of VOCs from each have been proportioned in the same amounts as the SO_2 emissions from SKM, 2010 this is considered a reasonable approach. It is also acknowledged that the estimated concentrations are low when compared with relevant air quality criteria.

3. Exposure to NO_X in the Sydney Region

Oxides of nitrogen (NO_x) are formed in nearly all combustion reactions and so are emitted from a range of sources throughout the Sydney area. There are two databases available to understand NO_x emissions in the Sydney region, these are:

- NSW Environment Protection Authority - GMR Air Emissions Inventory, refer **to Section 3.1**.
- Department of the Environment - National Pollutant Inventory (NPI), refer to **Section 3.2**.

These databases estimate the release of pollutants from sources but do not quantify the exposure to the pollutants. To determine the exposure much more detailed analysis is required to understand the dispersion conditions at the point of interest, including meteorological conditions, terrain influences and population density.

3.1 Greater Metropolitan Region Air Emissions Inventory

The contribution of each source of air pollution is quantified on a semi-regular basis by the NSW Environment Protection Authority (NSW EPA, 2012). The most recent published inventory of air quality emissions in NSW was completed for year 2008 for the Greater Metropolitan region with estimates for the Sydney region. The inventory includes emissions from biogenic (i.e. natural and living), geogenic (i.e. natural non-living) and anthropogenic (i.e. human-made) sources.

The emissions of NO_x in the Sydney region are dominated by human-made sources (98%), with the remaining 2% due to natural sources. From these human-sources the largest emission source is on-road mobile sources (i.e. vehicle emissions; 62%) followed by off-road mobile sources (i.e. industrial vehicles, ships, boats and trains; 22%). The comparative estimated annual emissions in tonnes per year by natural and human-made sources in Sydney are shown in **Figure 3.1**. The 10 most significant human-made NO_x sources in the Sydney region are shown in **Figure 3.2**.

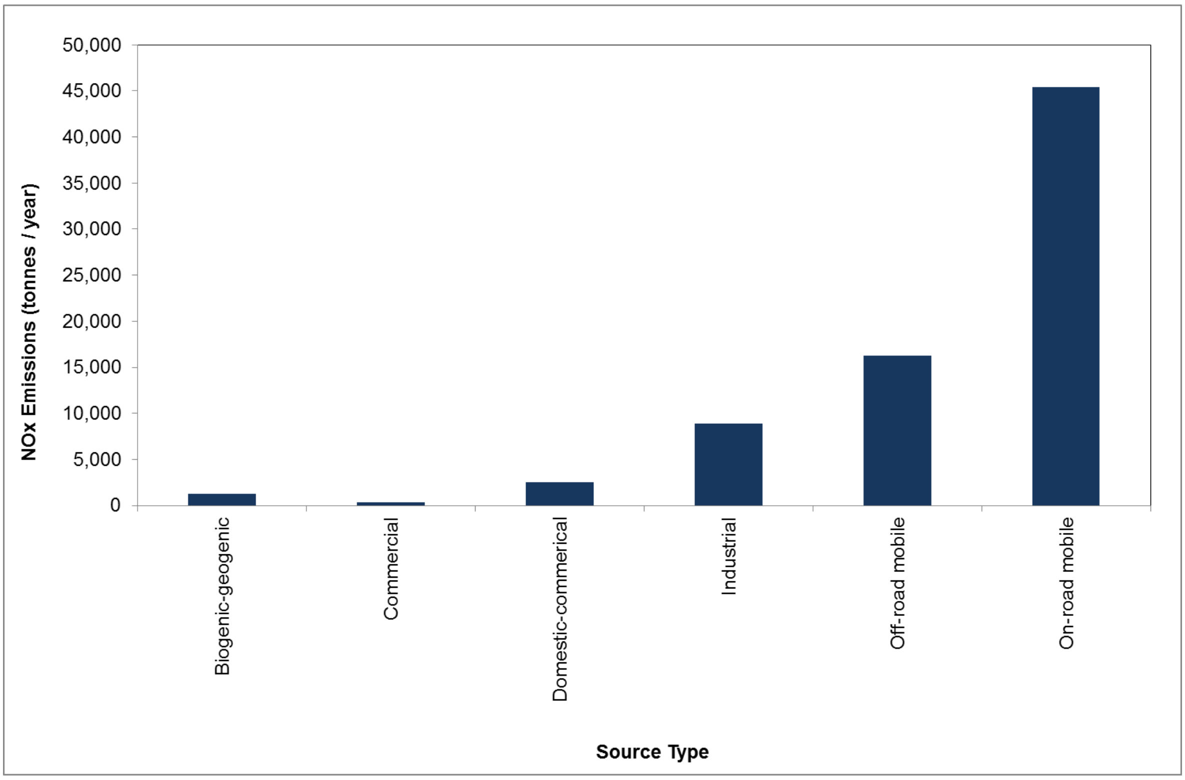


Figure 3.1 : Total estimate annual emission from natural and human-made sources in the Sydney region (NSW EPA, 2012)

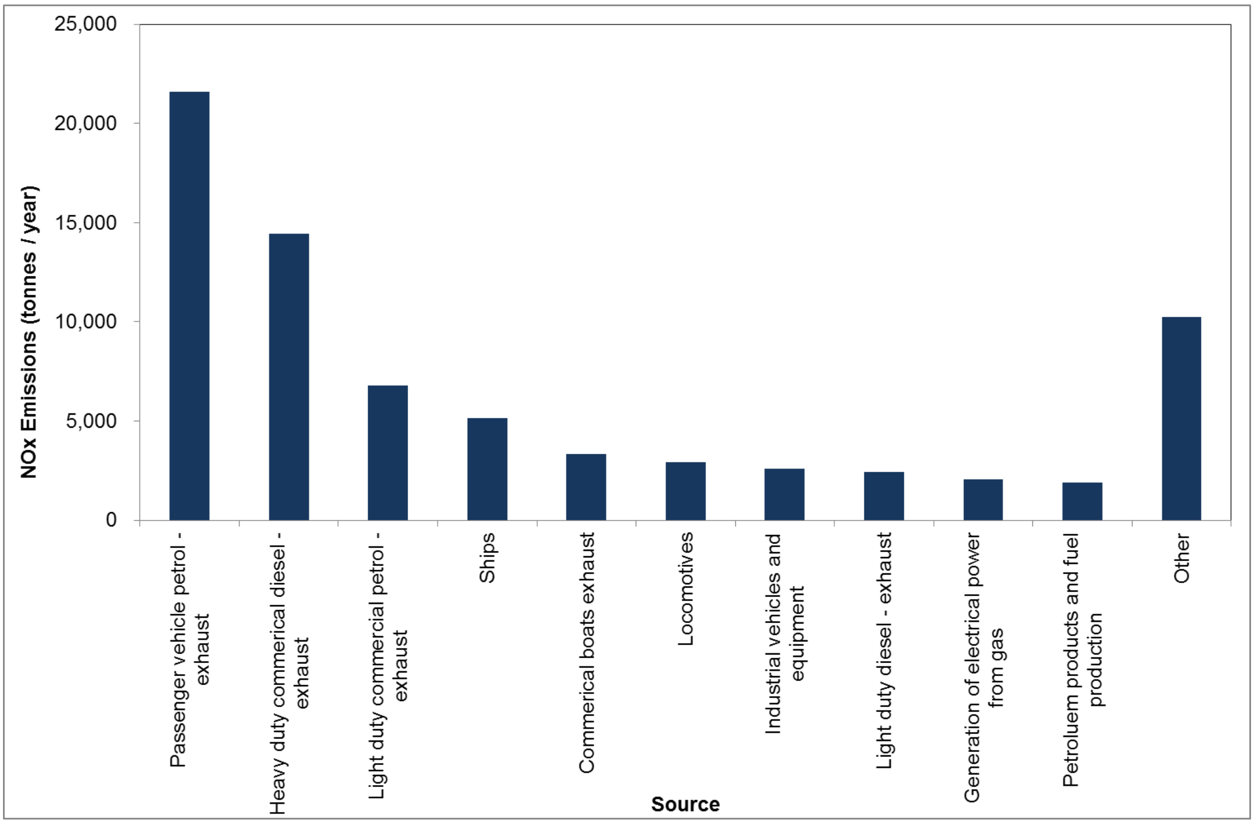


Figure 3.2 : Top 10 human-made NO_x sources in the Sydney region (NSW EPA, 2012)

3.2 National Pollutant Inventory

The National Pollutant Inventory (NPI) is a database maintained by the federal Department of the Environment to quantify emission sources around Australia. NPI data are a measure of the amount of pollutants released into the environment, and do not indicate exposure, toxicity or environmental effects.

The NPI is a combination of data from two source types:

- Facility (industry) – estimated and reported by industry.
- Diffuse (airshed / catchment) – estimated and reported by relevant State / Territory authority.

Industrial facilities must report on their estimated emissions annually using the appropriate emissions estimation techniques, which vary by source. Only facilities that exceed thresholds for fuel, waste electricity usage and emissions of certain substance types are required to report; currently over 4000 facilities report to the scheme. The reporting year 2013/2014 is the most recent NPI data available.

3.3 NO_x Emission Comparison Leichhardt (Balmain) and other Sydney LGAs (Suburbs)

There are no industrial facilities in the suburb of Balmain that are required to report to NPI, although there is one facility that reports to the NPI in the former Leichhardt Local Government Area (LGA) but that facility does not record emissions of NO_x.

As outlined in Section 1.1 the Inner West Council was proclaimed on 12 May 2016. It is made up of the former local government areas (LGAs) of Ashfield, Leichhardt and Marrickville. Acknowledging that 2013/14 NPI data is used for analysis to follow, emissions are associated with the pre-existing LGAs that is, those prior to Council amalgamation and formation of the Inner West Council.

To put Leichhardt including Balmain into context with the closest geographical LGAs and the wider Sydney region, the facility emissions reported under the NPI have been compared for LGAs near Leichhardt in **Table 3-1** and for suburbs in the wider Sydney region in **Table 3-2**.

A calculation of NO_x emissions across area and number of residents (using 2011 census data) has been included to take the scale and impact into consideration. The results show in general that residents of Leichhardt including Balmain are not in close vicinity to NO_x emissions from large industrial sources, as reported by the NPI.

Table 3-1 : NO_x Emissions reported by industrial facilities for LGAs near Balmain (2013/2014 reporting year)

Local Government Area	Number of facilities reporting to the NPI	NO_x Emissions to air (kg/year)	NO_x Emissions (kg/year/km^2)	NO_x Emissions (kg/year/no. of residents)	Major Sources
Leichhardt (includes Balmain)	1	-	-	-	Brewing
Marrickville	1	-	-	-	Train maintenance and fuelling
Sydney	3	24,000	960	0.1	Metal manufacturing; personal services.
Ashfield	-	-	-	-	-
Burwood	-	-	-	-	-
Canada Bay	-	-	-	-	-
North Sydney	1	20	2	0.0003	Waste treatment

Table 3-2 : NO_x Emissions reported by industrial facilities for LGAs in the wider Sydney region (2013/2014 reporting year)

Local Government Area	Number of facilities reporting to the NPI	NO_x emissions to air (kg/year)	NO_x Emissions (kg/year/km^2)	NO_x Emissions (kg/year/no. of residents)	Major Sources
Parramatta	13	170,000	2,787	1	Mineral and metal wholesaling; waste treatment and disposal services; concrete manufacturing; petroleum and coal manufacturing; bakery product manufacturing.
Fairfield	21	270,000	2,647	1	Ceramic manufacturing; waste treatment and disposal; concrete manufacturing; construction material mining; gas supply
Botany Bay	17	1,200,000	44,860	30	Chemical manufacturing; water transport; transport equipment manufacturing; grain mill; chemical manufacturing.

Local Government Area	Number of facilities reporting to the NPI	NO_x emissions to air (kg/year)	NO_x Emissions (kg/year/km^2)	NO_x Emissions (kg/year/no. of residents)	Major Sources
Blacktown	23	230,000	932	1	Electricity generation; ceramic manufacturing; metal manufacturing; waste treatment disposal.
Bankstown	15	21,000	273	0.1	Bakery manufacturing; paper manufacturing; metal manufacturing.
Campbelltown	11	110,000	353	1	Mineral product manufacturing; petroleum manufacturing; water supply and sewerage; glass manufacturing; grain mill.
Liverpool	16	44,000	144	0.2	Printing services; water supply and sewerage; paper manufacturing; bakery manufacturing; beverage manufacturing.

Diffuse sources are non-industrial sources and selected sub-threshold industries reported by regulatory authorities for inclusion in the NPI. Diffuse sources are not calculated on an annual basis, rather a semi-regular basis. The most recent year of study for diffuse sources was 2007 which was included as estimations for the 2013/2014 reporting year.

Diffuse sources include:

- Facilities too small to report individually.
- Mobile emission sources (i.e. aircraft in flight, ships at sea).
- Household activities (i.e. cooking, driving).

Ships are an example of a diffuse, mobile source, estimated using the Aggregate Emissions from Commercial Ships/Boats and Recreational Boats Emissions Estimation Technique Manual (Environment Australia, 1999). Emissions are calculated using the number of ships visiting a port in a particular year, the average number of hours at berth, the average speed of ships in the shipping channels and the locations and lengths of shipping channels in the airshed.

The diffuse NO_x sources for LGAs adjacent to Leichhardt (which includes Balmain) and those in the wider Sydney region are shown in **Table 3-3** and **Table 3-4** respectively. The top 5 major sources have been included to show where shipping emissions are ranked for each suburb if identified as a significant emissions source.

The total industrial and diffuse (non-industrial) NO_x emissions reported under NPI for the 2013/2014 reporting year for the selected LGAs are shown in **Figure 3.3**.

The commercial shipping / boating emission of NO_x estimated in the NPI for the suburb of Balmain for reporting year 2013 / 2014 was 40 tonnes/year (NPI, 2015). It is noted that the last year diffuse emissions were estimated was 2007 and while these are the most reliable inventory estimates available this estimation was calculated using data prior to the establishment of WBCT. So as to provide an emissions scenario with the WBCT, NO_X emissions calculated by Starcrest Consulting, 2017 have been added to the NPI estimates in **Table 3-3** and **Figure 3.3**.

If the emissions in Balmain are compared at a suburb-level to adjacent communities and those in the wider Sydney region, there is no indication that Balmain is subjected to materially higher NO_x emissions (**Figure 3.4**).

Table 3-3 : Diffuse NO_x emission sources for LGAs near Balmain (2013/2014 reporting year)

Local Government Area	NO_x Emissions to air (kg/year)	NO_x Emissions (kg/year/km²)	NO_x Emissions (kg/year/no. of residents)	Major Sources*
Burwood	410,000	58,571	13	Motor vehicles; railways; fuel combustion; gaseous fuel burning (domestic); solid fuel burning (domestic).
Ashfield	580,000	72,500	14	Motor vehicles; aeroplanes; railways; fuel combustion; gaseous fuel burning (domestic).
Leichhardt (includes Balmain)	820,000	74,545	16	Motor vehicles, aeroplanes, commercial shipping/boating, fuel combustion, gaseous fuel burning.
Canada Bay	940,000	47,427	12	Motor vehicles; aeroplanes; commercial shipping / boating; railways; fuel combustion.
Leichhardt (includes Balmain) with WBCT	943,340	85,758	18	Motor vehicles, aeroplanes, commercial shipping/boating (with WBCT added), fuel combustion, gaseous fuel burning.
Marrickville	1,100,000	64,706	14	Motor vehicles, aeroplanes, railways; fuel combustion; gaseous fuel burning (domestic).
North Sydney	1,200,000	110,092	19	Motor vehicles; commercial shipping / boating; railways; fuel combustion; gaseous fuel burning (domestic).
Sydney	3,200,000	128,000	19	Motor vehicles, aeroplanes, commercial shipping / boating, railways, fuel combustion.

* Top 5 emissions sources, in order of significance

Table 3-4 : Diffuse NO_x emission source for LGAs in the wider Sydney region (2013/2014 reporting year)

Local Government Area	NO_x emissions to air (kg/year)	NO_x Emissions (kg/year/km^2)	NO_x Emissions (kg/year/no. of residents)	Major Sources*
Botany Bay	1,500,000	56,075	38	Motor vehicles, solid fuel burning (domestic), aeroplanes, commercial shipping/boating, lawn mowing.
Fairfield	2,200,000	21,569	11	Motor vehicles, aeroplanes, fuel combustion, railways, gaseous fuel burning.
Campbelltown	2,400,000	7,692	16	Motor vehicles, railways, fuel combustion, gaseous fuel burning (domestic), solid fuel burning (domestic).
Parramatta	3,000,000	49,180	17	Motor vehicles, commercial shipping/boating, railways, fuel combustion, gaseous fuel burning (domestic).
Liverpool	3,200,000	10,475	18	Motor vehicles, aeroplanes, railways, fuel combustion, gaseous fuel burning (domestic).
Bankstown	3,400,000	44,271	18	Motor vehicles, aeroplanes, railways, fuel combustion, gaseous fuel burning (domestic).
Blacktown	4,500,000	18,226	15	Motor vehicles, railways, fuel combustion, gaseous fuel burning (domestic), solid fuel burning (domestic).

* Top five emissions sources, in order of significance

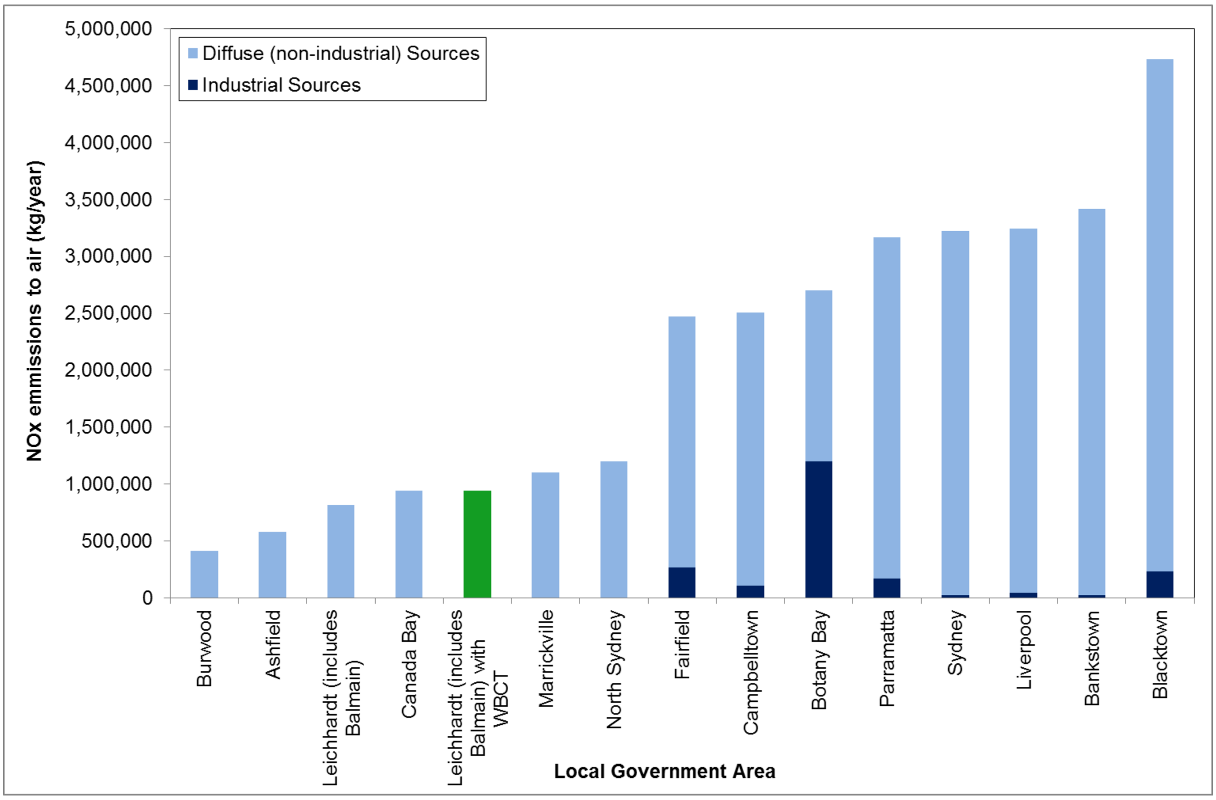


Figure 3.3 : Total industrial and diffuse NO_x emissions reported for NPI reporting year 2013/2014 by LGA

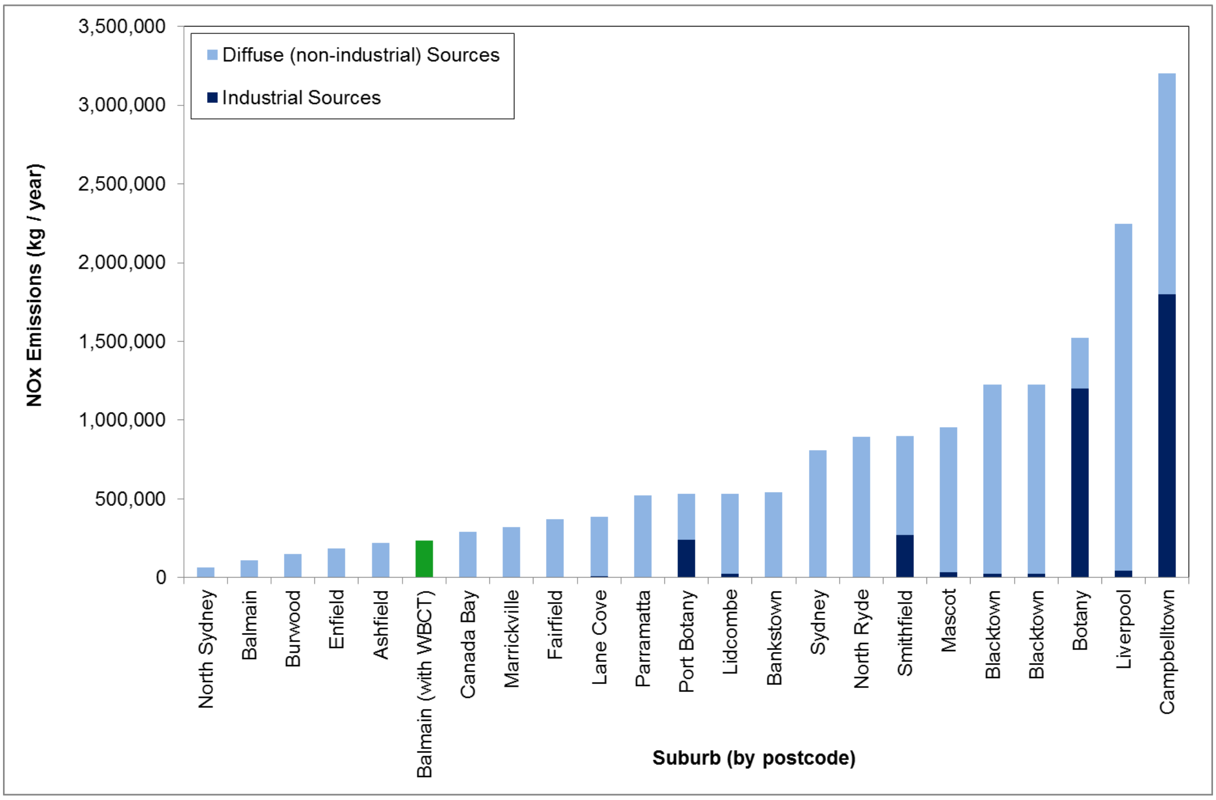


Figure 3.4 : Total industrial and diffuse NO_x emissions reported for NPI reporting year 2013/2014 by suburb

Balmain is governed by the Leichhardt LGA. When the estimated NO_x emissions from this municipality are compared to the adjacent communities such as Marrickville, Ashfield, Burwood and Canada Bay, Leichhardt is comparable. The total emissions in Leichhardt (including WBCT) were 943 tonnes compares to 1100 in Marrickville, 940 tonnes in Canada Bay, 580 tonnes in Ashfield and 410 tonnes in Burwood. None of these LGAs have industrial sources that report NO_x emissions to the NPI.

NO_x emissions in the Sydney area are dominated by diffuse sources in most areas, and generally the highest contribution is from motor vehicles. Only industrial areas, such as Botany Bay, record comparable emissions from industrial sources. Communities in the wider Sydney region are estimated, in some cases, to have much higher diffuse emissions than Leichhardt while also having industrial sources which report NO_x point source emissions. Blacktown total NO_x emissions are five times higher than Leichhardt with the contribution of WBCT included; whilst City of Sydney reports 3.4 times the volume of emissions. Of the 14 LGAs used in this comparison, Leichhardt (with WBCT) is ranked the 5th lowest for NO_x emissions.

The contribution of WBCT to the Leichhardt airshed was estimated as an additional 123 tonnes of NO_x per year, equivalent to 13% of the total NO_x emissions in the community. This number has been adopted from the recent Shore Power Report (Starcrest Consulting, 2017) for NO_x emissions, assuming no change to fuel sulphur content.

When the size of the land area of each LGA and the number of residents occupying the area are considered, Leichhardt is not shown to be more impacted than other communities (**Figure 3.5**). Owing to a relatively small population in City of Botany Bay (39,356 in 2011 ABS census), the emissions per residents are disproportionally higher in this LGA compared other areas in Sydney.

Similarly, when total NO_x emissions by number of residents are compared at a suburb-level between Balmain (both with and without WBCT) and suburbs adjacent to and in the wider Sydney region, Balmain is not shown to be impacted more than other communities (**Figure 3.6**). It is noted that there was no detailed consideration given to the suburbs chosen to include in the analysis, but a wide range of other suburbs impacted by non-road NO_X emission sources were included, for example:

- Enfield: Enfield Marshalling Yard where there is a concentration of diesel locomotive emissions;
- Port Botany: including the Port Botany container terminals where there is a concentration of heavy vehicles as well as ship emissions; and
- Mascot: including Sydney Airport where there is a concentration of aircraft emissions.

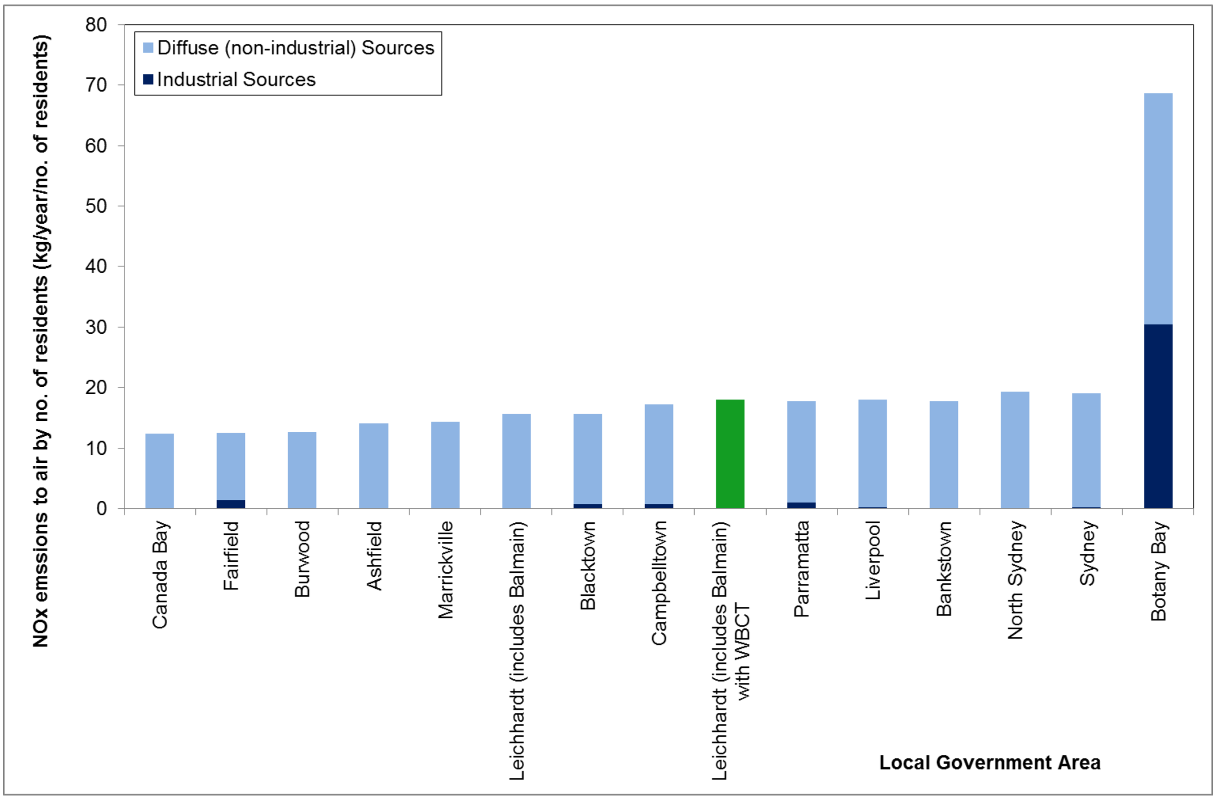


Figure 3.5 : Total industrial and diffuse NO_x emissions by number of residents for NPI reporting year 2013/2014 by LGA

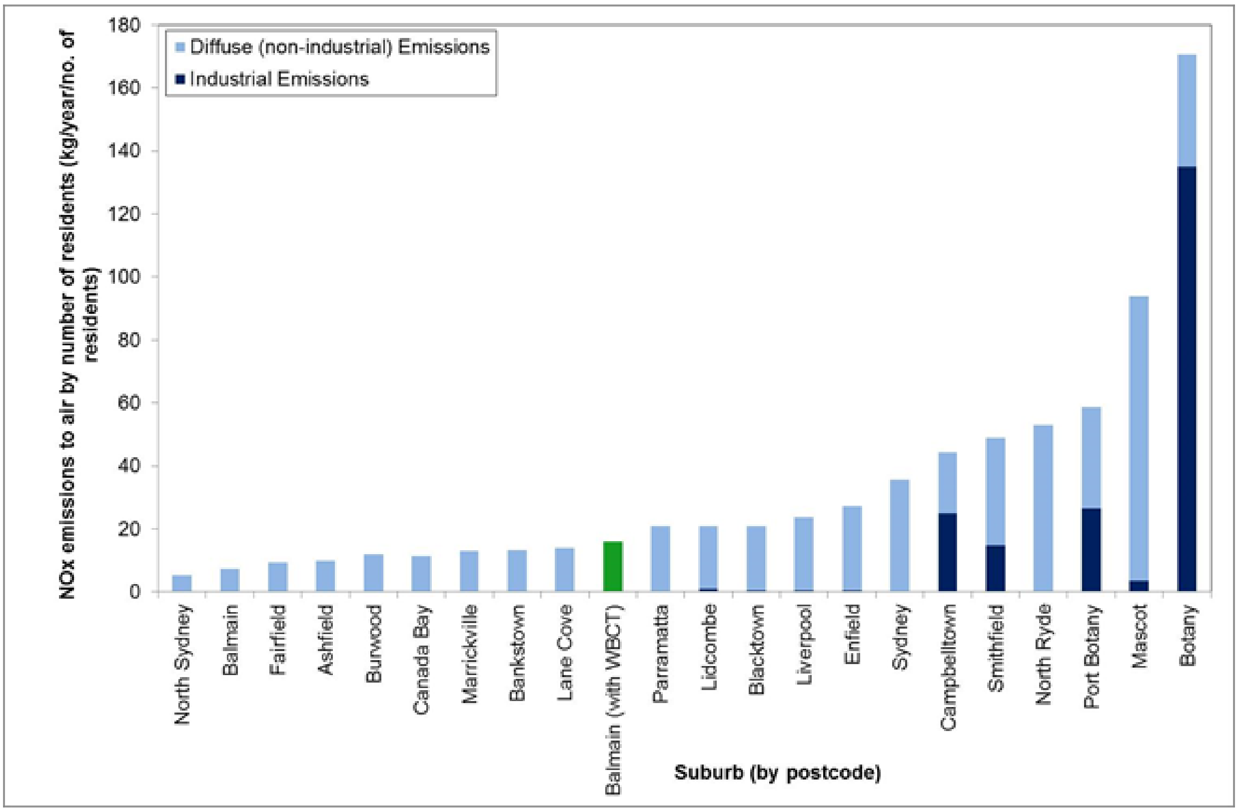


Figure 3.6 : Total industrial and diffuse NO_x emissions by number of residents for NPI reporting year 2013/2014 by suburb

4. Regional NO_X Emissions, Impacts and Abatement

4.1 Overview

This section of the report considers the range of NO_X emissions abatement that is either being considered or could be considered in the Sydney GMR including shore power, and how shore power compares with other potential abatement initiatives.

4.2 NSW EPA Initiatives for Air Pollution Control

Air pollution is recognised as an important health risk and environmental issue in NSW by both the regulator and residents. The NSW EPA is working on a number of initiatives to improve air quality by targeting sources with higher contributions and through cost-benefit analysis studies to target improvements.

Key pollutants of concern in the Sydney region are NO_x and VOCs as these are photochemical smog precursors which react with sunlight to form photochemical smog. This event is characterised by white atmospheric haze during warmer months. These pollutants, along with SO_2, react to form secondary organic aerosols which can cause brown haze pollution events during cooler months. The reduction of these smog events is a priority for the NSW EPA through the reduction of these precursors. These pollutants have been targeted through a number of initiatives:

- Reducing emissions from motor vehicles and non-road diesel sources through the smoky vehicles program and development of a strategy for managing non-road diesel emissions, including emissions from ports and locomotives.
- Reducing service station emissions through vapour recovery to VOCs and reduce regional ground-level O_3.
- Reducing cogeneration and tri-generation emissions from gas-fired power stations to reduce ozone and NO_x exposure.

Most recently the EPA Clean Air for NSW – Consultation Paper (NSW Government, 2016) notes some key considerations for the future of air quality management in NSW, including:

- Increasing populations will increase exposure to air pollution and associated health impacts and costs.
- New measures needed for significant sources of pollution, such as wood heaters.
- Increased development near significant sources, such as areas of bushfires and hazard reduction burns, will increase exposure to smoke.
- Increased urban densities along transport corridors will increase exposure.
- Changes to climate will influence changes in air quality.
- Air quality considerations need to be integrated into transport, land-use and energy planning.

4.3 Ship Emission Initiatives

The NSW EPA has produced a strategy for managing diesel and marine emissions to identify feasible and timely emission reduction options (NSW EPA, 2015b). A stakeholder workshop on shipping emissions management was held in November 2014. It was attended by over 80 stakeholders from the cruise industry, containerised and bulk cargo industry, bulk fuel suppliers and port authority stakeholders to discuss the strategy.

Background for the strategy was provided by a screening study completed in 2011 which addressed emission mitigation measures, ship emission control methods and options for ship emission reduction measures (PAE Holmes, 2011). The report provided a detailed emission inventory and a survey of major stakeholders involved in NSW ports on possible mitigation measures.

More recently Det Norske Veritas (Australia, DNV GL) was contracted by the NSW EPA to assess the technical feasibility, costs and emission impacts of adopting emission reduction measures for ships at major ports in NSW (DNV GL, 2015). The report concluded that low sulphur fuel will reduce SO_x and $PM_{2.5}$ but not have an impact of CO_2 nor NO_x. It also concludes that while shore power is technically feasible, the costs are prohibitive and the there is a long lead-time for implementation.

A second workshop was held for stakeholders in October 2015 to discuss the implementation of low sulphur fuel and the results of recent reports.

4.4 Starcrest Consulting 2017 Shore Power Report

The recently commissioned shore power analysis report (Starcrest Consulting, 2017) provides context for the potential to implement shore power at WBCT and determines the cost effectiveness of shore power for emissions reduction. The report notes that shore power has been implemented at only a small number of ports internationally due to the complex requirements for implementation and the relatively high costs involved.

With the use of shore power the emissions from the ship are reduced but not completely zero. Shore power eliminates the use of auxiliary engines while at berth, but not for approximately an hour after arrival and prior to departure, and the auxiliary boilers must still be run to generate hot water and steam for the ship. The emissions from the generation of the power required for the ship are shifted from local emissions to regional emissions, which are likely to be generated through coal-fired power station as this is the dominant source of power generation in NSW.

The emissions benefits analysis in this report estimated annual emission reductions for PM_{10} and NO_x with a weighting of 20:1 for PM_{10}:NO_x to account for the health effects of PM. The cost benefit analysis values the cost effectiveness of adopting shore power with 0.1% sulphur fuel as ranging from over $42,000 to $168,000 AUD per weighted tonne across 10 and 20 year time periods, local/regional benefits, and low/high scenarios.. The approach adopted to complete this study adopts the California Air Resource Board’s value of $21,522/tonne to determine whether the project is cost effective. In both scenarios the use of shore power is considered not cost effective.

The report notes other instances of emission reduction including:

- Improved engine and boiler technology.
- Use of exhaust treatment and control systems (e.g. Marine Exhaust Treatment System used in a California port).
- Use of natural gas for auxiliary engines and boilers, rather than fuel oil (e.g. those used in the new Carnival Corp cruise ships).
- Use of scrubbers on exhausts (e.g. Carnival Australia installing scrubber technology on all vessels from 2017–19).
- Use of barge-mounted alterative power systems (e.g. Becker Marine System in use at Port of Hamburg).
- Operational efficiency improvements (e.g. improvements to on-board lighting, air conditioning, refrigeration etc.).
- Improvements from other maritime sources (e.g. improvements to the engines of other vessels such as ferries and tug boats).

4.5 SKM 2010 Marginal Abatement Cost Curves (MACC) Study

In terms of considering where shore power sits in a hierarchy of Sydney GMR air pollution control measures compared with other alternatives, this was previously investigated at a very high level as part of a project undertaken by SKM for the NSW Department of Environment, Climate Change and Water (DECCW) – Cost Abatement Curves for Air Emission Reduction Actions (SKM, 2010).

Specifically DECCW engaged SKM to undertake a desktop study which identified and analysed a range of emission abatement initiatives across the Greater Metropolitan Region (GMR) and sub-regions of NSW. SKM developed a Marginal Abatement Cost Curve (MACC) model to assist in assessing the practicability of each identified initiative from a number of perspectives including economic, environmental and social impacts as well as technical feasibility. Separate MACC curves were developed for each of the substances considered in this study, VOC, NO_X and particulates (PM_{10}), showing the cost and abatement quantity from a range of potential initiatives to reduce emissions in the NSW GMR. Health benefits were not included in the assessment.

The curves identify potential sets of strategies that could be applied to achieve target emission reductions at the least estimated cost, and were intended to provide a guide to prioritising potential actions for further investigation. The cost and emission abatement estimates for actions on which the curves were based are indicative and not always readily compared across actions, given that they are drawn from a range of studies and jurisdictions.

The MACC modelling exercise yielded abatement cost curves that provide a range of measures, impacts and costs that can be considered as policy options to reduce ozone (precursor pollutants being NO_X and VOCs) and particulates (PM_{10} and not $PM_{2.5}$) in the NSW GMR.

One of the abatement initiatives considered the installation of shore power at the new berths developed as part of the Port Botany container terminal upgrade project. While not the WBCT, the cost of abatement is comparable for this technology when considering a range of emission abatement measures for the Sydney GMR.

Figure 4.1 sets out the information used to develop the Port Botany shore power emission abatement initiative including total emissions abated and the cost of abatement. With respect to NO_x in the Sydney GMR the abatement cost was $9.5M per tonne of total Sydney GMR ship NO_X where the measure is applied to 50% of berths the Port Botany container terminal. As can be seen in **Figure 4.2** this NO_x abatement initiatives had the second highest cost ($/tonne) of all initiatives investigated.

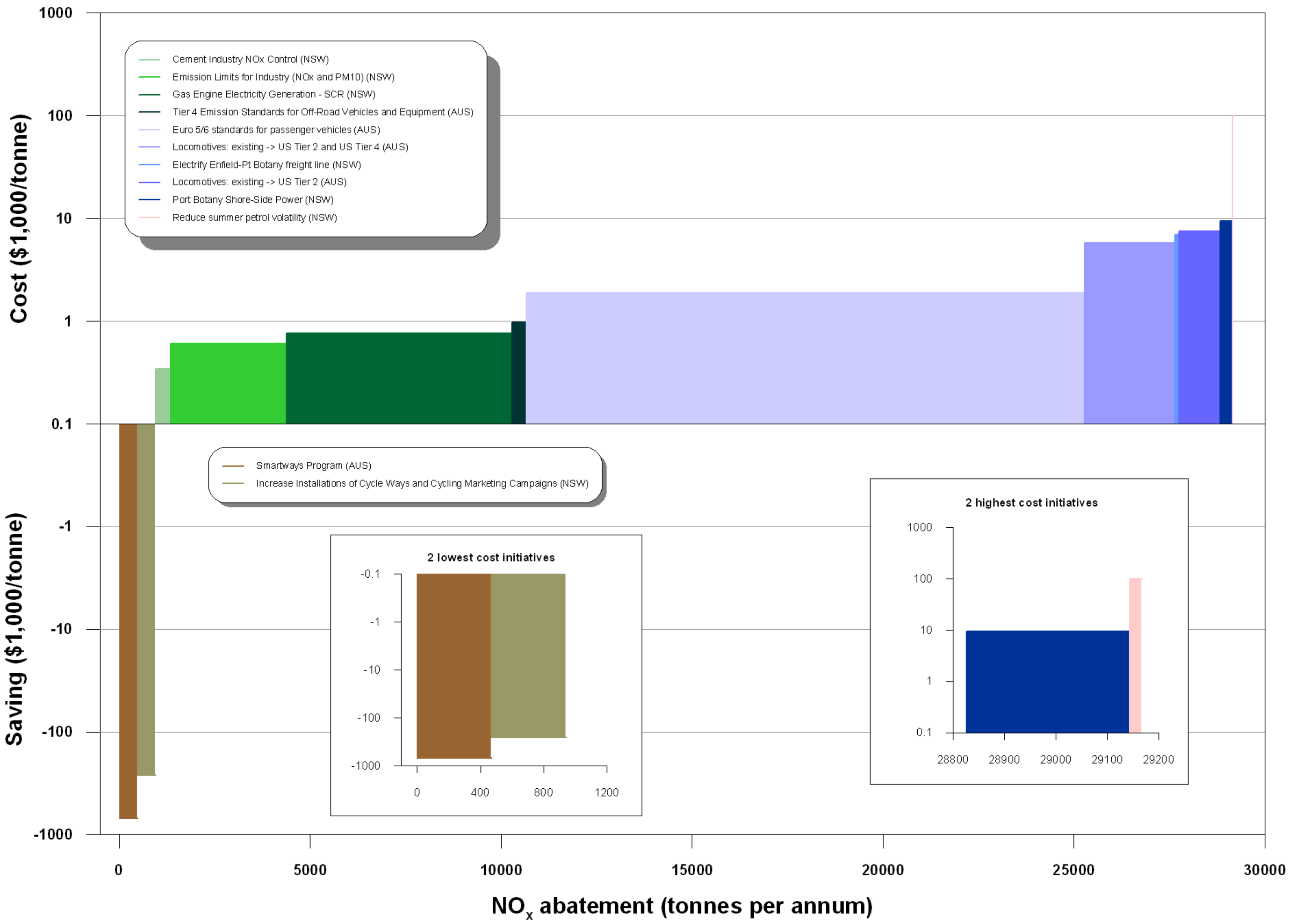
The $9.5M per tonne cost of NO_X abatement is very high as the basis of calculation was to apply it to all GMR AEI ship emissions, including emissions from travel to and from berth in the Sydney coastal and harbour regions. When applied to just ship emissions at berth in Port Botany, the cost reduces to approximately $135K per tonne, more comparable with the Starcrest Consulting 2017 estimates. Even at this cost, shore power still ranks as one the higher cost NO_X emission abatement initiatives.

It is acknowledged that the MACC study (SKM, 2010) is high level providing indicative comparisons across a range on air pollution abatement initiatives. It is included in this report for comparative purposes only.

Figure 4.1 Port Botany Shore Power Emissions Abatement (SKM, 2010)

Abatement Initiative #17: Port Botany Shore-Side Power					
Description	This abatement initiative involves installation of shore-side power on the 5 new berths proposed at Port Botany as part of the port expansion project.				
Regions:	Sydney,				Rating
Impact 1		**Pollutants**			**Medium**
AEI Activity:	Commercial Ships				
		NO_x	PM_{10}	VOCs	
	AEI 2008 Emission (tpa)	1,658	57	62	
	Abatement (tpa)	298	10	11	
	Abatement from proportion of source affected (%)	90%	90%	90%	
Impact 2		**Pollutants**			-
AEI Activity:	N/A				
		NO_x	PM_{10}	VOCs	
	AEI 2008 Emission (tpa)	-	-	-	
	Abatement (tpa)	-	-	-	
	Abatement from proportion of source affected (%)	0%	0%	0%	
Implementation costs					**Medium**
Program / set-up		500	000	AUD	
Implementation (capital)		20,912	000	EUR	
Annual operating / ongoing		2,385	000	EUR	
Assumptions and comments					
Relevant cost information was sourced from the American Association of Port Authorities Draft Use of Shore-Side Power for Ocean Going Vessels White Paper (May 2007). Source: http://www.westcoastcollaborative.org/files/sector-marine/AAPA-ShorePower-050107.pdf. This document provides various examples of shore power within international port. The example chosen for cost information is the Euromax port development in Rotterdam which has a capacity of 2.3 M TEU compared with Port Botany Expansion at 1.6 M TEU. The shore power capital an annual operating cost for Euromax are €28.5M and €3.25M respectively. These costs have been directly applied at Port Botany in the ratio of 1.6/2.3. In terms of estimating the proportion of the source affected it is noted that Port Botany and Port Jackson are both within the Sydney region and 90 % of emissions are from Port Botany. Additionally DECC's AEI includes emissions from ships berthed at port and travelling to and from port within 8 km of the coast. It was estimated that 90 % of emissions occur at berth and that 50 % of Port Botany's berths will be affected by the measures. As such the proportion of the source affected is 40% (0.9 x 0.9 x 0.5). It was further assumed that 90% of berthed emissions would be controlled by shore power. No account of costs needed to upgrade ships to use shore power have been included. It has been assumed that over the life of the abatement (2012 - 2031) that 50% achievable take-up is possible as new ships come on line and SPC can co-ordinate efforts with international shipping operators to use shore power compatible ships at these berths.					

Figure 4.2 Sydney GMR NO_X MACC (SKM, 2010)



5. Conclusions

This report provides an air quality assessment of cruise ships operating in the White Bay Cruise Terminal (WBCT). The conclusions of the report, consistent with the stated objectives, are as follows:

- **Potential exposure of residences in Balmain to cruise ship emissions:** In summary the cumulative air quality impacts of NO_2 and PM_{10} from the WBCT as assessed in 2010 remain valid, acknowledging that actual ship emission estimates by Starcrest Consulting, 2017 are consistent with those from SKM, 2010 and there has been no material change in background air quality. As such the predicted SO_2, NO_2 and PM_{10} impacts from the 2010 air quality study which showed compliance with EPA criteria are considered to provide an accurate representation of current impacts – potentially overestimates noting the lower pollutant emission rates for SO_2 and PM_{10} associated with the low sulphur fuel now required at WBCT. This report also found that it is not expected that in terms of BTEX, VOCs emissions from ship emissions operating at the WBCT would significantly contribute to any adverse cumulative impacts in the area.
- **NOx emissions and exposure in the Sydney GMR, so as to compare emissions in the Leichhardt / Balmain area which include cruise ship emissions and other areas that are not impacted by cruise ship emissions**: Considering industrial and diffuse sources of NO_X across the Sydney GMR the Leichhardt LGA which includes Balmain and emissions from the WBCT is exposed to similar levels of NO_X emission to other inner Sydney LGAs, and generally has lower NO_X emission than outer Sydney LGAs e.g. Parramatta, Blacktown and Liverpool. In terms of emission and exposure, calculated on a population (no. of residents) basis, the Leichhardt LGA is similar to all other LGAs, with the exception of the City of Botany which has a high exposure owing to its relatively low population and high industrial emissions. At a suburb level, Balmain (including WBCT) has comparable NO_X emissions to many other suburbs in Sydney.
- **Sydney GMR regional NO_X emissions:** Air pollution is recognised as an important health risk and environmental issue in NSW by both the regulator and residents. The NSW EPA is working on a number of initiatives to improve air quality by targeting sources with higher contributions and through cost-benefit analysis studies to target improvements. Various studies have considered shipping and shore power NO_X abatement costs including SKM, 2010, Det Norske Veritas (Australia; DNV GL), and Starcrest Consulting, 2017. In all cases the cost of shore power for NO_X abatement was considered high compared with other alternatives.

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Appendix 4 – Noise Assessment (SLR)

4 May 2016

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Port Authority of New South Wales
Level 4, 20 Windmill Street
Walsh Bay NSW 2000 Australia

Attention: Ryan Bennett
Senior Planning and Sustainability Manager

Dear Ryan

White Bay Cruise Terminal
Ship Noise Control by Shore Based Power

Introduction

SLR Consulting Australia Pty Ltd (SLR) has been commissioned by the Port Authority of New South Wales to review the potential reduction in noise levels when Cruise Ships berthed at the White Bay Cruise Terminal (WBCT) are operated using shore based power. The noise assessment has been based on the *Pacific Jewel* vessel, being typical of the vessels that berth at the WBCT. A 3D computer noise model of the vessel has been used which includes significant noise sources, as based on nearfield measurements and manufacturers data. The model has then been used to predict noise levels under normal operation and shore based power. It should be noted that, similar to the vast majority of cruise ships worldwide, the *Pacific Jewel* is not equipped for shore based power.

Ship Operation at Shore

The *Pacific Jewel* is typical of the cruise liners that berth at the WBCT, with four (4) diesel driven generators (DDG) of approximately 8 MW capacity each to provide all power for the vessel. The DDGs are located at a lower deck level, and there is an additional emergency DDG above the waterline not used or tested when in port under normal operating conditions. When berthed one (1) DDG will be operational to provide electrical power for ventilation, air-conditioning, lifts etc. Directly associated with the DDG operation are combustion air fans (one dedicated for each DDG), DDG room exhaust mechanical ventilation (four installed on variable frequency drives (VFD)), and DDG room comfort supply mechanical ventilation also installed with VFDs. Other general ventilation equipment, such as galley exhaust and passenger area ventilation and air-conditioning etc will operate independently of the DDG(s) and their associated ventilation equipment.

The provision of shore based power via an electrical connection to the vessel will enable the DDG to be turned off. The DDG combustion air fans would also be turned off, with other systems including the general ventilation and air-conditioning equipment operating normally. Whilst no DDG would be operational, the DDG room comfort supply and DDG room exhaust mechanical ventilation would continue to operate in automatic mode, however, given the reduced heat load at reduced capacity.

Noise Modelling and Results

A 3D computer model was used to predict noise levels at the nearest residential receiver in Grafton Street. At this location noise monitoring surveys have measured the *Pacific Jewe*l LAeq noise level at 50 dBA on two occasions, and this will be the assumed ship noise level with a single DDG operational.

The noise model consists of all significant noise sources with the model calibrated to the 50 dBA measured noise level. To determine the individual sound power levels (SWLs) for significant sources near field measurements were conducted where access to source, such as the supply and return air louvres was possible. Additionally, reverberant noise level measurements of the DDG exhaust fans were conducted within the ship funnel to estimate the SWLs of the DDG exhaust fans. Where access was not possible, such as the elevated DDG engine exhausts, then SWLs were estimated based manufacturer's for similar sized diesel engines and the insertion loss provided by absorptive mufflers.

Specific operational parameters (volume and static pressure) for the operation of the DDG exhaust room fans and DDG comfort fans when the ship is supplied by shore based power are not available, and for this study are assumed to range from 5 dB to 10 dB below that when operational for a single DDG operation.

Predicted noise levels for the significant noise sources are presented in **Table 1** for DDG (normal) and shore based power operation.

Table 1 Contribution of Noise Sources at Grafton Street - Normal Operation

Ship Noise Source	Estimated Grafton Street Noise Level – DDG Operation	Estimated Grafton Street Noise Level – Shore Based Power
DDG exhaust room fans	40 dBA	30 to 35 dBA
DDG combustion air supply fans	36 dBA	Off
DDG engine exhaust	48 dBA	Off
All other sources	40 dBA	39 dBA
Total	**50 dBA**	**40 to 41 dBA**

The 50 dBA measured noise level from the *Pacific Jewel* has been previously analysed to determine the low frequency content of the noise in response to vibration complaints. The analysis indicated the *Pacific Jewel* noise contained low frequency noise, and the source of this low frequency noise is expected to be from the DDG exhaust, the exhaust room fans and the combustion air supply fans. Accordingly, by switching off the DDG and the combustion air supply fans, and running the exhaust room fans at reduced capacity the low frequency noise will be reduced. The reduction in dB will be by at least the overall reduction in the A-weighted noise level.

Comparison with Potential Alternative Mitigation Solution - Noise Wall

SLR has previously conducted a study into the effectiveness of reducing the noise level from vessels berthed at the WBCT using a noise wall on the southern side of Grafton Street. The study concluded a noise wall along Grafton Street of height 11.5 m would provide typically an 8 dB reduction in noise and a 15.5 m noise wall, typically 16 dB for residences on Grafton Street. However, residences to the west of Adolphus Street and those in Cameron's Cove would receive limited benefit as the wall provides negligible shielding to these areas. The noise wall cost would be of the order of $2.5 – 4 million, dependant on height. In comparison, the cost of shore power is estimated to be of the order of $36 million for the shore facilities and the additional cost estimated to retrofit the fleet currently calling at WBCT is in the order of $27 million.

Summary

SLR has been commissioned by the Port Authority of New South Wales to review the potential reduction in noise when vessels at the WBCT operate from shore based power. The study has been based on the *Pacific Jewel*, which is a typical vessel that uses the WBCT. The predicted noise level reduction is therefore specific to the *Pacific Jewel*, however it should provide an indication of that likely from similar vessels berthed at the WBCT under shore based power, noting that every ship will be different in terms of the potential noise reduction, and that not all vessels currently have the ability connected to shore power.

Noise levels from the *Pacific Jewel* have been measured to be 50 dBA, at the nearest receivers to the WBCT in Grafton Street. The provision of shore based power will enable the DDG to be shut down and the associated mechanical ventilation systems either switched off or reduced in capacity. The resultant noise level at the nearest receiver is predicted to decrease by an estimated 9 dB to 10 dB.

In comparison to a noise wall as a mitigation option, shore power provides a similar reduction in noise level and could be considered more effective, as the noise wall would not reduce levels at residences to the west of Adolphus Street, or at Cameron’s Cove. However, the provision of shore power facilities to WBCT is an order of magnitude more expensive and is limited by the number of vessels that have or would be required to have capability to accept shore based power.

Yours sincerely

JOHN SLEEMAN
Principal