White Bay Cruise Terminal

Port Authority of NSW

Air Quality Assessment

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Air Quality Assessment
Port Authority of NSW

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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.

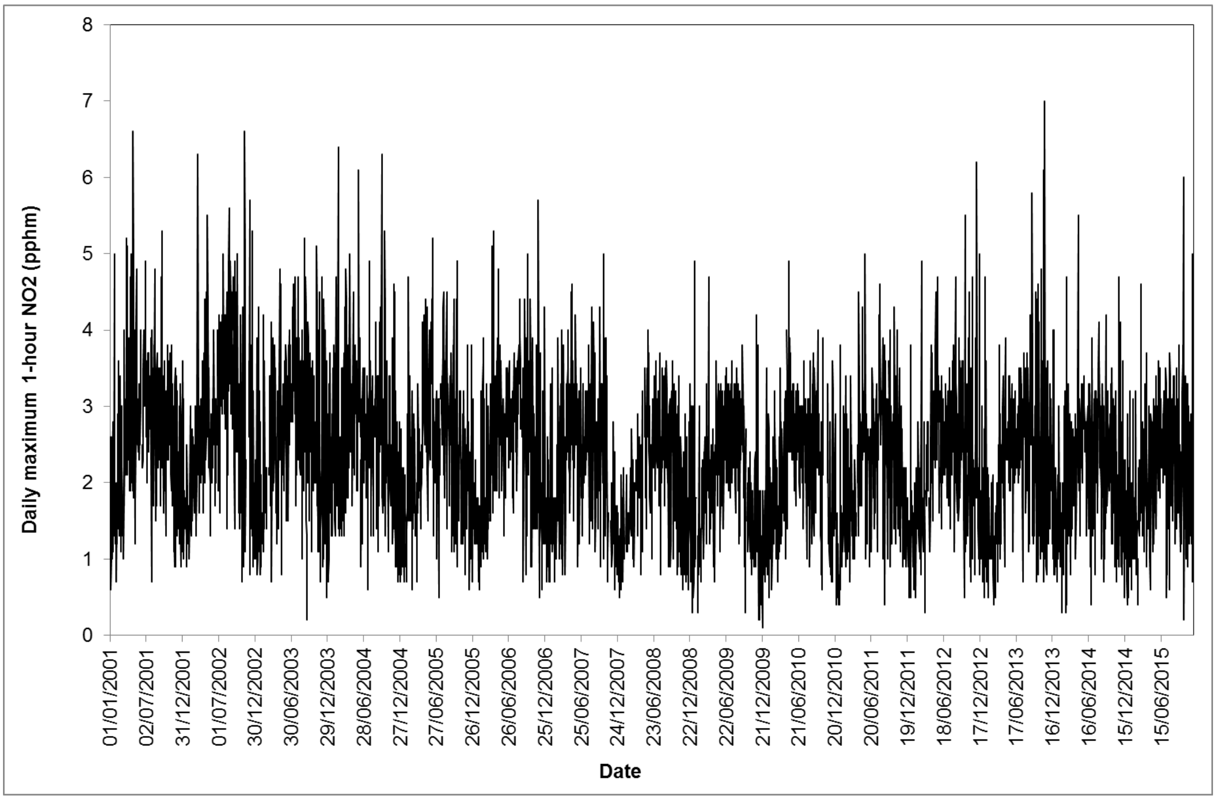


Figure 2.1 : Daily maximum 1-hour NO_2 (ppb) at Rozelle OEH Monitoring Station

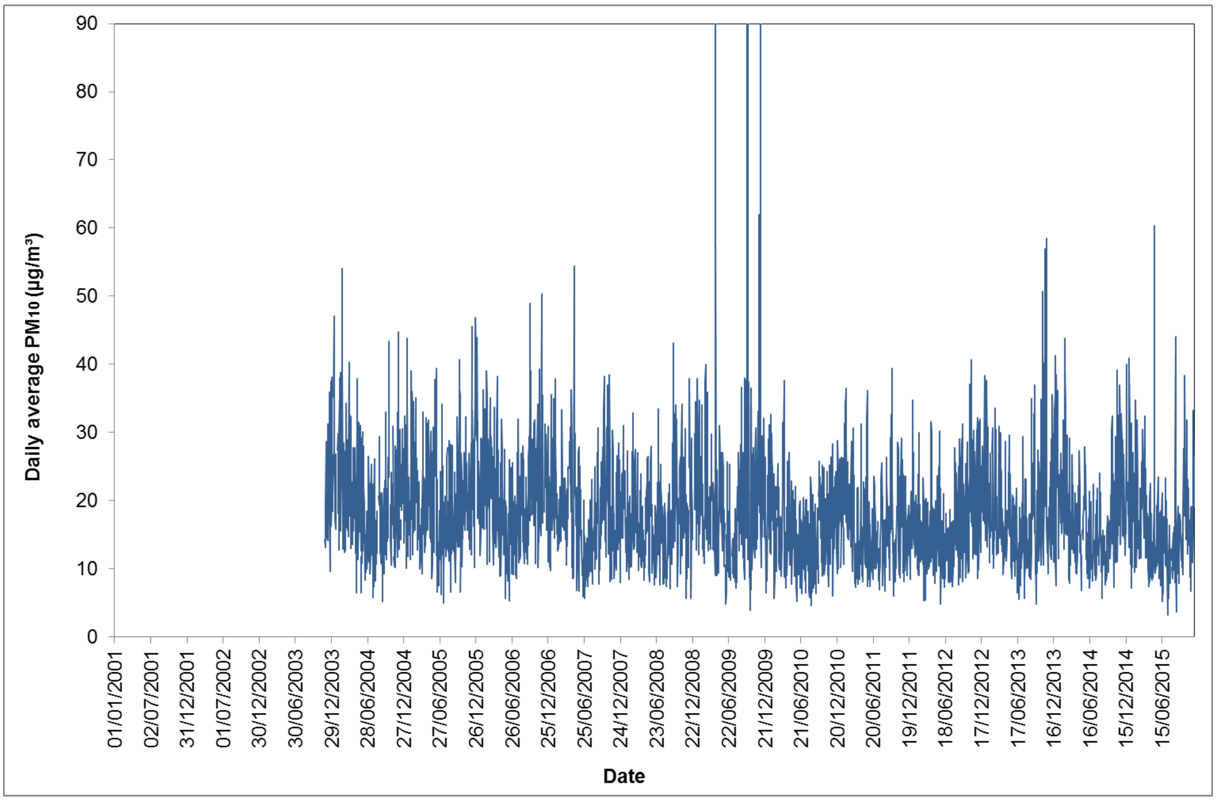


Figure 2.2 : Daily average PM_{10} (ug/m3) at Rozelle OEH Monitoring Station

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/m^3)
	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**.

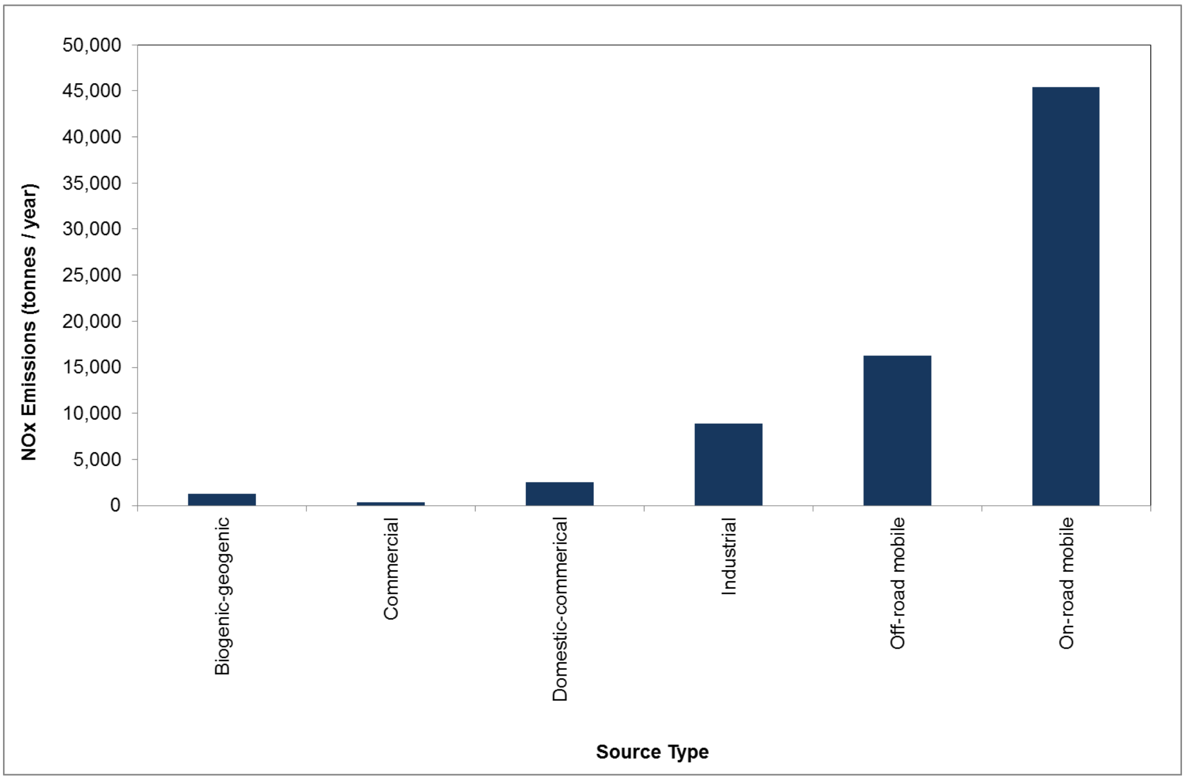


Figure 3.1 : Total estimate annual emission from natural and human-made sources in the Sydney region (NSW EPA, 2012)

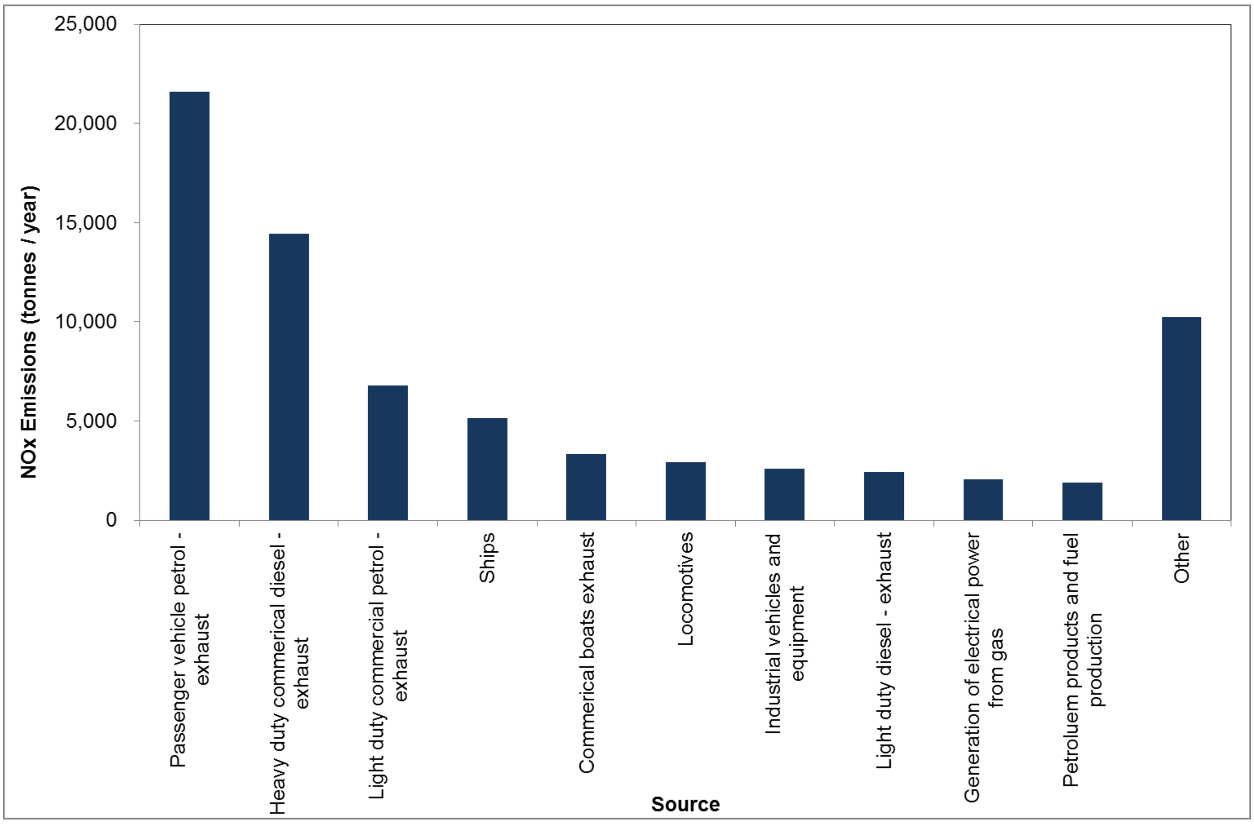


Figure 3.2 : Top 10 human-made NO_x sources in the Sydney region (NSW EPA, 2012)

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

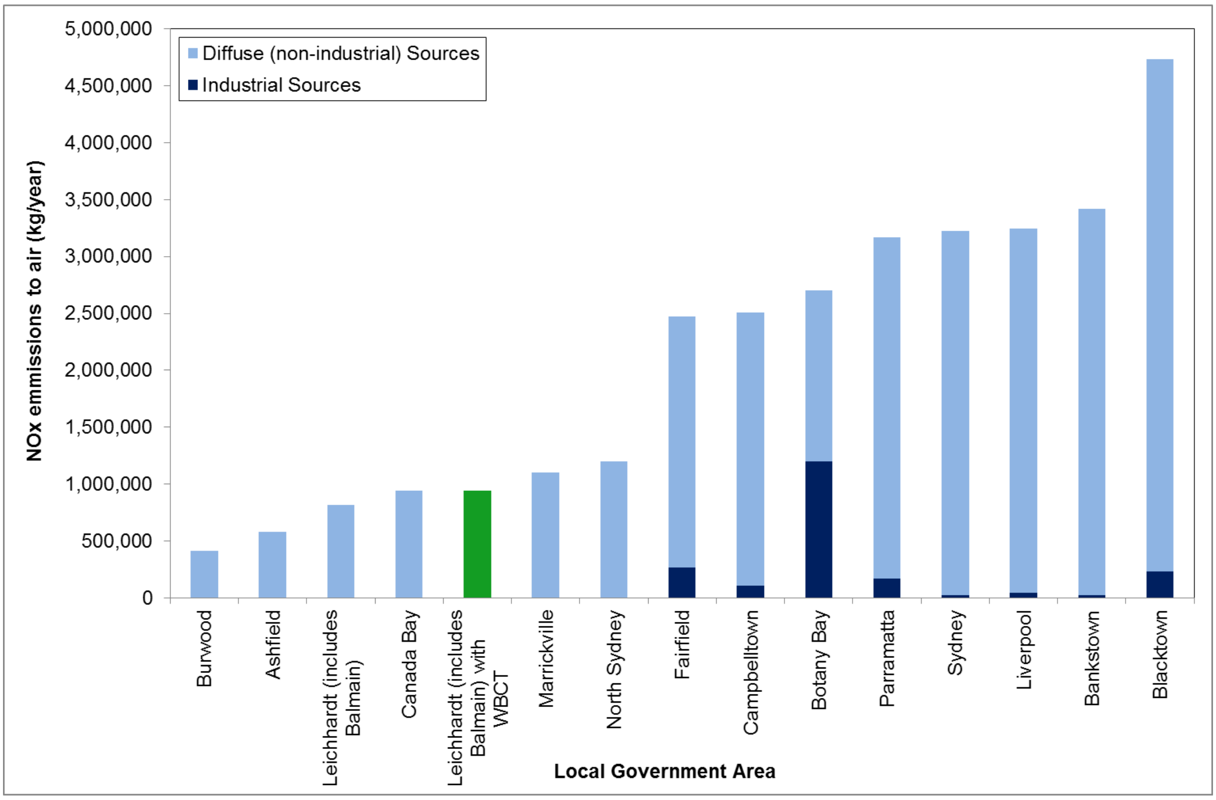


Figure 3.3 : Total industrial and diffuse NO_x emissions reported for NPI reporting year 2013/2014 by LGA

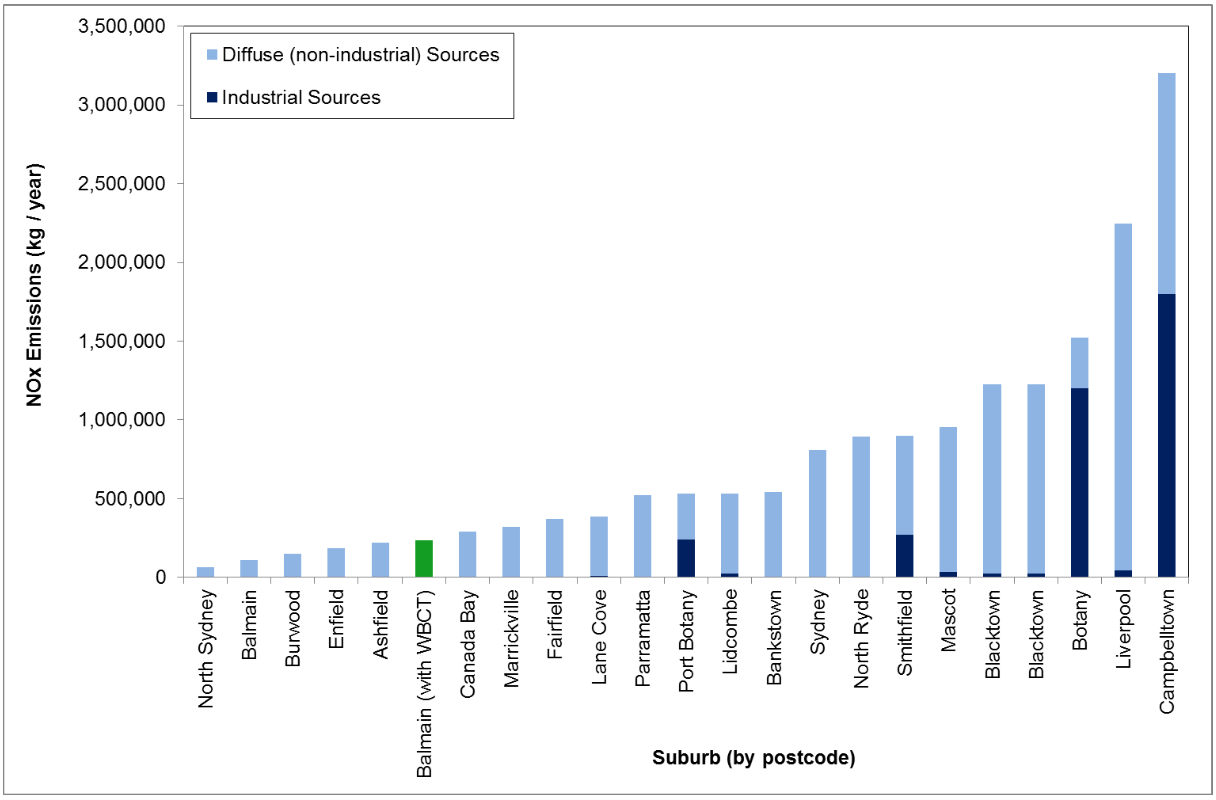


Figure 3.4 : Total industrial and diffuse NO_x emissions reported for NPI reporting year 2013/2014 by suburb

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.

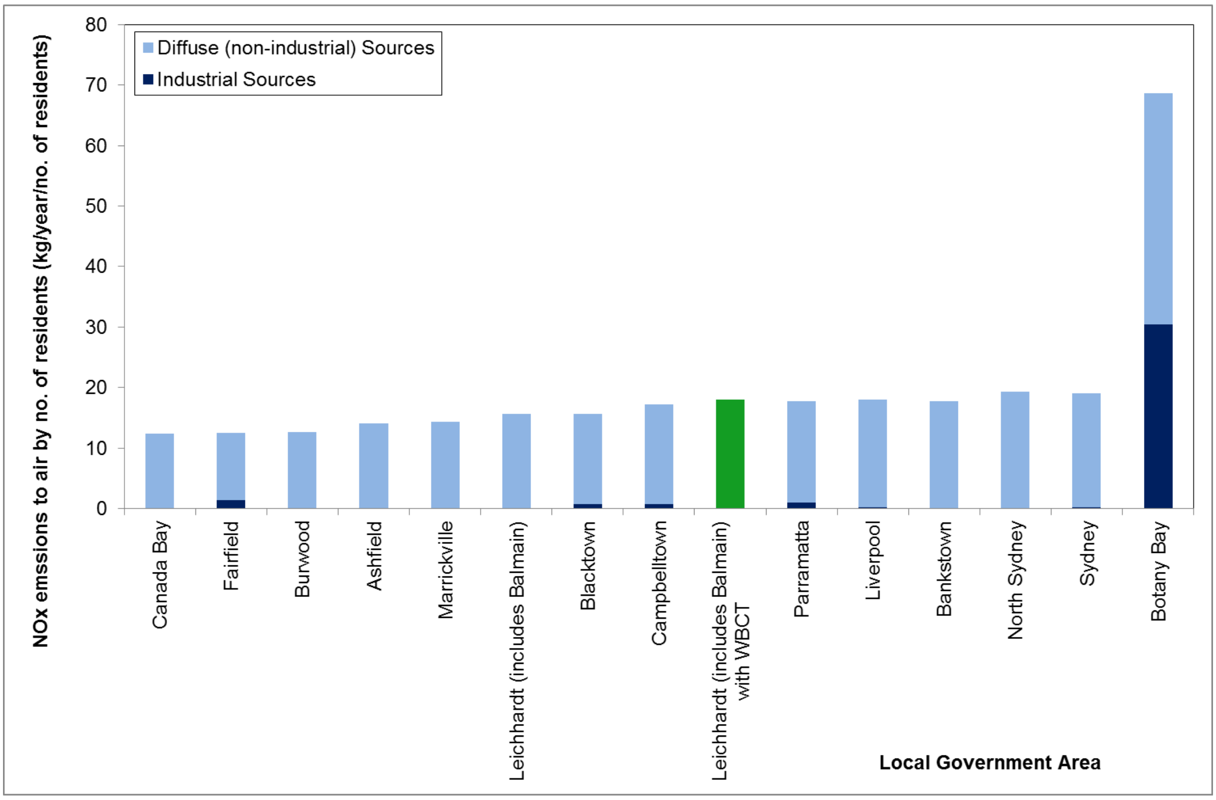


Figure 3.5 : Total industrial and diffuse NO_x emissions by number of residents for NPI reporting year 2013/2014 by LGA

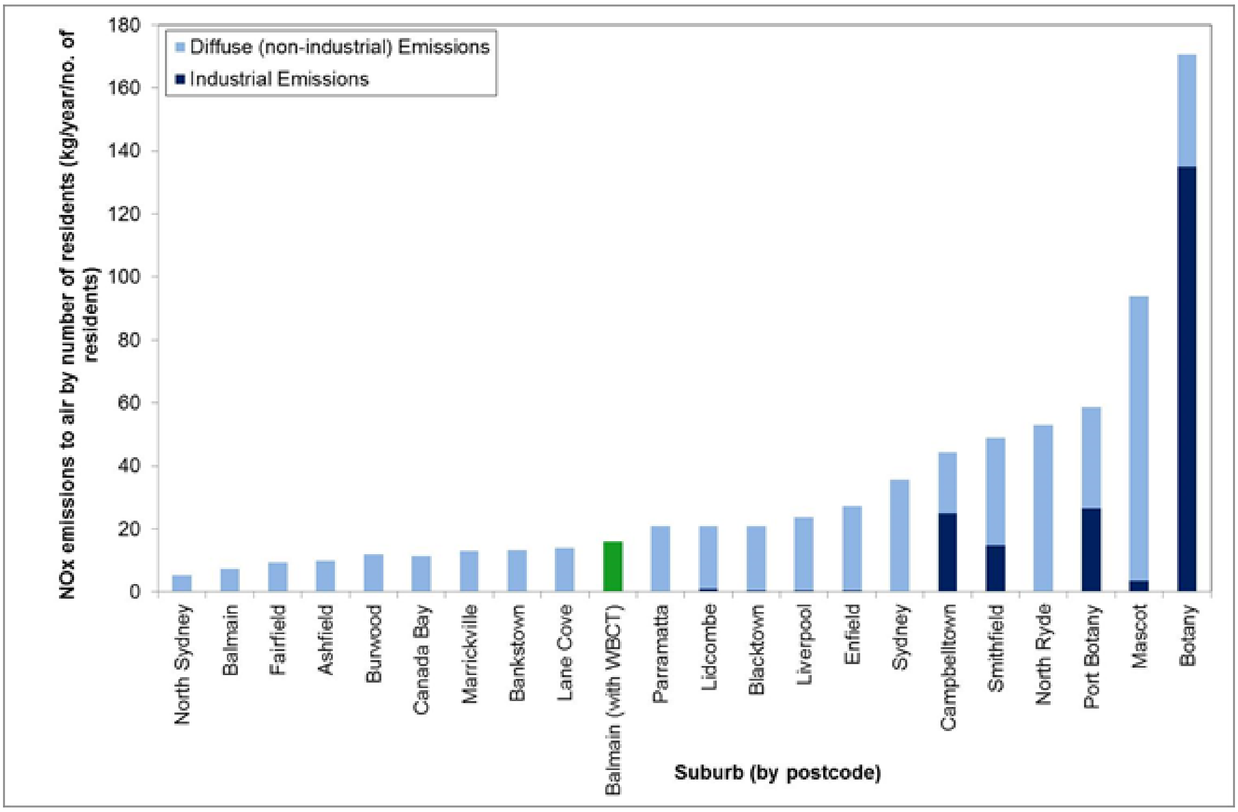


Figure 3.6 : Total industrial and diffuse NO_x emissions by number of residents for NPI reporting year 2013/2014 by suburb

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.

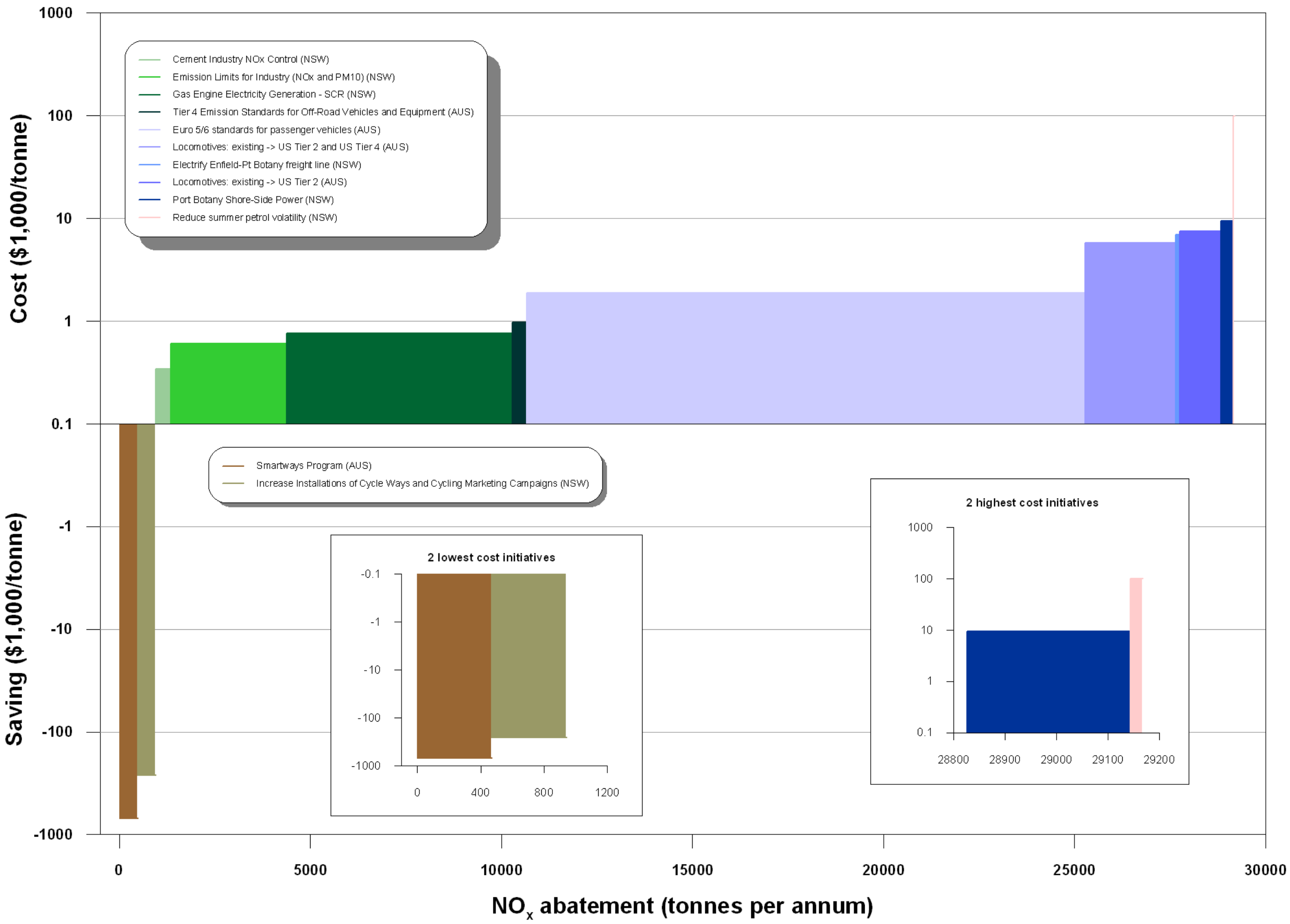
The $9.5M per tonne cost of NO_X abatement is very high as the basis of calculation was to apply it to all GMR AEI ship emissions, including emissions from travel to and from berth in the Sydney coastal and harbour regions. When applied to just ship emissions at berth in Port Botany, the cost reduces 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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