Waratah Coal Technical Note

Air quality modelling input data: Galilee Power Project

Caveat

The following technical memo is based upon concept level design and, as such, is subject to change. The results rely upon assumptions, heuristics, limited geotechnical sampling, uncertainty in analysis and information supplied by third parties. The memo may contain errors. As such the actual performance of the plant will vary from that predicted in these calculations.

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Introduction

The following note sets out the basis for emissions rates and input data provided to Katestone Environmental for the purposes of air quality modelling undertaken for the proposed Galilee Power Project.

Abbreviations

- %**ad** Air dried: A value expressed as a percentage of a mass of air dried coal.
- **%daf** Dry, ash free: A value expressed as a percentage of a mass of dry, ash free coal.
- **LHV** Lower heating value: the calorific value of a fuel assuming that the latent heat of evaporation of combustion products is not recoverable.

Input data provided to Katestone Environmental

The following input data was provided by Waratah Coal to Katestone Environmental:

	Units	Overload	100%	60%	25%
Power generated	MW	756	702	421.2	175.5
Power sent out	MW	722	670	402	167.5
Exhaust temperature	°C	120	120	120	120
Flue diameter (each flue)	m	7.0	7.0	7.0	7.0
Volume flow	$Nm^3/s/unit$	604	521	325	163
Concentrations					
NOx (at 15% O_2)	mg/Nm3	200	200	200	200
PM	mg/Nm3	50	50	50	50
Emission rates – total for two units					
Nox	g/s	789	680	425	213
SO_2	g/s	100	87	54	27
PM	g/s	197	170	106	53
Metals					

arsenic	g/s	8.1E-04	7.0E-04	4.4E-04	2.2E-04
boron	g/s	3.7E-02	3.2E-02	2.0E-02	1.0E-02
cadmium	g/s	2.2E-05	1.9E-05	1.2E-05	6.1E-06
fluorine	g/s	2.8E-02	2.4E-02	1.5E-02	7.5E-03
mercury	g/s	1.7E-05	1.5E-05	9.1E-06	4.5E-06
lead	g/s	6.8E-03	5.9E-03	3.7E-03	1.8E-03
selenium	g/s	9.6E-04	8.3E-04	5.2E-04	2.6E-04

Power generated and sent out

Power generated at 100% rated load was based upon a nominal unit size of 700 MW. The actual unit size will be subject to detailed design but will not exceed 700 MW. Auxiliary power (including air cooled condenser fan operation) was estimated at 3.0%.

Overload operation, achieved by taking high pressure heaters out of service and allowing additional steam to pass through the turbine, was based upon a nominal increase of 7.5% in output.

Part load operation was scaled at 60% and 25%.

Exhaust temperature

Exhaust temperature will be controlled to 120°C (a nominal 20°C above the saturation pressure at atmospheric pressure) by the flue gas desulphurisation reheater in order to avoid condensation in the stack and maximise energy recovery. The temperature will be close to constant throughout the normal operating range of the boilers.

Flue diameter

The flue diameter has been estimated at 7.0 m on the basis of similar 700 MW power stations elsewhere globally. Katestone Environmental calculate an effective single flue diameter representing the two flues exhausting through one stack.

Volumetric flow of flue gas

The volumetric flow rate of flue gas has been calculated through the combustion equations worked through below.

NOx emission rates

NOx emission rates were based upon the typical performance of modern low NOx burners. The emission rate modelled was 200 mg/Nm^3 at 15% O_2. This rate is consistent with practice in Japan and the European Union[1] (as at 2017).

The 200 mg/Nm^3 performance will not be exceeded at part load or overload operation (i.e. it is anticipated that this performance specification will not be exceeded).

1 Aurecon, “Control of NOx Emissions from Coal Fired Combustion”, Rev 2, 23 June 2017, Table 3-5

The following extract[2] from the IEA Clean Coal Centre's webpage explains the operation of low NOx burners.

"Low NOx burners are designed to control fuel and air mixing at each burner in order to create larger and more branched flames. Peak flame temperature is thereby reduced, and results in less NOx formation. The improved flame structure also reduces the amount of oxygen available in the hottest part of the flame thus improving burner efficiency. Combustion, reduction and burnout are achieved in three stages within a conventional low NOx burner. In the initial stage, combustion occurs in a fuel rich, oxygen deficient zone where the NOx are formed. A reducing atmosphere follows where hydrocarbons are formed which react with the already formed NOx. In the third stage internal air staging completes the combustion but may result in additional NOx formation. This however can be minimised by completing the combustion in an air lean environment.

"Low NOx burners can be combined with other primary measures such as overfire air, reburning or flue gas recirculation. Plant experience shows that the combination of low NOx burners with other primary measures is achieving up to 74% NOx removal efficiency. A large number of low NOx burners have been developed and are currently used in over 370 coal-fired units (125 GWe). Nevertheless, developmental work continues to enhance the design, and improve the performance of existing burners and engineer and develop new and advanced low NOx burners".

The mass flow rate for NOx is calculated from the concentration and the flue gas flow rates, which is calculated through the combustion calculations stepped through below.

SO_2 emission rates

SO_2 emission rates are calculated through the combustion calculations worked through below and are based upon the elemental sulphur contained within the fuel.

Sulphur emissions rates are increased by 20% to allow for variations in the fuel supply.

The project will include a flue gas desulphurisation plant, which has been modelled with a recovery of 95%.

PM emission rates

A PM (particulate matter) emission rate of 50 mg/Nm^3 was utilised for the modelling on the basis of current practice in Australia at power station such as Eraring and Mount Piper[3].

The PM emission rate is controlled by the bag filters and would not be exceeded under the overload or part load operating scenarios.

The mass flow rate for PM is calculated from the concentration and the flue gas flow rates, which is calculated through the combustion calculations stepped through below.

2 https://www.iea-coal.org/low-nox-burners/ (accessed 18 December 2019)

3 NSW Environmental Protection Authority, "Review of Coal Fired Powe Stations Air Emissions and Monitoring", March 2018, Table 3.

Metals

Emissions of metals are set through the composition of the ash and the PM emission rates. Metal emission rates are taken as the proportion of each metal in ash multiplied by the PM emission rate. The ash composition has been derived through analysis of D seam coal samples and is tabulated below:

	Arsenic	Boron	Cadmium	Fluorine	Mercury	Lead	Selenium
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Trace analysis (daf)	1.1	49.3	0.03	37.4	0.02	9.1	1.3
Trace analysis (db)	0.9	40.9	0.02	31.0	0.02	7.6	1.1

Coal Characteristics

The following coal quality characteristics were taken as averages of data collected from D Seam exploration samples taken from the Galilee Coal Project corrected to 8.8% moisture.

Proximate (%ad)	
Moisture	8.80%
Ash	8.35%
Volitile matter	35.43%
Fixed Carbon	47.42%
Gross energy	26.80 MJ/kg ad
Net energy (LHV)	25.78 MJ/kg ad
Ultimate (%daf)	
Carbon	79.91%
Hydrogen	4.91%
Nitrogen	1.98%
Sulphur	0.67%
Oxygen	12.53%

Heat rate

Base Load

A heat rate of 8972 kJ/kWhr (LHV, sent out) or 8710 kJ/kWhr (LHV, generated) has been estimated for base load operation, on the basis of indicative performance data from a global supplier.

The global supplier has indicated that a heat rate of 8270 kJ/kWhr can be achieved at the project site; therefore, the heat rate estimate is considered to be conservative.

Load scenarios

The heat rate was increased by 7.5% for the overload scenario to account for efficiency losses resulting from the removal of the high pressure feed water heaters from service during overload operation.

The heat rate was increased by 4% and 25% to account for part load efficiency losses at the 60% and 25% load scenarios.

Combustion calculations

Fuel flow

Fuel flow is calculated for each of the load scenarios as the product of heat rate and output divided by the net calorific value of the fuel.

Per unit data			**700 MW**		
	Overload	**100% Load**	**60%**	**25%**	
Generation	756	702	421	176	MW
Sent out	722	670	402	168	
Heat rate (Net)	9650	8972	9346	11215	kj/kWhr
Fuel Cv	25.78	25.78	25.78	25.78	MJ/kg (LHV)
Fuel Flow	270	233	146	73	Tons per hour per unit (ad)

Combustion calculations

Combustion chemical equations for each of the coal components are as follow below:

$C + O_2 \Rightarrow CO_2$
$4H + O_2 \Rightarrow H_2O$
$S + O_2 \Rightarrow SO_2$
$N + O_2 \Rightarrow NO_2$

Oxygen demand and airflow

Oxygen demand and airflow is calculated on the basis of fuel input mass flow rate as follows:

	% of fuel flow (%daf)	**Mole weight**	**O2 demand**	**O2 demand (%daf)**	**O2 demand (%ad)**
Carbon	79.91%	12	32	213.09%	176.55%
Hydrogen	4.91%	4	32	39.31%	32.57%
Sulphur	0.67%	32	32	0.67%	0.56%
Nitrogen	0.21%*	14	32	0.48%	0.40%
Oxygen	12.53%	16	-16	-12.53%	-10.38%
Oxygen demand (%DAF)				241.02%	199.69%
Oxygen demand (%AD)					199.69%
Excess air (%AD)	20%				39.94%
Total O2 (% AD)					239.63%
Total airflow (%AD)					1033.82%

The above indicates that airflow (by mass) will be 1034% of the fuel flow (by mass on an air dried basis).

*The nitrogen content is reduced to reflect the amount of nitrogen in the fuel/air mix that leaves the combustion system oxidised as NO_2; this figure is back calculated from a typical, modern low NOx burner performance of 15 ppm.

Excess air of 20% is passed through the combustion system to ensure complete combustion in order to maintain combustion efficiency.

Combustion products

The combustion products are then calculated as a proportion of fuel input mass flow as follows:

	Product	Mole weight	Product mass (%daf)	Product mass (%ad)
Carbon	CO2	44	293.00%	242.75%
Hydrogen	H2O	18	44.22%	36.64%
Sulphur	SO2	64	1.34%	1.11%
Nitrogen	NO2	46	0.21%	0.17%
Oxygen			0.69%	0.57%

Exhaust flow

The constituents of the combustion air are then calculated as a proportion of fuel input mass flow as follows:

	% v/v	Mole weight	Weighted mole weight	%m/m	%ad fuel flow
Nitrogen	78.09%	28	21.9	75.49%	780.44%
Oxygen	20.98%	32	6.7	23.18%	239.63%
Argon	0.93%	40	0.4	1.28%	13.28%
CO2	0.03%	44	0.0	0.05%	0.47%
Total airflow			29.0	100.00%	1033.82%

The flue gas composition is then summed from the combustion products and the inert constituents of the inlet air as a proportion of fuel input mass flow as follows:

Flue Gas	%ad fuel flow	%mass/mass	Mole weight	Weighted mole weight	Moles/100% AD fuel flow	Mole%
CO2	243.22%	21.6%	44	9.51	0.06	14.7%
H2O	45.44%	4.0%	18	0.73	0.03	6.7%
SO2	1.11%	0.099%	64	0.06	0.00017	0.046%

NO2	0.16%	0.015%	46	0.01	0.00	0.01%
N2	782.37%	69.5%	28	19.46	0.28	74.3%
O2	39.94%	3.5%	32	1.14	0.01	3.3%
Ar	13.28%	1.2%	40	0.47	0.00	0.9%
Total exhaust mass flow	1125.52%	100.00%		31.38	0.38	100.00%

95% of the SO_2 produced is recovered in the flue gas desulphurisation plant; therefore, the SO_2 emission rate is reduced by 95% as shown below.

The exhaust mass and SO2 production rates is calculated on the basis of fuel flow and the normalised exhaust volumetric flow rate is calculated one the basis of the ideal gas law and the weighted mole weight of the flue gas.

Per unit data		**700 MW**			
	Overload	**100% Load**	**60%**	**25%**	
Fuel Flow	270	233	146	73	Tons per hour per unit (ad)
SO_2 production rate	1.11%	1.11%	1.11%	1.11%	Of fuel flow (ad)
FGD recovery	95%	95%	95%	95%	
SO_2 emission rate	0.06%	0.06%	0.06%	0.06%	Of fuel flow (ad)
SO_2 emission rate	0.15	0.13	0.08	0.04	Tonnes per hour
Exhaust flow	1125.52%	1125.52%	1125.52%	1125.52%	Of fuel flow (ad)
Exhaust flow	3042	2625	1641	820	Tonnes per hour
Exhaust flow	604	521	325	163	Nm^3/s

Sulphur adjustment and desulphurisation

For the purposes of modelling, the sulphur emission rate is then increased by 20% to account for variations in fuel sulphur content.