REPORT 10-4044-R5

Revision 1

Proposed Gas Turbine Power Station, Bamarang
Addendum to Air Quality Impact Assessment and Plume Rise Assessment
March 2010

PREPARED FOR

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Proposed Gas Turbine Power Station, Bamarang

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1 INTRODUCTION

Heggies Pty Ltd (Heggies) has been commissioned by GHD Pty Ltd (GHD) on behalf of Delta Electricity (DE) to conduct an air quality impact assessment (including a plume rise assessment) for the proposed gas turbine power station at Bamarang, NSW (hereafter, the Project).

The Project was originally designed to be implemented in two stages:

- Stage 1: Open Cycle Gas Turbine facility for peaking periods. Generation capacity of 300 MW; and,
- Stage 2: Conversion of facility to Combined Cycle Gas Turbine for base load power supply. Generation capacity of 400 MW.

Stage 1 of the Project gained approval in March 2007. Concept approval was also granted for Stage 2.

It is understood that DE propose to increase the capacity of the Stage 2 phase of the Project from 400 MW to 450 MW.

A revised air quality impact assessment was provided by Heggies on 8 October 2009 which quantitatively and conservatively assessed the impact of this capacity increase on ground level concentrations of nitrogen dioxide (NO_2) [10-4044 Addendum to AQIA 20091008 - provided in **Appendix A**, hereafter 'the addendum']. A revised plume rise assessment was not provided, since it was assumed that the increase in exit velocity of the two exhaust stacks (additional 1.4 m/s) would be offset by a significant reduction in the exit velocity of the air cooled condenser (ACC) system (reduction of 3.2 m/s).

After submission of the addendum to the relevant authorities, comments were received which raised issues regarding:

- The absence of a quantitative plume rise assessment;
- Concerns regarding the apparently large increase in modelled NO_2 concentrations at some sensitive receptors when increasing generation capacity from 400 MW to 450 MW; and,
- The absence of a quantitative air quality assessment addressing PM_{10}, carbon monoxide (CO), sulphur dioxide (SO_2) and volatile organic compounds (VOC) in addition to just NO_2.

The purpose of this document is to address the points raised above.

Additionally, an update to the greenhouse gas (GHG) assessment provided in the Air Quality Impact Assessment for the 400 MW Stage 2 Operations has been included to reflect 450 MW generation capacity. The 400 MW GHG assessment used emission factors which have since been superseded and this addendum report presents a comparative assessment of the potential GHG impacts for the generation capacities.

2 PLUME RISE ASSESSMENT

The Royal Australian Navy Air Station (NAS Nowra) is located approximately 4 km to the southwest of the site of the proposed gas turbine power facility at Bamarang.

The proposed power station will have two exhaust stacks, both of which are anticipated to have a height of 40 m Above Ground Level (AGL). Additionally, the power station will have an air cooled condenser (ACC) system, consisting of 36 release points at 30 m AGL. The Defence (Areas Control) Regulations (DACR) controls the height of structures, and the purpose for which they may be used, within a 15 km radius of an aerodrome. Although the exhaust stacks and ACC system proposed for the Bamarang site are located within this 15 km radius, the structures will not infringe on the Obstruction Clearance Surface (OCS) for NAS Nowra.

However, the exhaust plumes of the stacks have the potential to affect aircraft operations in terms of damage caused to airframes and the handling of aircraft during flight. The Civil Aviation Safety Authority (CASA) has identified that there is a need to assess the potential hazards that the vertical velocity from gas efflux present to the aviation activities in the surrounding region.

According to CASA's Advisory Circular entitled *Guidelines for Conducting Plume Rise Assessments*, June 2004, exhaust plumes with a vertical velocity in excess of 4.3 m/s may cause damage to an aircraft airframe, or disturb aircraft handling when flying at low levels.

The proposed gas turbine power facility at Bamarang is located within the Conical Surface OCS for NAS Nowra. Through correspondence with the Department of Defence it is understood that the exhaust plume velocity from the power station should not exceed 4.3 m/s at the height of the Conical Surface OCS. The Conical Surface OCS at the site of the Bamarang stacks has been determined as 167 m AHD.

Topographical data for the site indicates that the Bamarang site lies at an elevation of approximately 107 m AHD. Accordingly, the critical OCS used for this assessment is 60 m AGL directly above the stacks. **Figure 1** shows the location of the NAS Nowra in relation to the gas turbine power facility at Bamarang, including a scaled illustration of the 15 km radius. **Figure 2** illustrates the site layout.

Figure 1 NAS Nowra, Location of proposed Bamarang Site and 15km OCS

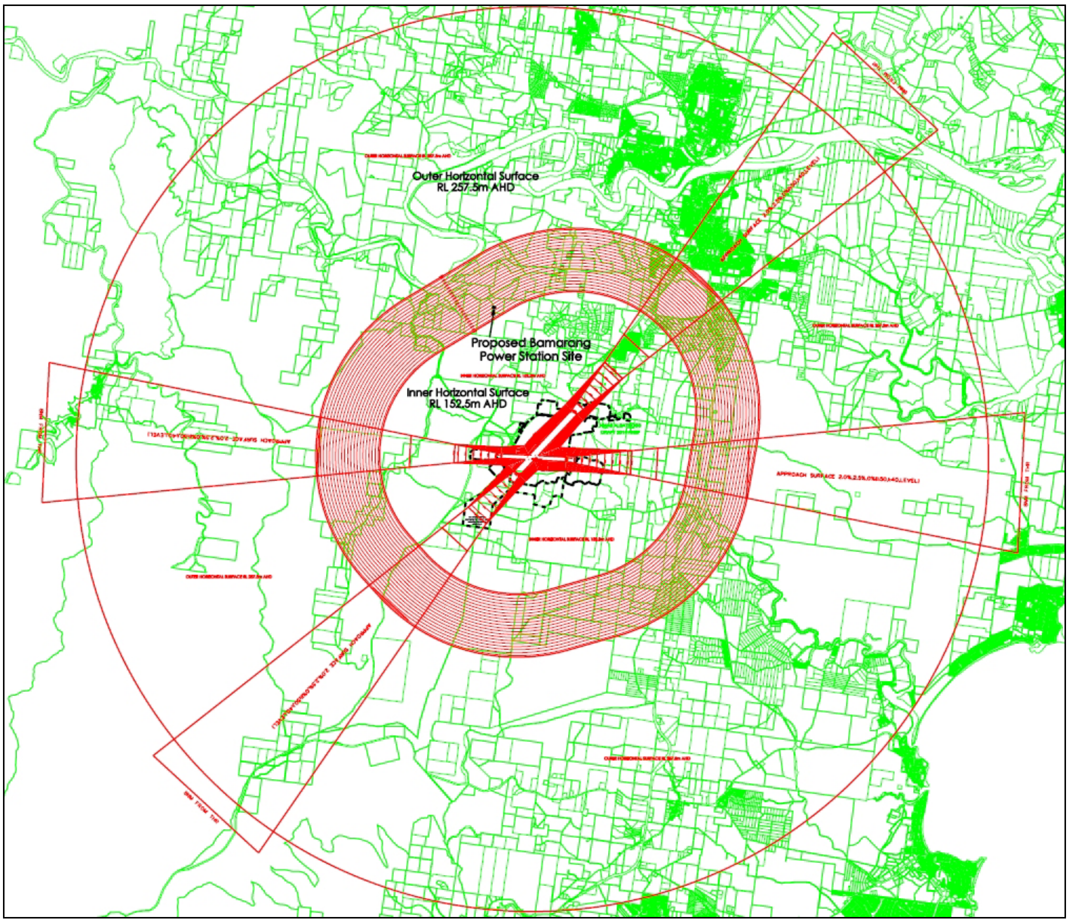
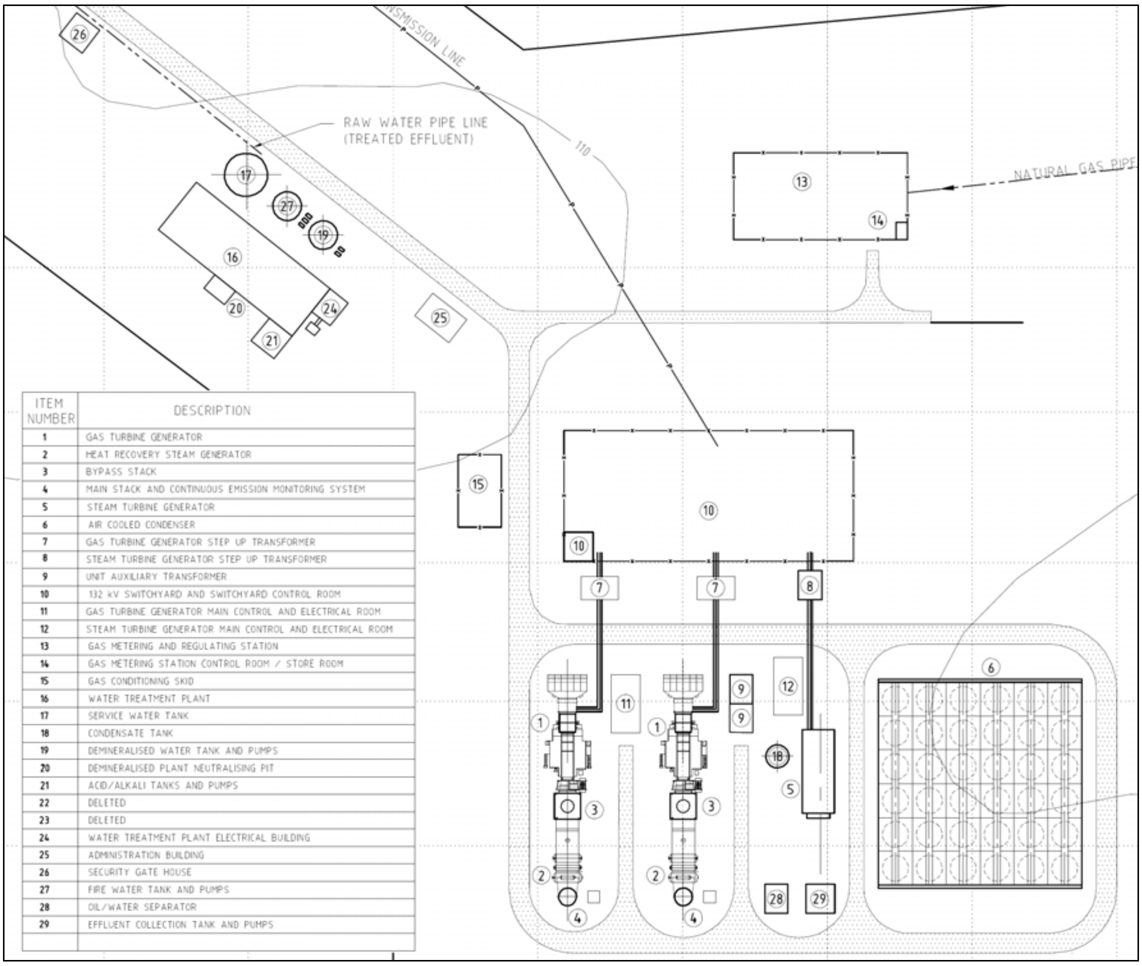


Figure 2 Layout of Project Site – with Air Cooled Condenser System



The Air Pollution Model (TAPM) software, developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), is a prognostic model which may be used to predict three-dimensional meteorological data, with no local data inputs required. The model predicts wind speed and direction, temperature, pressure, water vapour, cloud, rain water and turbulence. The program allows the user to generate synthetic observations by referencing databases (covering terrain, vegetation and soil type, sea surface temperature and synoptic scale meteorological analyses) which are subsequently used in the model input to generate site-specific hourly meteorological observations.

The TAPM plume rise estimation uses commonly referenced plume rise algorithms for the determination of vertical plume rise velocity. For multiple sources TAPM allows a buoyancy enhancement factor to be input to account for overlapping (or “aggregated”) plumes from multiple stacks. The buoyancy enhancement factor used is based on the Briggs (1984) equations discussed in Manins et al. (1992).

The proposed gas turbine power facility at Bamarang will have two units operating online with corresponding identical stacks situated 40 m apart. Additionally, the ACC system comprises of 36 identical release points equally spaced within a 70 m x 70 m area. **Table 1** and **Table 2** details the other parameters of the exhaust stacks and ACC system respectively. The plumes from each source group (i.e. exhaust stacks and ACC system) may merge for some wind conditions and accordingly the combined plume may rise higher than the plumes would have in isolation.

CASA have determined that TAPM is not suitable for the determination of plume dynamics for plumes that merge significantly.

2.1.1 Merging of Identical Plumes

To conservatively account for the possibility that plume merging may occur between the two stacks resulting in enhanced plume rise, an hourly-varying plume rise enhancement factor for each source group can been applied to the TAPM exit velocity input. The buoyancy enhancement factor used is based on the Briggs (1984) equations discussed in Manins et al. (1992).

Manins et al. (1992) identifies that for a number of stacks with the *same emission geometries and exit conditions*, as is the case with this Project for the two exhaust stacks and the 36 ACC system release points, then the buoyancy enhancement factor (N_E) is defined as:

$$N_E = \left[\frac{n+S}{1+S} \right]$$

Where n is the number of stacks and S is the dimensionless separation factor, defined as:

$$S = 6 \cdot \left[\frac{(n-1) \cdot \Delta s}{n^{1/3} \cdot \Delta z} \right]^{3/2}$$

Where Δs is the stack separation and Δz is the rise of an individual plume.

The plume rise enhancement factor is then determined by the following:

$$E_N = N_E^{1/3} < N^{1/3}$$

However, the above equations cannot be applied to the plume enhancement resulting from the ACC system and exhaust stack merging due to the different geometries and exit parameters. In order to analyse the extent of plume merging and potential buoyancy enhancement, the approach of Anfossi et al in 1978 (as discussed by Zanetti et al, 2003) has been applied.

2.1.2 Merging of Non-Identical Plumes

Anfossi et al (Zanetti et al, 2003) developed a methodology in 1978 that allows for the calculation of final plume rise from multiple sources of differing buoyancy and stack heights (ΔH^N), as is the case with the exhaust stacks and ACC system, by first deriving the point of plume merging (H_i), as follows:

$$\Delta H^N = H_i + C \sum_{j=1}^{N} \left\{ F_j^{1/3} - \left[\left(H_i - H_j \right) / C \right]^3 \right\}^{1/3}$$

in which

$$H_i = H_{MAX} + \frac{\Delta H_{MIN} - (H_{MAX} - H_{MIN})}{1 + \left[\Delta H_{MIN} - (H_{MAX} - H_{MIN}) \right] / D}$$

is the merging point, ΔH_{MIN} is the maximum single plume rise from the lowest stack H_{MIN}, $C = \Delta H_{MIN} / F_{MIN}^{1/3}$ and $D = (n-1)\Delta s$. F_{MIN} is the buoyancy flux parameter, F_B, for the lowest stack defined by Anfossi et al (Zanetti et al, 2003):

$$F_b = U_{SC} R^2 g \left[\frac{(\rho_a - \rho_s)}{\rho_a} \right]$$

where U_{SC} is the plume centreline velocity, R is the plume radius, g is the acceleration due to gravity and ρ_a and ρ_s are the density of the air and plume respectively. Ambient air density is assumed to be 1.2 kg/m^3 while the plume density for the exhaust stacks and ACC system are 0.87 kg/m^3 and 1.16 kg/m^3 respectively (personal correspondence, GHD, 2007).

In order to calculate the distance between the ACC system and exhaust stacks, the West exhaust stack (see **Table 1**) has been adopted as the marker point. In order to account for the varying separation distance between this marker exhaust stack and the 36 ACC system release points, the lower left, centre and upper right release points of the ACC system (see **Figure 2**) have been utilised as calculation points to assist in deriving plume merging.

Application of the Anfossi et al (1978) approach to the Manins (1992) buoyancy enhancement factor equation shows that the ACC system plume will have an average plume enhancement factor of between 1.12 (Upper Right release point) and 1.25 (Lower Left release point) on the exhaust stack release velocity.

The hourly varying plume rise enhancement factors were applied to the exit velocities for each source (17.4 m/s for the exhaust stacks; 3.2 m/s for the ACC system release points) to account for varying ambient conditions.

The combined plume enhancement allowing for the effect of the ACC system on the exhaust stacks and the exhaust stacks on each another results in a plume enhancement factor of between 1.39 and 1.57. This enhancement factor has been applied to one exhaust stack to derive the final plume rise estimations.

Table 1 Exhaust Stack Exit Parameters – 450 MW

Stack Parameter	East and West HRSG Exhaust Stacks	
Project Stage	Stage 2	
Description	Exhaust stack servicing the Eastern Gas Turbine, operating in Combined Cycle mode. Combustion gases passed through the Heat Recovery Steam Generator prior to exhaust – 450 MW	
Location (Easting, Northing)	273812 6134875	273851 6134869
Height (m)	40	40
Diameter (m)	6.7	6.7
Area (m^2)	35.3	35.3
Exit Temperature (K)	403	403
	Ambient Temperature	
	273	
Exit Temperature (K)	403	
Flow Rate (Nm3/s)	414	
Flow Rate (Am3/s)	612	
Exit Velocity (m/s)	17.4	

Table 2 ACC System Parameters

Parameter	Value
Number of Release Points	36
Exit Velocity (m/s)	3.2
Exit Diameter (m)	9.14
Exit Temperature (°K)	315.15
Exit Flow Density (kg/m^3)	1.16
Total Area of Structure (m^2)	4,900
Centre of Structure (m AMG)	273958 E, 6134892 N

It is noted that the two source groups (exhaust stacks and ACC system) have been modelled as one individual plume utlising a combined enhancement factor calculated as described above, using a combined Manins (1992) and Anfossi (1978) approach.

The modelling period was 1 January 2002 to 31 December 2006. TAPM was used in a nested mode, consisting of 25 × 25 × 25 grid points, and 30-km, 10-km, 3-km spaced horizontal grids for meteorology. The number of vertical levels was set to 25 and the grid centre coordinates were extracted over the plume source. No observational meteorology data was assimilated into the model.

2.2 Results

2.2.1 Vertical Plume Rise

CASA has requested that results of the plume rise be provided, specifically identifying the height above ground level in metres where the frequency of exceedance of the established critical velocity of 4.3m/s is 0.1%.

Table 3 details the percentage of time and height (m AGL) that the average vertical velocity of the exhaust stack, adjusted to take into account the enhancement of the ACC system and adjacent stack, exceeds the critical vertical velocity during each of the 5 model years (2002-2006) and a five year average, as required by CASA.

Table 3 Frequency of Exceedance of Critical Vertical Velocity with Height – Exhaust Stack Plume Enhancement

Frequency of Exceedance of Critical Velocity	Height AGL (m)					
	2002	2003	2004	2005	2006	*All Years*
100%	50	50	50	50	50	***50***
90%	52	52	52	52	52	***52***
80%	53	53	52	53	53	***53***
70%	54	55	54	54	55	***54***
60%	57	57	57	57	58	***57***
50%	59	59	58	58	60	***59***
40%	62	63	60	61	64	***62***
30%	65	66	64	65	67	***65***
20%	71	71	68	69	72	***71***
10%	77	78	76	76	78	***77***
9%	78	78	77	77	79	***78***
8%	79	79	78	78	80	***79***
7%	79	80	79	79	81	***80***
6%	81	81	80	80	82	***81***
5%	82	82	81	81	83	***82***
4%	84	84	83	83	85	***84***
3%	86	87	85	85	88	***86***
2%	110	109	104	103	112	***109***
1%	132	122	119	119	139	***123***
0.5%	163	149	145	144	171	***152***
0.3%	185	171	168	166	201	***177***
0.2%	206	193	186	178	234	***200***
0.1%	240	227	223	210	276	***238***
0.05%	263	252	260	248	306	***272***

The results presented in **Table 3** suggest that at 100 m (60 m above stack height), the probability of exceedance of the critical vertical velocity is between 2% and 3%.

The critical vertical velocity is exceeded on 0.1% of occasions at between 210 m AGL and 276 m AGL with a five year model average of 238 m AGL.

Furthermore, **Table 4** details the maximum, minimum and mean heights (AGL) that the average vertical plume velocity exceeds the critical vertical velocity for the modelling period (2002-2006).

Table 4 Minimum, Average and Maximum Heights of Average Plume Vertical Velocity Exceedances of Critical Vertical Velocity – Exhaust Stack Plume Enhancement

Height	Height AGL (m)
	Enhanced Exhaust Stack (2002-2006)
Minimum	50
Average	63
Maximum	386

2.2.2 Horizontal Plume Radius

The predicted horizontal plume radius values for each hour of the modelled period have been calculated for a range of heights to illustrate the plume growth. In order to determine the likely horizontal plume radii that occur when the critical vertical velocity is exceeded, the corresponding minimum, average and maximum horizontal plume radii are presented in **Table 5**.

Table 5 Minimum, Average and Maximum Horizontal Plume Radii with Height - 450 MW Operations

Height (m AGL)	Minimum	Average	Maximum
50	6.0	9.4	10.0
100	12.9	20.4	25.9
150	20.7	27.2	33.3
200	26.5	32.5	37.8
250	32.9	37.8	42.0
300	39.8	43.0	44.8

2.2.3 Horizontal Plume Extent

In addition to determining the minimum, average and maximum vertical plume extent, the horizontal movement and extent of the generated plume from the Project Site has also been assessed. This analysis assists in determining the affected area from plume rise.

Horizontal plume extent has been generated by summing the distance travelled by the plume centreline, calculated by horizontal wind speed and model timesteps, until the height where the critical vertical velocity is no longer exceeded. The relevant plume radius is then added to this distance. **Table 6** details the minimum, average and maximum horizontal plume extent predicted for the 450 MW operations at the Project Site.

Table 6 Minimum, Average and Maximum Horizontal Plume Extent – 450 MW Operations

	450 MW Operations
Minimum (m)	7.1
Average(m)	16.1
Maximum (m)	172.3

2.3 Conclusions

An assessment has been conducted of the potential hazard that exhaust plumes from the proposed gas turbine power facility at Bamarang present to aviation activities in the surrounding region.

The Air Pollution Model (TAPM) was used in plume rise mode to analyse plume behaviour from the exhaust stacks and ACC system for meteorological conditions predicted for the site over a modelling period of 5 years (2002-2006).

The plume rise from a single stack was modelled, and an hourly-varying plume rise enhancement factor was applied to the vertical velocity inputs to conservatively account for the impact of enhanced buoyancy as a result of plume merging from the exhaust stacks and ACC system.

Results of the assessment indicate that the probability of an exceedance of the critical vertical velocity (4.3 m/s) decreases significantly with altitude. Approximately 98% of all predicted exceedances of the critical vertical velocity occur beneath 100 m AGL (60 m above stack height) for the facility.

The maximum height at which the average vertical plume velocity is predicted to exceed the critical vertical velocity is 386 m AGL. The frequency with which this was predicted to occur was less than 0.05%.

3 AIR QUALITY IMPACT ASSESSMENT

The Air Quality Impact Assessment (AQIA) presented below concentrates on emissions and predicted ground-level impacts of oxides of nitrogen (NO_X as NO_2) and particulate matter (as PM_{10}) which have been identified as the primary pollutants of concern during the consultation exercise. Carbon monoxide (CO), sulphur dioxide (SO_2) and volatile organic compounds (VOC) emissions and ground level impacts have also been modelled to demonstrate compliance.

The aim of this assessment is to demonstrate that the increased generation capacity of the proposed Project will not detrimentally affect the air quality in the surrounding area and at the identified sensitive receptor locations (refer **Section 3.1**). Therefore, two scenarios have been modelled to reflect 400 MW and 450 MW generation capacities for comparative purposes.

A previous Air Quality Impact Assessment was undertaken by Heggies in March 2008 (Report 10-4044 R3R1, dated 27 March 2008, hereafter the "original submission") in which pollutant emissions were modelled and reported at the sensitive receptors noted in **Section 3.1** below for the 400 MW generation capacity option. The addendum (introduced earlier) identified the impacts of a 450 MW generation capacity on the surrounding receptors.

The results presented in this report are generally dissimilar to those presented in previously submitted reports. The reasons for these dissimilarities are outlined below:

The Original Submission (10-4044 R3R1, March 2008)

- Examined air quality impacts of a 400 MW generation capacity.
- Calculated plume rise enhancement based on ACC emission velocity of approximately 6.4 m/s and exhaust stack exit velocity of 16 m/s.
- Reported concentrations of PM_{10}, NO_2, CO and SO_2 well below Project criteria.

The Addendum (10-4044 Addendum to AQIA 20091008, November 2009)

- Examined impacts of a 450 MW generation capacity.
- Information provided by proponent indicated that exit velocity of the exhaust stacks was to increase to 17.4 m/s (450 MW) from 16 m/s (400 MW) but the ACC exit velocity was shown to be approximately 3.2 m/s not 6.4 m/s.
- As the original submission showed minimal impacts from the 400 MW option, a worst case modelling assessment was undertaken assessing NO_2 only, using a zero plume enhancement. The reduced dilution and dispersion afforded by a non-enhanced plume resulted in increased NO_2 concentration predictions at the receptors.

This Submission (10-4044 R5, March 2010)

- Examines impacts of 400 MW and 450 MW generation capacity options.
- Calculates plume enhancements for each option based on the most recent understanding of the Project (17.4 m/s exhaust exit velocity, 3.2 m/s ACC exit velocity).
- Employs plume enhancements in the dispersion modelling process for each option.
- Resulting pollutant concentrations vary from those reported previously:
  - Very minor changes (variable increase / decrease in predicted concentrations) comparing the original 400 MW assessment to the current 400 MW assessment.
  - Large changes (significant decrease in concentrations of NO_2) comparing the addendum 450 MW assessment to the current 450 MW assessment.

The significant decrease in predicted concentrations of NO_2 when compared to the addendum is easily explained by the use of enhanced plume rise within the current modelling exercise which results in increased dispersion and dilution and consequently lower ground level concentration predictions.

The relatively minor changes between predictions of pollutant concentrations within the original 400 MW and current 400 MW modelling assessments are not as easily explained. The small changes in the plume enhancement employed within the current assessment would result in lower concentrations at certain receptors and, dependant on the prevailing meteorological conditions and terrain, possibly higher concentrations at other receptors. However, it is shown in the following sections that concentrations of all modelled pollutants are well below the Project criteria at all modelled receptor locations.

3.1 Nearest Sensitive Receptors

The NSW DECCW defines a sensitive receptor as a location where people are likely to work or reside, including dwellings, schools, hospitals, offices or public recreational areas.

The proposed site at Bamarang is located 8 km to the south-west of Nowra, a regional centre of the Shoalhaven Local Government Area. The nearest potentially affected residential properties are summarised in **Table 7** including property name, dwelling locations and coordinates.

Table 7 Nearest Potentially Affected Residential Dwellings and other Property types

Receptor ID	Property Name	Description	AMG Dwelling Coordinates	
			East (m)	North (m)
R1	"Bundanon"	2.6 km north east of proposed site	271728	6136340
R2	Water Treatment Plant	1.3 km west north-west of proposed site	272710	6135389
R3	Bamarang Bush Cabins	1.2 km north north-east of proposed site	273436	6136080
R4	"Katalives"	1.8 km north of proposed site	274343	6136620
R5	"Mundamia" Properties	2.3km west north-west of proposed site	275993	6135903
R6	"Lot 7" Gannet Road	1.8 km south west of proposed site	275018	6133615

The "Lot 7" Gannet Road property [R6] has been selected as representative of the residences of Gannet Road and Stringybark Road, the two closest streets to south west of the Project Site.

In the same way, the Bamarang Bush Cabins [R3] has been selected as the representative property for the residential dwellings located along Bamarang Road.

3.2 Methodology

TAPM (v3.0) is a prognostic model which may be used to predict three-dimensional meteorology and air pollution concentrations with no local meteorological data inputs required.

Such a complex and computationally intensive model is required to simulate chemical transformation of stack emissions and influences of relatively complex terrain that would not be accounted for using a conventional Gaussian model (such as Ausplume).

Given that the location of the proposed site is approximately 20 km inland, coastal recirculation is not anticipated to play a major role in atmospheric dispersion of pollutants from the proposed power facility. However, TAPM is known to accurately account for any such influences.

TAPM reflects local topographical influences by drawing on terrain databases and is thus able to simulate the impacts of local topography on atmospheric dispersion.

The TAPM model has been run in chemistry mode, and as such accounts for the photochemistry that will drive the formation / destruction of NO_2. In chemistry mode, gas-phase photochemistry is based on the semi-empirical mechanism called the Generic Reaction Set of Azzi et al. (1992), with a hydrogen peroxide (H_2O_2) modification (Hurley, 2005).

The following parameters were used in the TAPM model for stack emissions associated the operation of the proposed power facility.

- TAPM was used in a nested mode, consisting of 25 × 25 × 25 grid points, and 30 km, 10 km, 3 km, 1 km and 300m spaced horizontal grids for meteorology, and with 23 × 23 × 25 grid points and 30 km, 10 km, 3 km and 300 m spaced horizontal grids for pollution; and,
- An hourly varying background concentration file, incorporating measured concentrations of NO_X (from Nowra Water Treatment Plant air quality station) and ozone (O_3) (from Albion Park South DECC station) has been used as input into TAPM during chemistry mode in order to accurately simulate the transformation of NO_X to NO_2. It is noted that the background file is used by TAPM as boundary inflow at the outermost grid of the computations. Additionally, it should be noted that modelling has assumed a high level of photochemical reactivity for the region (background R_{smog} equal to 0.5 ppb).

Further detailed information on the modelling methodology can be found in Heggies report 10-4044-R3R1 dated 27 March 2008.

3.2.1 Emissions Estimations

Stack emissions parameters were adopted from **Table 1** for the 450 MW option and **Table 8** Considering the information above, to simulate "worst-case" release parameters, stack exit parameters corresponding to an ambient temperature of 273 K (0°C) have been used in dispersion modelling.

Table 8 Exhaust Stack Exit Parameters – 400 MW

Stack Parameter	East and West HRSG Exhaust Stacks	
Description	Exhaust stack servicing the Eastern Gas Turbine, operating in Combined Cycle mode. Combustion gases passed through the Heat Recovery Steam Generator prior to exhaust – 400 MW	
Location (Easting, Northing)	273812 6134875	273851 6134869
Height (m)	40	40
Diameter (m)	6.7	6.7
Area (m^2)	35.3	35.3
Exit Temperature (K)	398	398
	Ambient Temperature	
	273	
Exit Temperature (K)	398	
Flow Rate (Nm^3/s)	392	
Flow Rate (Am^3/s)	572	
Exit Velocity (m/s)	16.0	

Stack emission rates for NO_X were provided by the technical design team (Pers. Comm. GHD). The emission rates for each generation option (400 MW and 450 MW) are presented in **Table 9**.

Table 9 Stack Emission Rates

Atmospheric Pollutant	Emission rate (g/s) at 273K	
	400 MW	**450 MW**
Particulate Matter [1] (g/s)	2.8	2.8
Oxides of Nitrogen (g/s)	18.3	20.4
Sulphur Dioxide (g/s)	0.5	0.6
Carbon Monoxide (g/s)	4.4	4.7
Unburnt Hydrocarbons [2] (g/s)	1.7	1.8

Note 1 Particulate Matter refers to Total Particulate, and not the PM_{10} size fraction in this instance. For modelling purposes, however, all Particulate Matter has been assumed to be PM_{10}.

Note 2 No DECCW or NEPM criterion exists for unburnt hydrocarbons, and no speciation has been provided by the proponent. Within this assessment, all hydrocarbon emissions are assumed to be of benzene and will be assessed accordingly against the NEPM air toxic criterion for benzene.

To predict "worst-case" conditions an emission rate for particulate has been derived based on vendor maximum of 10 kg/hour for a gas fired turbine (URS, 2001). This emission rate may be regarded as conservatively high.

Emission rates are greatest corresponding to an ambient temperature of 273 K (0°C). As with the stack exit parameters, these values have therefore been used in dispersion modelling to present a "worst case" operational scenario.

3.2.2 Building Wake Effects

Plumes trapped in building wakes can either be recirculated in the cavity region immediately downwind of a building or subjected to plume downwash and enhanced horizontal or vertical spreading due to the turbulent zone that exists further downwind.

Buildings generate downwind wake effects up to 5 times the lesser of the building height or projected building width. If there are stacks less than approximately 2.5 times the building height within this zone, then the effect of building wakes should be considered.

Due to the size and proximity of the ACC system to the exhaust stacks (see **Figure 2**), the above criteria for building wakes effects are met. Consequently, the dimensions of this structure have been inserted within TAPM to allow for potential interaction with predicted dispersion.

3.2.3 Buoyancy Enhancement

As discussed in **Section 2** the potential exists for plume enhancement effects resulting from interaction between the two 40 m exhaust points and the ACC system. The hourly varying enhanced exit velocities calculated as part of the plume rise assessment have been utlised in both modelling scenarios to appropriately reflect the expected plume rise enhancement.

3.3 Accuracy of Modelling

Atmospheric dispersion models represent a simplification of the many complex processes involved in the dispersion of pollutants in the atmosphere. To obtain good quality results it is important that the most appropriate model is used and the quality of the input data (meteorological, terrain, source characteristics) is adequate.

The main sources of uncertainty in dispersion models, and their effects, are discussed below.

- **Oversimplification of physics:** This can lead to both under-prediction and over-prediction of ground level pollutant concentrations. Errors are greater in Gaussian plume models as they do not include the effects of non-steady-state meteorology (i.e. spatially- and temporally-varying meteorology).
- **Errors in emission rates:** Ground level concentrations are proportional to the pollutant emission rate. In addition, most modelling studies assume constant worst case emission levels or are based on the results of a small number of stack tests, however operations (and thus emissions) are often quite variable. Accurate measurement of emission rates and source parameters requires continuous monitoring.
- **Errors in source parameters:** Plume rise is affected by source dimensions, temperature and exit velocity. Inaccuracies in these values will contribute to errors in the predicted height of the plume centreline and thus ground level pollutant concentrations.
- **Errors in wind direction and wind speed**: Wind direction affects the direction of plume travel, while wind speed affects plume rise and dilution of plume. Inaccurate assumptions in these parameters can result in errors in the predicted distance from the source of the plume impact, and magnitude of that impact. In addition, aloft wind directions commonly differ from surface wind directions. The preference to use rugged meteorological instruments to reduce maintenance requirements also means that light winds are often not well characterised.
- **Errors in mixing height:** If the plume elevation reaches 80% or more of the mixing height, more interaction will occur, and it becomes increasingly important to properly characterise the depth of the mixed layer as well as the strength of the upper air inversion.
- **Errors in temperature:** Ambient temperature affects plume buoyancy, so inaccuracies in the temperature data can result in potential errors in the predicted distance from the source of the plume impact, and magnitude of that impact.

- **Errors in stability estimates:** Gaussian plume models use estimates of stability class, and 3D models use explicit vertical profiles of temperature and wind (which are used directly or indirectly to estimate stability class for Gaussian models). In either case, errors in these parameters can cause either under-prediction or over-prediction of ground level concentrations. For example, if an error is made of one stability class, then the computed concentrations can be off by 50% or more.

The US EPA makes the following statement in its Modelling Guideline (US EPA, 2005) on the relative accuracy of models:

"Models are more reliable for estimating longer time-averaged concentrations than for estimating short-term concentrations at specific locations; and the models are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere within an area. For example, errors in highest estimated concentrations of ±10 to 40% are found to be typical, i.e., certainly well within the often quoted factor-of-two accuracy that has long been recognized for these models. However estimates of concentrations that occur at a specific time and site, are poorly correlated with actually observed concentrations and are much less reliable."

3.4 Results

3.4.1 Particulate Matter (PM_{10})

Table 10 shows the TAPM v3.0 predictions for maximum 24-hour average PM_{10} concentration. It has been assumed that background levels of PM_{10} are at the 24-hour maximum concentration (44.1 µg/m^3) of the Albion Park South 2006 dataset (excluding the two exceedance days).

Table 10 Predicted Worst-Case Maximum 24-hour PM_{10} Concentrations at the Nearest Sensitive Receptors and Grid Maxima

Receptor	400 MW			450 MW		
	Max 24-hour PM_{10} concentration (µg/m^3)					
	Increment	Background	Cumulative	Increment	Background	Cumulative
R1	0.3	44.1	44.4	0.3	44.1	44.4
R2	0.4	44.1	44.5	0.4	44.1	44.5
R3	0.4	44.1	44.5	0.4	44.1	44.5
R4	0.3	44.1	44.4	0.3	44.1	44.4
R5	0.4	44.1	44.5	0.4	44.1	44.5
R6	0.8	44.1	44.9	0.8	44.1	44.9
Grid Maximum	2.2	44.1	46.3	2.2	44.1	46.3

Table 11 shows the TAPM v3.0 predictions for annual average PM_{10} concentration. It has been assumed that background levels of PM_{10} are 17.2 µg/m^3, taken from the Albion Park South 2006 dataset.

Table 11 Predicted Worst-Case Annual Average PM_{10} Concentrations at the Nearest Sensitive Receptors and Grid Maxima

Receptor	400 MW			450 MW		
	Annual Average PM_{10} concentration (µg/m^3)					
	Increment	Background	Cumulative	Increment	Background	Cumulative
R1	0.01	17.2	17.2	0.01	17.2	17.2
R2	0.02	17.2	17.2	0.02	17.2	17.2
R3	0.01	17.2	17.2	0.01	17.2	17.2
R4	0.01	17.2	17.2	0.01	17.2	17.2
R5	0.02	17.2	17.2	0.02	17.2	17.2
R6	0.3	17.2	17.5	0.4	17.2	17.6
Grid Maximum	0.8	17.2	18.0	0.8	17.2	18.0

Table 10 indicates that at the nearest sensitive receptors, the maximum 24-hour average incremental concentration of PM_{10} associated with both the 400 MW and 450 MW generation capacity of the proposed power facility are predicted to be between 0.3 µg/m^3 and 0.8 µg/m^3. When combined with the maximum 24-hour PM_{10} concentration from the Albion Park South 2006 dataset (excluding the two exceedance days), maximum concentrations are predicted to be less than 45 µg/m^3 at all receptors.

The predicted increments are significantly lower than the background PM_{10} concentration, which was adopted in this assessment from the Albion Park South station. This background concentration is highly conservative. Furthermore, as the assumption that all emitted particulate matter from the facility is PM_{10} has been made (the actual PM_{10} emissions may be 50% lower than the modelled emissions), the predicted PM_{10} increments presented in **Table 10** and **Table 11** are also highly conservative.

The predictive dispersion modelling indicates that the increase in the annual concentration of PM_{10} associated with the proposed power facility may yield an increase of up to 0.3 µg/m3 (annual average) during both 400 MW or 450 MW generation capacity, assuming worst-case emissions and continuous operation. Consequently, it is anticipated that the annual concentration of PM_{10} (background plus increment) will be well below the project air quality goal of 30 µg/m^3 at all sensitive receptors.

It can be seen in **Table 10** and **Table 11** that there is very little difference in the predicted maximum 24-hour mean and annual mean PM_{10} concentrations for the 400 MW and 450 MW generation capacity scenarios.

3.4.2 Nitrogen Dioxide (NO_2)

Table 12 shows the TAPM v3.0 predictions for NO_2 concentrations experienced both at the nearest sensitive receptors and across the entire modelling domain surrounding the Project Site. Predictions are presented for the 400 MW and 450 MW generation capacities as 1-hour maximum and annual average concentrations. The percentage change in predictions between both generation capacities is presented. These predictions take into account both the changes in emission rates and exit velocities as discussed in **Section 3.2.1**.

Table 12 Predicted Worst-Case NO_2 Concentrations at the Nearest Sensitive Receptors and Grid Maxima

Receptor	400 MW	450 MW	% Change	400 MW	450 MW	% Change
	Max 1-hour NO_2 concentration (ppb)			Annual Average NO_2 concentration (ppb)		
R1	11.03	11.03	+0.00	1.02	1.03	+0.98
R2	12.98	14.07	+8.40	1.02	1.03	+0.98
R3	18.98	20.26	+6.74	1.02	1.03	+0.98
R4	19.86	20.31	+2.27	1.02	1.03	+0.98
R5	13.39	14.13	+5.53	1.04	1.05	+0.96
R6	11.08	11.08	+0.00	1.04	1.04	+0.00
Grid Maximum	25.01	25.24	+0.92	1.9	1.96	+3.16

Note: Measured NO_x concentrations from the Nowra Water Treatment Plant Station were input in the TAPM simulations to quantify baseline NO_2 concentrations as specified in the TAPM methodology. TAPM uses the background NO_x concentrations to characterise the pollutant influx at the boundary of the study airshed. Due to meteorological characteristics and chemical transformations simulated within the airshed, the predicted peak cumulative NO_2 concentrations were predicted by the model at the discrete sensitive receptor sites to be lower than the measured peak NO_x concentrations. Full details of the background datasets used in modelling can be found in Heggies Report 10-4044R3R1

Table 12 indicates that at the nearest sensitive receptors, the maximum cumulative 1-hour average and annual average concentrations of NO_2 associated with the proposed gas fired power facility is predicted to satisfy the project goals of 120 ppb (1-hour maximum) and of 30 ppb (annual average) for both the 400 MW and 450 MW generation capacities.

It is also demonstrated that the increase in capacity to 450 MW has a minor impact on the ground level concentrations of NO_2 (maximum 8.4% increase) when viewed in the context of the project criteria.

Comparison between the maximum predicted 1-hour average NO_2 concentration across the entire modelling domain and the peak 1-hour average recorded concentration is presented in **Table 13**.

Table 13 1-hour Maximum NO_2 Comparison – Peak Predicted vs Peak Measured

	1-hour Maximum NO_2 Concentration - ppb
Maximum Predicted – 400 MW	25.01
Maximum Predicted – 450 MW	25.24
Peak Monitored	16

It can be seen in **Table 13** that over the modelling period for 2006, the 400 MW and 450 MW generation capacities of the proposed facility presents a maximum increase of 63.9% (400 MW) and 63.4% (450 MW) at any point over the modelled domain (7 km x 7 km) on the maximum recorded 1-hour average background concentrations from the Nowra Water Treatment Plant Station.

3.4.3 Sulphur Dioxide

Table 14 shows the TAPM v3.0 predictions for SO_2 concentrations experienced at the nearest sensitive receptors surrounding the Project Site. Predictions are presented for the 400 MW and 450 MW generation capacities as 1-hour maximum, 24-hour maximum and annual average concentrations. These predictions take into account both the changes in emission rates and exit velocities as discussed in **Section 3.2.1**.

Table 14 Predicted Worst-Case SO_2 Concentrations at the Nearest Sensitive Receptors

Receptor	Averaging Period	Increment (ppb)		Background Concentration (ppb)	Increment plus Background (ppb)		Project Goal (ppb)
		400 MW	450 MW		400 MW	450 MW	
	1-hour	0.39	0.42	38	38.39	38.42	200
	24-hour	0.12	0.12	9.6	9.72	9.72	80
R1	Annual	0.03	0.03	0.85	0.88	0.88	20
	1-hour	0.54	0.59	38	38.54	38.59	200
	24-hour	0.12	0.12	9.6	9.72	9.72	80
R2	Annual	0.03	0.03	0.85	0.88	0.88	20
	1-hour	0.48	0.52	38	38.48	38.52	200
	24-hour	0.12	0.12	9.6	9.72	9.72	80
R3	Annual	0.03	0.03	0.85	0.88	0.88	20
	1-hour	0.47	0.50	38	38.47	38.50	200
	24-hour	0.12	0.12	9.6	9.72	9.72	80
R4	Annual	0.03	0.03	0.85	0.88	0.88	20
	1-hour	0.39	0.42	38	38.39	38.42	200
	24-hour	0.12	0.12	9.6	9.72	9.72	80
R5	Annual	0.03	0.03	0.85	0.88	0.88	20
	1-hour	0.43	0.46	38	38.43	38.46	200
	24-hour	0.19	0.21	9.6	9.79	9.81	80
R6	Annual	0.06	0.07	0.85	0.91	0.92	20

Table 14 indicates that at the nearest sensitive receptors, the maximum cumulative 1-hour average, 24-hour average and annual average concentrations of SO_2 associated with the proposed gas fired power facility is predicted to satisfy the project goals of 200 ppb (1-hour maximum) 80 ppb (24-hour maximum) and of 20 ppb (annual average) for both the 400 MW and 450 MW generation capacities. Background concentrations were sourced from the Albion Park South monitoring station during calendar year 2006.

It is also demonstrated that the increase in capacity to 450 MW has a minor impact on the ground level concentrations of SO_2 when viewed in the context of the project criteria.

3.4.4 Carbon Monoxide

Table 15 shows the TAPM v3.0 predictions for CO concentrations experienced at the nearest sensitive receptors surrounding the Project Site. Predictions are presented for the 400 MW and 450 MW generation capacities as 1-hour maximum and 8-hour maximum concentrations. These predictions take into account both the changes in emission rates and exit velocities as discussed in **Section 3.2.1**.

Table 15 Predicted Worst-Case CO Concentrations at the Nearest Sensitive Receptors

Receptor	Averaging Period	Increment (ppm)		Background Concentration (ppm)	Increment plus Background (ppm)		Project Goal (ppm)
		400 MW	450 MW		400 MW	450 MW	
R1	1hr	0.003	0.003	2.7	2.7	2.7	25
	8hr	0.001	0.001	1.5	1.5	1.5	9
R2	1hr	0.005	0.005	2.7	2.7	2.7	25
	8hr	0.001	0.001	1.5	1.5	1.5	9
R3	1hr	0.004	0.004	2.7	2.7	2.7	25
	8hr	0.001	0.001	1.5	1.5	1.5	9
R4	1hr	0.004	0.004	2.7	2.7	2.7	25
	8hr	0.001	0.001	1.5	1.5	1.5	9
R5	1hr	0.003	0.003	2.7	2.7	2.7	25
	8hr	0.001	0.001	1.5	1.5	1.5	9
R6	1hr	0.004	0.004	2.7	2.7	2.7	25
	8hr	0.003	0.003	1.5	1.5	1.5	9

It is demonstrated that cumulative concentrations of carbon monoxide (using background data from Albion Park South, 2006) are well below the relevant Project criteria for both the 400 MW and 450 MW capacity options.

3.4.5 Volatile Organic Compounds

Table 16 shows the TAPM v3.0 predictions for VOC (as benzene) concentrations experienced at the nearest sensitive receptors surrounding the Project Site. Predictions are presented for the 400 MW and 450 MW generation capacities as annual average concentrations. These predictions take into account both the changes in emission rates and exit velocities as discussed in **Section 3.2.1**.

Table 16 Predicted Worst-Case VOC Concentrations at the Nearest Sensitive Receptors

Receptor	Increment (ppb)		Project Goal (benzene) (ppb)
	400 MW	450 MW	
R1	0.1	0.1	3
R2	0.1	0.1	3
R3	0.1	0.1	3
R4	0.1	0.1	3
R5	0.1	0.1	3
R6	0.2	0.2	3

Note: All VOC assumed to be emitted as Benzene

No background concentration of benzene is available for the region surrounding the Project site, although can be assumed to be negligible. It is demonstrated that the Project criterion of 3 ppb is easily satisfied and no changes between the 400 MW an 450 MW options are observable.

3.5 Start-Up and Shut-Down Emissions

The impacts of start-up and shut down emissions on ground level concentrations are not predicted to be an issue of concern for the 450 MW generation option. The findings presented on page 44 Section 7.6 of the original assessment apply.

3.6 Photochemistry Impact

It is not anticipated that the 450 MW generation option will have impacts over and above those noted in Section 7.5 on page 44 of the original assessment.

3.7 Construction Air Quality Impacts

Construction air quality impacts are as stated within Section 7.9 on page 47 of the original assessment.

3.8 Mitigation Measures and Safeguards

Mitigation Measures and Safeguards are as stated within Section 8 on page 48 of the original assessment.

4 GREENHOUSE GAS ASSESSMENT

The proposed power facility at Bamarang has the potential to produce greenhouse gases, with the primary source being the two gas turbines during electricity generation operations.

Carbon dioxide (CO_2) is produced during fuel combustion as a result of the oxidation of the fuel carbon content. CO_2 is likely to make the largest contribution to greenhouse gas emissions from fuel combustion as approximately 99.5% of natural gas fuel is oxidised during the combustion process (Australian Greenhouse Office, 2002).

Other greenhouse gases emitted as a result of the proposed operations at the Bamarang site may include CO, CH_4, NO_X and non-methane volatile organic compounds (NMVOCs). These are produced by incomplete fuel combustion, reactions between air and fuel constituents during fuel combustion, and post-combustion reactions. Fugitive emissions of NMVOCs may also be expected due to fuel evaporation.

For comparative purposes, non-CO_2 greenhouse gases are awarded a "CO_2-equivalence" based on their contribution to the enhancement of the greenhouse effect. The CO_2-equivalence of a gas is calculated using an index called the Global Warming Potential (GWP). The GWPs for a variety of non-CO_2 greenhouse gases are contained within Table 27 of Appendix 1 of the Australian Department of Climate Change (DCC) document *National Greenhouse Accounts (NGA) Factors – June 2009* (NGA Factors, DCC, 2009). The GWPs of relevance to this assessment are:

- **Methane (CH_4)**: GWP of 21 (21 times more effective as a greenhouse gas than CO_2).
- **Nitrous Oxide (N_2O)**: GWP of 310 (310 times more effective as a greenhouse gas than CO_2).

The short-lived gases such as CO, NO_2, and NMVOCs vary spatially and it is consequently difficult to quantify their global radiative forcing impacts. For this reason, GWP values are generally not attributed to these gases nor have they been considered further as part of this assessment.

Based on an assumed 8,300 hours of actual operation and an hourly natural gas consumption rate of 3,623 GJ/hr, the 450MW power facility is anticipated to have an estimated annual gas demand of 30.1 PJ. This is an approximate 13.2% increase on the annual consumption rate assumed for the 400 MW power facility (26.6 PJ). Heggies Report 10-4044R3R1 assumed an annual consumption rate of 24.0 PJ for the 400 MW facility, although this was based on a lower consumption rate. Information has since been received from GHD which confirms that the consumption rate should be 26.6 PJ for the 400 MW facility and 30.1 PJ for the 450 MW facility.

Heggies Report 10-4044R3R1 estimated greenhouse gas emissions from the proposed 400 MW facility using the Australian Greenhouse Office (AGO) document "*Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2002 – Energy (Stationary Sources)*". This document has been superseded by the NGA Factors and for consistency, the greenhouse gas impact of both options (400 MW and 450 MW) has been calculated using the NGA Factors.

A summary of the predicted greenhouse gas emissions from the 400 MW and 450 MW facility options are provided in **Table 17**. The CO_2-equivalent emissions are also detailed as a percentage of the total emissions from electricity generation operations in Australia during 1990 and 2007 (129.5 and 199.5 Mt/year respectively, as referenced in the DCC National Greenhouse Accounts – State and Territory Greenhouse Gas Inventories – May 2007).

Table 17 Predicted Emissions of Greenhouse Gases – 400 MW and 450MW operations

400 MW				
Compound	**CO_2**	**CH_4**	**N_2O**	**Total Emissions**
Predicted Emissions (tonnes/year)	1,361,920	127	3	1,362,049
CO_2-Equivalent (tonnes/year)	1,361,920	2,660	798	1,365,378
% of CO_2 emissions of Australian electricity generation, 1990	1.05%	0.002%	0.001%	1.05%
% of CO_2 emissions of Australian electricity generation, 2007	0.68%	0.001%	0.0004%	0.68%
450 MW				
Compound	**CO_2**	**CH_4**	**N_2O**	**Total Emissions**
Predicted Emissions (tonnes/year)	1,541,120	143	2.9	1,541,266
CO_2-Equivalent (tonnes/year)	1,541,120	3,010	903	1,545,033
% of CO_2 emissions of Australian electricity generation, 1990	1.19%	0.002%	0.001%	1.19%
% of CO_2 emissions of Australian electricity generation, 2007	0.77%	0.0015%	0.0005%	0.77%

Emissions of CO_2-e are anticipated to increase by approximately 180,000 tonnes per annum with the increase in generating capacity from 400 MW to 450 MW, representing a percentage increase of 0.09% on the Australian electricity sector emissions, 2007.