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Subject	Sulfur Oxide (SOx) emissions and reduction options for Vales Point Power Station		
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From	F Biggs, A Sobey, I Fletcher		
Date	30 September 2021		
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1. Introduction

Delta Electricity have requested that Jacobs undertake a review of Sulfur Oxide (SOx) emissions from Vales Point Power Station and identify SOx reduction measures, and the feasibility to implement these at Vales Point Power Station.

Vales Point Power Station (Vales Point) is located on the NSW Central Coast and has a gross installed capacity of 1,320 megawatts. Vales Point is a coal-fired power station providing baseload electricity. It consists of 2 boiler-turbine units designated Units 5 and 6 (U5, U6), the original A station Units 1-4 having been retired in 1989.

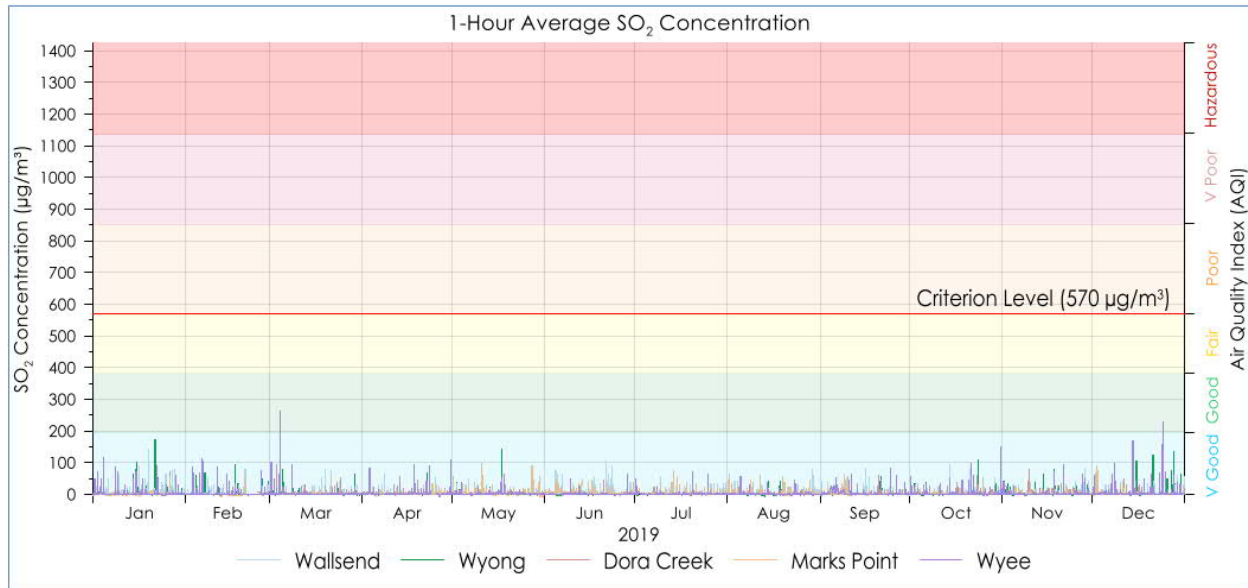
Delta holds an Environment Protection Licence (EPL) No. 761 for Vales Point and Coal Unloader issued under Section 55 of the Protection of the Environment Operations (POEO) Act 1997. Under this licence, Vales Point must comply with air emission concentration limits for nitrogen oxides (NOx), sulfur dioxide (SO₂), sulfuric acid mist (SO₃), solid particles, and trace elements. SO₂ is measured continuously by CEMS¹ at two locations on each Unit's connection to the stack (5A, 5B, 6A, 6B). The 99th and 100th percentile concentration limits are 1400 mg/Nm³ and 1700 mg/Nm³ respectively (1 hour average).

Vales Point is located outside the Sydney airshed and ambient air quality in the area is good. A 2019 study of emissions concentrations in the Lake Macquarie – Wyong area found that 1-hour average SO₂ concentration were significantly below the criterion level². On most occasions, the ambient Air Quality Index was "very good", and on a few occasions air quality was "good" (see Figure 1.1).

¹ Continuous Emissions Monitoring System

² Lake Macquarie – Wyong Review of Annual Ambient Air Quality Data 2019 – Delta Electricity & Origin Energy, by Todoroski Air Services

Figure 1.1: 1-Hour Average SO₂ Concentration near Vales Point Power Station (Todoroski, 2019)³



2. SO₂ Data from Vales Point CEMS

SO₂ emissions 1 hour data was reviewed from the Vales Point CEMS over the period July 2017 – Jun 2021. In this time, SO₂ emissions concentrations never exceeded the 100th percentile limit of 1700 mg/Nm³ and on only two occasions exceeded the 99th percentile limit of 1400 mg/Nm³. Table 2.1 below outlines the average and 1-hour maximum concentrations of SO₂ from Unit 5 and Unit 6 as well as the number of instances in which the 99th percentile limit was exceeded.

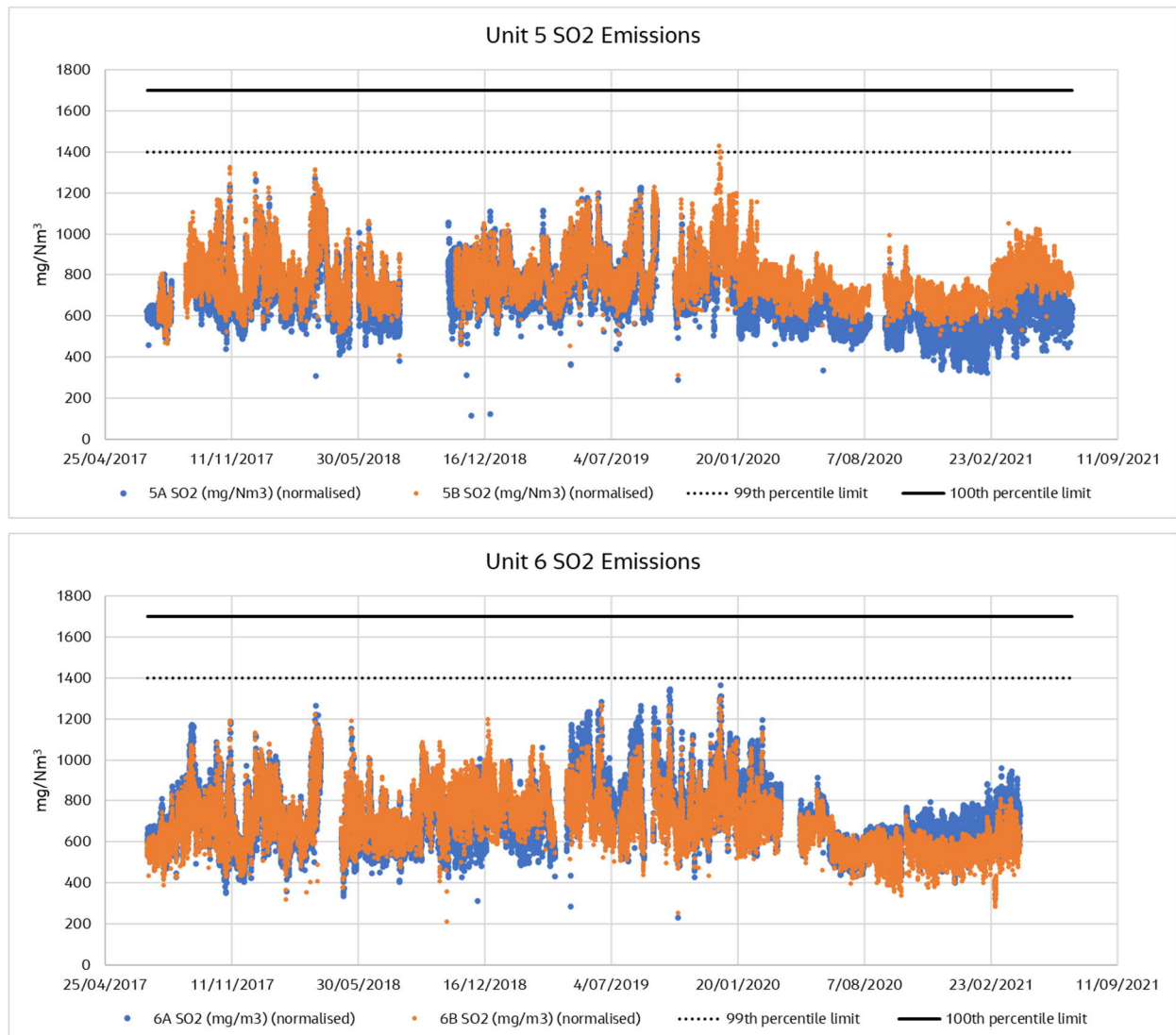
Table 2.1: Summary of SO₂ CEMS Data

	Unit 5			Unit 6		
	Average Concentration (mg/Nm ³)	Maximum Concentration (mg/Nm ³)	Events > 1400 mg/Nm ³	Average Concentration (mg/Nm ³)	Maximum Concentration (mg/Nm ³)	Events > 1400 mg/Nm ³
2017 (Jul-Dec)	735	1,280	0	678	1,187	0
2018	756	1,293	0	713	1,241	0
2019	804	1,428	2	783	1,331	0
2020	666	1,199	0	643	1,153	0
2021 (Jan-Jun)	682	933	0	630	910	0
2017-2021	733	1,428	2	702	1,331	0

³ Lake Macquarie – Wyong Review of Annual Ambient Air Quality Data 2019 – Delta Electricity & Origin Energy, by Todoroski Air Services

The SO₂ concentrations from Units 5 & 6, furnaces A and B, are shown in Figure 2.1 below. There is some fluctuation in the concentration levels during operation depending on the sulphur content in the coal however most data points are consistently significantly below the 99th percentile limit. There is some variation between the furnaces A and B emissions concentrations reported by the CEMS on both units, especially in the last year.

Figure 2.1: SO₂ Emissions from Furnace A and B, Unit 5 and 6

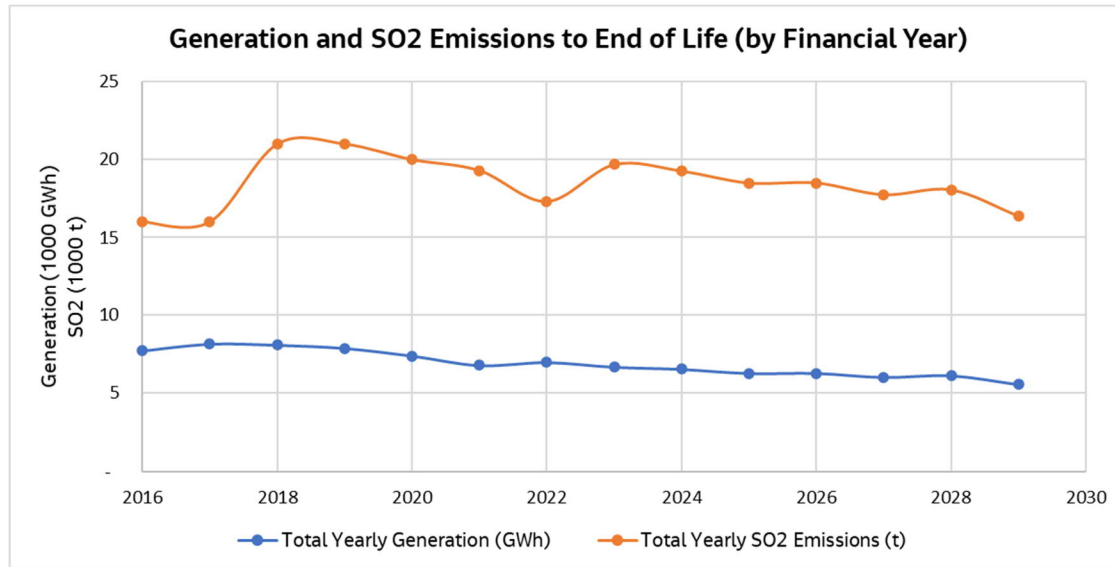


3. Forecast Mass Emissions of SO₂ to End of Station Life

The current forecast closure date for Vales Point Power Station is 2029. The generation from VPPS is forecast to reduce until end of life, due to increasing penetration of renewables in the National Electricity Market. Reduced generation will also reduce the mass emissions of SO₂ from the station, but this may be

offset by a minor increase in sulfur content in the coal in future years (refer to Section 4.1). Overall, mass emissions of SO₂ from Vales Point are forecast to remain approximately the same until closure in 2029, refer to Figure 3.1 and Table 8.1 for forecast mass emissions per year.

Figure 3.1: Generation and SO₂ Emissions to End of Life⁴



4. Mitigation of SO_x Emission

SO_x emissions can be controlled to meet required emission levels by either:

- Firing coals containing low sulfur
- Reducing the sulfur content in the fuel prior to its combustion by washing (removes iron pyrites)
- Removing sulfur oxides from the combustion gases before they are released to the atmosphere via the stack (post combustion controls).

4.1 Low Sulfur Containing Coals

For ultra-low sulfur (<0.2% S) and low-sulfur coal (< 1% S), the sulfur content is derived primarily from parent plant material. For medium-sulfur coal (1 to < 3% S) and high-sulfur (≥ 3% S) coals, there are two major sources of sulfur: 1) parent plant material, and 2) sulfate in seawater that flooded peat swamps.

As per Table 4.1, the coal supplied to Vales Point is predominately in the range 0.34-0.60% by weight for as received basis depending on supplier. When the coals are blended for firing, the range is 0.34-0.45 % which is the lower spectrum of *low sulfur* coal.

⁴ FY16-20 SO₂ emissions data is from the NPI database

Table 4.1: Content of Sulfur in Coal Supplied to Vales Point

Colliery	Total Sulfur % Wt in coal	Proportion of Coal Supplied FY22 (%)	Proportion of Coal Supplied FY23-29 (%)
Chain Valley	0.34	48	52-78
Mandalong	0.34	52	17-18
Airly Coal	0.45	0	17-18
Invincible Coal	0.60	0	10-12
Average S % Wt for year		0.34	0.40

4.2 Removal of Sulfur from Coal by Washing

Sulfur in coal is found in both inorganic and organic forms of sulphates. Inorganic sulphur, in the form of pyrite (FeS₂), can be removed from coal simply by washing the coal. This method can result in a reduction of 10 - 50% of total sulphur content in high sulphur coals, but the beneficiation with low sulfur coal is minimal. Large quantities of wastewater are produced, and washing can also change the physical characteristics of the as delivered coal, resulting in operational problems during the combustion process.

Coal washing is not recommended for the Vales Point low sulfur coals.

4.3 Removing SO_x from the Combustion Gases

Emissions of SO_x generated during the combustion of fossil fuels can be reduced by treating the flue gases before they are emitted into the atmosphere via the stack. This process removal is termed Flue Gas Desulfurisation (FGD).

The SO_x formation is covered in more detail in section 4 below.

Three types of FGD systems are generally selected for larger power utility installations or retrofitting:

- Wet Flue Gas Desulfurisation (Wet FGD) or wet scrubbing
- Dry Flue Gas Desulfurisation (Dry FGD) or dry scrubbing, used in conjunction with fabric filter
- Seawater FGD.

Wet FGD is also referred to as Limestone Forced Oxidation. Similarly, Dry FGD is also referred to as Lime/Sorbent Spray Dryer and generally used for smaller (less than 300 MW) low-sulfur coal plants. Seawater FGD is a form of Wet FGD but exploits the natural alkalinity of seawater to absorb acidic gases. Each of these technologies and their effectiveness are described further in the Section 5 below. Indicative costing for retrofitting and operating costs are provided in Section 6.

5. SO_x Formation During Fuel Combustion and Emission

SO_x are a by-product of the combustion of most coals and fuel oils i.e., any fuel that contains sulfur.

During combustion, most of the sulfur in fuel converts to SO₂ with small quantities of sulfur trioxide (SO₃).

Some of the SO₂ that forms during combustion, converts to SO₃. The typical conversion rate is 1% or less in the boiler. The SO₂-to-SO₃ conversion is dependent on several parameters such as: combustion temperature, O₂ concentration, and the presence of catalytic compounds in the fly ash.

Low O₂ concentration in the flue gas leads to significantly lower levels of SO₃.

The SO₃ readily combines with water to form sulfuric acid (H₂SO₄) at flue gas temperatures less than 260°C which can create extremely corrosive conditions if the temperature falls below the sulfur dewpoint.

6. Post Combustion Sulfur Oxide Pollution Control Technologies

6.1 Wet Scrubbing Technology

Wet and dry flue gas desulfurisation (FGD) systems are internationally the most commonly used technologies in the coal-fired electric utility industry, but with no FGD installed in Australian power plants. Both scrubbing technologies use slurries of sorbent and water to react with SO₂ in flue gas, producing wet and dry waste products respectively.

In the wet scrubbing process, a sorbent slurry consisting of water mixed with limestone, lime, magnesium promoted lime or sodium carbonate (Na₂CO₃) is contacted with flue gas in a reactor vessel. Wet scrubbing is a highly efficient (>97% removal at calcium/sulfur molar ratios close to 1.0) and is a well-established technology which can produce usable by products (gypsum).

There are four steps to this process:

Reagent preparation ⇒ SO₂ absorption ⇒ slurry dewatering ⇒ final disposal.

In the reagent preparation process, limestone is crushed into a fine powder and mixed with water in a slurry preparation tank. Sorbent slurry from this tank is then pumped into the absorber reaction tank. From the reaction tank, sorbent slurry is pumped continuously to one or more spray headers. Each header has numerous individual nozzles that spray the slurry as droplets. The flue gas enters the side of the absorber at about its midpoint and flows upwards through the limestone slurry sprayed downwards. During this process, SO₂ in the flue gas is removed by both absorption and reaction with the slurry, and water in the slurry is vaporized into the flue gas. The treated flue gas leaving the absorber is saturated with moisture.

To convert absorbed SO₂ to sulfate and cause gypsum to precipitate, forced oxidation is obtained by blowing air into the slurry in the reaction tank. A slurry bleed stream is pumped from the reaction tank to the dewatering system equipment. In the dewatering system, by-product (gypsum CaSO₄ 2H₂O) or waste solids are separated from the bleed slurry and made ready for final delivery or disposal. Where there is no market for recovered gypsum, the FGD slurry may be added to the ash for disposal in the ash dam.

Wet FGD also lowers particulate emissions, by collecting fine particulates which may pass through the fabric filter. Wet FGD systems consume large amounts of fresh water. Wet FGD systems may use a gas to gas heat exchanger to reduce water consumption and to reheat the flue gas to avoid a stack vapour plume.

6.2 Dry Scrubbing Technology

In the dry scrubbing or dry flue gas desulfurization (FGD) system, the sorbent injection does not require modification of the combustion process. The sorbent injection is applied in temperature regions, ranging from those just outside the combustion zone in the upper furnace, to those at the economizer and flue ducting following the air heater.

Sorbent injection involves adding an alkali compound to the coal combustion gases for chemical reaction with the SO₂. Typical calcium sorbents include:

- limestone (calcium carbonate (CaCO₃))
- lime (CaO)
- hydrated lime (Ca(OH)₂).

Modifications of these compounds with special additives such as sodium or magnesium-based compounds are also used.

Semi-Dry scrubbing or Spray Dryer Absorber (SDA) involves spraying the aqueous sorbent slurry into a reactor vessel so that the slurry droplets dry as they contact the hot flue gas ~149°C. The SO₂ reaction occurs during the drying process and results in a dry particulate containing reaction products and unreacted sorbent entrained in the flue gas along with flyash (this may render the flyash unsuitable for recycling). These materials are captured downstream in the bag filter. Dry scrubbing is a well-established technology with considerable operational flexibility. The waste residue is a dry product.

A lime spray drying FGD system consists of three process steps:

Reagent preparation ⇒ SO₂ absorption ⇒ dry particulate collection.

In the reagent preparation process, lime is slaked in a lime slaker with water and held in a slurry tank for use. The slurry is fed to the absorber by an atomizer. The feed rate of fresh lime is controlled by the flue gas inlet SO₂ content and SO₂ removal efficiency, and the water flow rate within the slurry is controlled to maintain the desired gas outlet temperature. Flue gas is treated in an absorber by mixing the gas stream concurrently with atomized lime slurry droplets. Water in the spray evaporates and cools the gas to about 7-10°C above the saturation. At the same time, the spray droplets capture SO₂ from the gas and the SO₂ reacts with the lime in the slurry to form a solid by-product.

The treated flue gas, along with reaction products and other particulate matter, flows through the absorber to the fabric filter. The filter fabric will collect most of the particulates and continue to remove some of the remaining SO₂. The majority of SO₂ is removed within the absorber. An additional 15% to 20% SO₂ can be captured by the baghouse. Some of the SO₃ also will also be removed in the particulate collector. An optional flyash recycle circuit is used to improve the lime utilization rate.

Dry Sorbent Injection (DSI) injects dry sodium-based sorbent directly into the furnace or into the ductwork following the furnace. DSI is not a typical standalone, add-on air pollution control system but a modification to the combustion unit or ductwork. Due to its simpler configuration, DSI can typically

achieve SO₂ control efficiencies ranging from 50 to 70%. Using sodium based DSI with a bagfilter, SO₂ control efficiencies of 70 to 80% or higher can be achieved (if sorbent milled).

Dry FGD systems place an additional load onto the ash handling system but use less water than Wet FGD.

6.3 Process Chemistry for Wet and Dry FGD

The SO₂ absorbed in the atomized slurry reacts with lime in the slurry to form calcium sulfite (CaSO₃). In the Sulfite reaction cited above for the Wet FGD process, and a part of the CaSO₃ reacts with oxygen in the flue gas to form calcium sulfate (CaSO₄) in the Sulfate reaction cited above.

The waste product contains CaSO₃, CaSO₄, calcium hydroxide and ash.

6.4 A Seawater FGD system

For power plants located on an ocean coast, seawater FGD becomes an attractive alternative to other FGD systems which use commercial alkaline chemicals to remove the sulfur dioxide from the flue gas. Natural seawater contains a certain amount of bicarbonate ions (HCO₃⁻), which cause a pH higher than 7, in the range of 7.8 up to 8.5 or more. Because of this alkaline pH, seawater can be used as an absorbent, to remove SO_x and other acidic species from flue gases.

The absorber of the FGD uses the seawater to absorb the sulfur dioxide from flue gas and subsequently oxidizes it to sulfate. The acidified seawater leaving the absorber undergoes a neutralization process in the treatment basin, by using the natural alkalinity present in a parallel stream of seawater, before being discharged back to the ocean. Compared with the conventional wet FGD, the seawater FGD offers many advantages:

- no reagent or sorbent required
- no by-product,
- lower energy consumption and lower capital cost
- maintains the same (or higher) sulfur removal efficiency (>95%).

This technology is only effective when using coal with a relatively low sulfur content (<1.5%), hence the process could potentially be suitable for Vales Point with a low sulfur coal (but not including environmental factors).

A seawater FGD system consists of the following process steps:

Pumping of fresh seawater ⇒ SO₂ absorption in absorber ⇒ oxidation in aeration basin ⇒ neutralisation.

Flue gases are directed and contained in an absorption tower where they flow counter current and come into intensive contact with the fresh seawater. The heat of the flue gas causes the seawater to be heated and the gases cooled. During this process, SO₂ is absorbed by the seawater and is bound completely as bisulphite and sulphite before passing to an aeration basin. The forced oxidation of the seawater, using aeration fans, forms hydrogen bisulphite / sulphite as an integral part of the aeration basin. The oxidation occurs under optimal conditions i.e., pH, so that bisulphate and sulphate is obtained.

The following reactions take place in the absorber, the aeration basin.

- Absorption $\text{SO}_2 (\text{gas}) + \text{H}_2\text{O} \rightarrow \text{SO}_3^{2-} + 2\text{H}^+$
- Oxidation $\text{SO}_3^{2-} + 1/2 \text{O}_2 \rightarrow \text{SO}_4^{2-}$
- Neutralisation $\text{H}^+ + \text{HCO}_3^- \rightarrow \text{H}_2\text{O} + \text{CO}_2$

A flue gas-gas heat exchanger (GGH) is used such that the clean flue gas leaving the absorber is heated to 70°C by GGH and leaves through the stack. The warmed flue gas assists with flue gas dispersion and removes a stack vapour plume.

Prior to discharge back to the sea, more fresh seawater is required to be mixed with the absorber effluent in the return channel, or in the aeration basin, and then discharged to the sea.

This system is a simple and inherently reliable technology with lower capital and operational costs, which can remove up to 98% of SO₂, with no disposal of waste to land. However, any heavy metals and chlorides which are present in the water are released to the sea.

This technology has not been considered an option for Vales Point due to the environmental sensitivity of Lake Macquarie (i.e., it may require discharge of seawater to the ocean).

6.5 SOx Removal Efficiency for Pollution Abatement Technologies

The main FGD technologies are compared in Table 6.1 below:

Table 6.1: Removal efficiencies for SOx Pollution Control Technologies

Technology	DRY	SEMI-DRY	WET	SEAWATER
Removal Efficiency	Furnace sorbent injection SO ₂ 30-50%, 70-80% by recycling the reaction product. Duct sorbent injection SO ₂ 70-80% with sodium-based sorbent and bagfilter	SO ₂ 85-92% SO ₃ >99% For S in fuel >3%, removal efficiency decreases	Limestone scrubber SO ₂ 92-99.5%	SO ₂ 90-98%

A Wet FGD system would achieve the highest removal efficiency and therefore, represents the best technology that is available with regards to SOx removal efficiency. However, the high-water consumption for this technology, given the limited supplies on the Central Coast, is an important consideration and may not be considered the optimal solution.

7. SOx Pollution Control Technology Comparative Costs

The potential emission reduction for the Vales Point 2 x 660MW units and the associated indicative CAPEX and OPEX with the retrofitting installation of the specified SOx mitigation technologies are provided in Table 7.1.

The costs are stated in Australian dollars, have been factored for Australian conditions and based on operational hours of 8000 hours/year per unit.

Table 7.1: SO_x Pollution Control Technology Indicative CAPEX and OPEX for 600MW unit

AREA	DRY	SEMI-DRY (3)	WET (3)	SEAWATER (4)
Capital Expenditure	Furnace Sorbent Injection A\$ 35-50 m (1)	Spray Dry A\$ 100-310 m	Wet Limestone Scrubber A\$ 200-365 m	A\$ 150-275 m
Operating and Maintenance Expenditure (5)	A\$ 15 - 20 m /year (1)	A\$ 5 - 8 m /year	A\$ 4 - 8 m /year	A\$ 3 - 5 m /year
Energy Use	0.1-0.17 MW	8.3 MW	8 MW	8-9 MW
Reagent Use	34,000 Tonne/year	23,600 Tonne/year (lime)	28,600 Tonne/year (lime) (2)	Not required
Residue Generation	28,500 Tonne/year Reacted product (Na ₂ SO ₄) & unreacted sorbent (excludes flyash)	53,700Tonne/year	44,200 Tonne/year Gypsum is produced and may either be sold to third parties or landfilled.	None
Water Consumption	Not required.	1,050 Megalitres/year	1,500 Megalitres/year	No treated water required
(1) Capex & Opex based on sodium-based sorbent (\$260/Tonne), 70% removal efficiency with bagfilter. Lower capital cost due to simplicity and adaptability in retrofitting but lower SO ₂ removal efficiency. (2) Lime commonly used in early plants for its better reactivity with SO ₂ . Lime has since been replaced with limestone to reduce the risk of lime calcination, which is energy intensive, costly and time consuming to repair. (3) U.S. Environmental Protection Agency, Air Pollution Control Cost Estimation Spreadsheet, For Wet and Dry Scrubbers May 2021 (4) Environmental Progress Vol.22, No.1 April 2003, Table 4 (5) Opex does not include operational labour, assumes disposal to ash dam, and is highly dependent on reagent, fresh water, and electricity costs				

Most of the FGD systems installed in USA are Wet FGD (lime and limestone) and Semi-Dry FGD (Lime). Indicative pricing for the other options is limited or not available.

Retrofit Capex costs can vary significantly between sites and will depend on such factors as space limitations, major modifications to existing equipment (e.g., ductwork and stack) and the operation conditions of the units. There is thus also a lot of variability in the published costs for the retrofitting of the flue gas desulfurisation equipment.

8. SO_x Control Feasibility at Vales Point

With the supply of low sulfur Coals (<1.0% by wt) to Vales point Power utility, the requirement for advanced post combustion SO_x emission control equipment is mitigated to a large extent.

There is the incentive for Delta to consider reducing the Load Based Licensing (LBL) fees associated with lower SO_x emissions. The projected fees up to end of life in 2029 are set out in the Table 8.1 below.

Table 8.1: LBL Fee associated with SO_x emissions

Year	Coal Generation U5&U6 (GWh)	Tonne SO _x /GWh (1)	Total U5&U6 SO _x (tonnes)	LBL FEE SO _x (tonnes)	Total U5&U6 LBL Fee (\$)
FY 22	6,922	2.50	17,305	11.58	200,392
FY 23	6,624	2.97	19,673	11.82	232,538
FY 24	6,485	2.97	19,260	12.07	232,474
FY 25	6,226	2.97	18,491	12.07	223,189
FY 26	6,228	2.97	18,497	12.07	223,261
FY 27	5,973	2.97	17,740	12.07	214,120
FY 28	6,079	2.97	18,055	12.07	217,919
FY 29	5,512	2.97	16,371	12.07	197,594
Total	50,049	2.27	145,392	11.98	1,741,486
(1) For FY 22, the average SO _x emission of 667 mg/Nm ³ is based on 3.4% S in the coal. For FY23-29, the average emission of SO _x 785 mg/Nm ³ is based on 4.0% average S in the mixed coal. Refer Table 4.1 for S in coal averages.					

The key mitigation of SO_x emission at Vales Point Power Station is the sourcing and combustion of low sulfur containing coals from local mines. The listed SO_x mitigation or control measures options in Table 6.1 are not considered feasible primarily due to the total estimated costs for retrofitting these technologies far outweighing the saving in LBL (Load Base Licensing) fees that can be achieved. These prohibitively high capex cost options to mitigate SO_x cannot be accommodated by a utility nearing the end of its life. In addition, the 8-9MW additional auxiliary power load per unit for the more efficient SO_x abatement technologies would increase the CO₂ intensity of generation. This would equate to an additional 8 Tonne/hour of CO₂ emissions per unit, or 300,000 tCO₂ over the remaining lifetime⁵.

This Capex expenditure is also not considered warranted, considering the level of impact the power station has on ambient air quality in the region, which was extensively evaluated in the Vales Point Power Station - EPL 761 Licence Variation Application Extension of Group 5 NO_x Emission Limit Exemption' report – Delta, Sept 2015. A more recent 2019 study also found that 1-hour average concentrations of SO₂ were significantly below the criterion level.⁶ This shows that additional SO_x control measures are not required for Vales Point Power Station in order to meet ambient air quality regulations.

9. Conclusion

Considering the good ambient air conditions, the relatively short remaining time to the forecast closure date, and the SO₂ emissions concentrations from VPPS which consistently meet EPA limits; no additional SO_x abatement technology is considered feasible for implementation at Vales Point Power Station.

⁵ Based on 0.9 tCO₂/MWh emissions intensity

⁶ Lake Macquarie – Wyong Review of Annual Ambient Air Quality Data 2019 – Delta Electricity & Origin Energy, by Todoroski Air Services