15 October 2021

Department of Planning, Industry and Environment
Locked Bag 5022
PARRAMATTA NSW 2150
Via Email: Stephen.ODonoghue@planning.nsw.gov.au

Dear Steve,

RE: NARRABRI UNDERGROUND MINE STAGE 3 EXTENSION PROJECT – GREENHOUSE GAS ADDITIONAL INFORMATION

We refer to the advice from the Department of Planning, Industry and Environment (DPIE) regarding the Narrabri Underground Mine Stage 3 Extension Project provided to Narrabri Coal Operations Pty Ltd (NCOPL) on 22 September 2021.

This response has been prepared to address the request for additional information regarding the:

- Greenhouse Gas Emission Forecast (GGEF);
- Amended Greenhouse Gas Calculations; and
- Abatement Technology Assessment.

Six requests for information (RFIs) were provided by DPIE in their letter dated 22 September 2021. Responses to RFIs 1, 2 and 4 to 6 are provided in Attachment 1, and a response to RFI 3 is provided separately below.

RFI 3

DPIE stated:

> *does the introduction of mine ventilation air to goaf gases at the longwall face present a risk of underground explosion in any part of the Project area? Does this risk exist regardless of whether drained goaf gas is flared? If so, please report on these risks (including the affected part/s of the Project area) and how they would be managed to the satisfaction of the NSW Resources Regulator;*

Response

The introduction of ventilation to goaf gases at the longwall can present a risk of underground explosion if not controlled. For an explosion to occur, the minimum concentration of oxygen is 12% and a methane range of 5 – 14.5% is required and an ignition source must be present. The risk of explosive gas concentrations occurring in the goaf does exist if appropriate controls are not implemented. This risk can still be present with or without potential goaf gas flaring, except that flaring does introduce a potential ignition source that is connected to the goaf via gas pipelines and boreholes.

When attempting to flare low concentrations of methane, the ability to maintain a constant flow of gas is highly desirable as sudden changes in flow can cause difficulties in managing the flame. When dealing with higher methane content, the ability to manage changes in flow is considered less problematic as the gas compositions (in particular, the oxygen percentage) remain well outside of the explosive range. A relatively consistent composition gas stream is also required to maintain the safety at the mine. A major risk associated with the combustion of methane gas when flaring is associated with the amount of oxygen contained within the gas stream. As the goaf contains a high amount of oxygen, that high oxygen content is also transferred through the gas stream making flaring of goaf gases extremely difficult.

Theoretically, the risk of explosive gas concentrations can occur anywhere where there is a source of methane. As the methane composition increases in the Stage 3 Project area compared to the operating area of the existing mine, the risk of explosive gas concentrations occurring does also slightly increase. The mitigation measures described in Section 2.3.4 of the EIS are proposed to address this risk.

The mine actively manages the goaf to attempt to mitigate the presence of oxygen within the goaf and any potential explosive concentrations. This is done through an extensive real time gas monitoring network throughout the whole mine as well as testing of gas samples through the site's gas chromatograph. Some control measures that are already utilised at the mine include:

- reducing ventilation quantities if the longwall is down for an extended period of time;
- installing rocsil (or the like) foam plugs behind the longwall within the goafed main gate roadway to limit the path for ventilation air behind the shields; and
- injection of nitrogen from the onsite nitrogen plant into the goaf to displace oxygen and injection of nitrogen firefighting foam (or the like) to limit ventilation paths.

In addition, the Narrabri Mine must manage the risk of explosion under obligations in the *Work Health and Safety Act 2011*, *Work Health and Safety Regulations 2017*, *Work Health and Safety (Mines and Petroleum sites) Act 2013* and *Work Health and Safety (Mines and Petroleum sites) Regulations 2014*. This requires the Narrabri Mine to develop Principal Hazard Management plans, Principal control plans and other documents, conduct risk assessments to identify appropriate controls and comply with specific requirements within the legislation.

Other Residual Matters

Attachment 1 includes responses to RFI's 4 and 5. Further to Attachment 1, additional detail regarding the applicable approval pathways is provided below.

As noted in Section 3.3.3 of the Amendment Report, NCOPL would prepare and implement a Research Program for the Project that will consider, among other things, enrichment of methane content in gas streams to be burnt by flaring or power generation of gas with low methane content (less than 30% methane) and use of VAM at relatively low methane contents (0.2% to 0.5% methane).

The responses to the RFI prepared by Palaris (Attachment 1) provides preliminary commentary on current and emerging technologies which would be further considered as part of the Research Program. The approval pathway of any measures identified via the Research Program would depend on the final recommendation of the Research Program (i.e. the type of equipment needed, footprint and any secondary impacts). However, considering the types of options identified by Palaris, it is expected that they may be either "generally in accordance" with any development consent granted for the Project or would be "substantially the same" and require a modification of any development consent. NCOPL would consult with DPIE through the Research Program, including identification of appropriate approval pathways for the recommended greenhouse abatement technology prior to its implementation.

Further to the matters raised in the DPIE letter, DPIE also requested a comparison of the Stage 3 Project Scope 1 greenhouse gas emissions against other underground coal mines. This comparison is provided in Table 1.

Table 1
Comparison of Scope 1 Emissions per ROM Tonne of Coal

Project	Scope 1 Emissions Per Tonne ROM Coal (t CO_{2-e}/t ROM coal)	Source
Narrabri Stage 3 Project	0.16	Jacobs (2021)[1].
Russell Vale Underground Expansion	0.813	Environmental Resources Management Australia (2013)[2]
Tahmoor South Project	0.585	Development Consent SSD 8445
Integra Coal Mine	0.346	Jacobs (2017)[3]
Ensham Life of Mine Extension Project	0.162	Idemitsu Resources Australia (2021)[4]
Dendrobium Mine Extension Project	0.198	Ramboll Pty Ltd (2019)[5]
Newstan Colliery	0.164	GHD (2018)[6]
Maxwell Project	0.067	Independent Planning Commission NSW (2020)[7]

[1] Jacobs Group (Australia) Pty Limited (2021) *Air Quality and Greenhouse Gas Assessment Response to Submissions.*

[2] Environmental Resources Management Australia Pty Ltd (2013) *NRE No.1 Colliery Project Application (09_0013) Environmental Assessment.*

[3] Jacobs Group (Australia) Pty Limited (2017) *Integra Underground Mine Modifications Air Quality and Greenhouse Gas Assessment.*

[4] Idemitsu Resources Australia (2021) *Ensham Life of Mine Extension Project Environmental Impact Statement.*

[5] Ramboll Pty Ltd (2019) *Dendrobium Mine – Plan for the Future: Coal for Steelmaking Air Quality and Greenhouse Gas Assessment.*

[6] GHD (2018) *Newstan Colliery Development Consent Modification Environmental Assessment.*

[7] Independent Planning Commission NSW (2020) *Maxwell Underground Coal Mine Project SSD-9526 Statement of Reasons for Decision.*

We trust this meets your immediate requirements; please don't hesitate to contact me should you have any queries.

Yours sincerely,

David Ellwood
Director NCO Stage 3 Project

ATTACHMENT 1

NARRABRI UNDERGROUND MINE STAGE 3 EXTENSION PROJECT
GREENHOUSE GAS BENCHMARKING

palaris

Report Final

Narrabri Underground Stage 3 Extension Project GHG Abatement Benchmarking

Client	Whitehaven Coal
Site	Narrabri Mine Stage 3 Extension Project
Date	14 Oct 2021
Doc No.	WHC5976-01

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Version Management

Process	Name	Date	Version
Author	Felipe Palominos	11 Oct 2021	1
Peer Review By	Mark Blanch John Pala	12 Oct 2021 12 Oct 2021	4 5
Draft Issued To	David Ellwood	12 Oct 2021	6
Final Review By	John Pala	14 Oct 2021	7
Final Issued To	David Ellwood	14 Oct 2021	11

Contents

EXECUTIVE SUMMARY

The purpose of this engagement is to provide input in response to a request for information (RFI) from the Department of Planning, Industry and Environment (DPIE) in relation to the Narrabri Underground Mine Stage 3 Extension Project (the Project). The RFI items addressed by Palaris refer to opportunities for the mine to reduce its carbon footprint during mining of the Project.

The following conclusions were reached:

- Currently, one mine in Australia is flaring mine gas at concentrations of <30% methane. There is however an approved mine expansion that is exploring alternatives that will enable flaring concentrations of 15 – 20% methane. The mine is investigating enrichment technologies to increase the gas concentrations
- No specific examples of flaring low methane concentration goaf gas independently have been found
- Narrabri Mine has at times reduced gas seam gas content levels below 3.5 cubic metres per tonne (m^3/t), albeit inconsistently. Other mines with more favourable conditions (higher seam permeability and gas saturation levels) consistently reduce seam gas contents to between 2 and 3.5 m^3/t. An audit of current pre and post gas drainage practices at Narrabri Mine is proposed with the aim of identifying opportunities to consistently deliver gas pre-drainage recovery rates in the order of 60 – 80%
- Other opportunities to further reduce return airway gas levels requiring further investigation are identified as:
  - Pre-drain gate roads as well as longwall blocks
  - Pre-drainage of seams adjacent to the working seam
  - Optimisation of near face, deep goaf, and adjacent goaf gas production rates
- Theoretically, coal seam stimulation methods offer the opportunity to increase gas production rates, for a given borehole spacing and lead time, and potentially lower remaining gas content levels to < 3.5 m^3/t. They are however yet to be proven on a mine wide scale in the underground coal industry and recent efforts are less than encouraging:
  - A nitrogen injection trial undertaken in circa 2009 in the Bowen Basin reportedly improved gas production rates but failed to lower gas content levels below those normally achieved
  - Recent hydraulic fracture trials aimed at enhancing seam permeability and in-turn gas drainage rates have delivered mixed results:
    - In the southern coalfields an underground hydraulic fracture (FRAC) trial undertaken in 2020 failed to consistently place FRACs due to borehole integrity and packer failure
    - A surface based, indirect FRAC trial in the Bowen Basin earlier this year successfully placed the FRAC but saw no discernible increase in gas production rates

- Gas separation and enrichment technologies exist and are widely used in oil & gas and landfill industries. These include Pressure Swing Absorption, Amine Gas Sweetening and Membrane Separation Technology. None of these technologies are currently being used in the Australian underground coal mining industry. Membrane Separation appears most compatible with Narrabri Mine surface gas plant infrastructure and the need for modular units. A concept level simulation assuming a gas feed of 1,200 litres per second (l/s) of 10%-40% methane indicates application of a two-stage membrane would deliver 358 l/s of 63% methane, more than adequate for flaring. A comprehensive study of each technology is proposed to determine the best technical and commercially viable option for the Project
- There are currently no active applications of ventilation air methane (VAM) technology in underground coal mines within Australia. This technology was previously successfully used in the Southern Coalfields at a site with an operating range of 0.3 – 1.0% methane. For the Project, considering the likely low levels of methane in the mine return (< 0.3%) and the technical challenges of maintaining the Regenerative Thermal Oxidizer's (RTO) self-sustaining process temperature, as well as the high capital and operating cost, the installation of VAM equipment alone is potentially uneconomic

1 RFI ITEMS

Palaris have been engaged to assist with responses following a request for information (RFI) from the Department of Planning, Industry and Environment (DPIE). The items in the RFI are as follows:

1. Are there any underground coal mines in Australia where pre-mining gas drainage containing <30% methane is flared? If so, please report on the technologies and practices in place at these mines
2. Are there any underground coal mines in Australia where goaf gas drainage containing a) <20% and b) <15% methane is flared? If so, please report on the technologies and practices in place at these mines
3. Does the introduction of mine ventilation air to goaf gases at the longwall face present a risk of underground explosion in any part of the Project area? Does the risk exist regardless of whether drained goaf gas is flared? If so, please report on these risks and how they would be managed to the satisfaction of the NSW Resources Regulator
4. What technologies might be applied a) now or b) at some future part of the Project life in order to increase the amount of seam gas that can be effectively pre-drained (i.e., residual gas content to less than 3.5 m^3/t). Please report on these technologies, including whether NCOPL considers that they would be likely to require an amendment to the development application (or modification to any development consent) in order to be implemented
5. What technologies might be applied either a) now or b) at some future part of the Project life in order to safely flare drained goaf gas. Please report in detail on these technologies including whether NCOPL considers that they would be likely to require an amendment to the development application
6. Are there any UG coal mines in Australia where the relatively low methane content within mine ventilation air (VAM) is combusted? If so, please report on which mines, whether these are in pilot, demonstration or large-scale operations, what proportion of their VAM is combusted, capex and opex costs and resultant GHGE mitigation

The limits of the engagement for Palaris excluded RFI item #3 and it will be addressed by NCOPL. In addition, the elements of items #4 and #5 relating to approval requirements have been left for Approvals Specialists. It is understood that NCOPL will separately address these items.

2 INPUT FOR RFI

2.1 RFI Item #1 and RFI Item #2

1. Are there any underground coal mines in Australia where pre-mining gas drainage containing <30% methane is flared? If so, please report on the technologies and practices in place at these mines

2. Are there any underground coal mines in Australia where goaf gas drainage containing a) <20% and b) <15% methane is flared? If so, please report on the technologies and practices in place at these mines

The flaring of methane gas via enclosed flares is applied at many NSW and QLD underground mines. Additionally, in Queensland, the practice of flaring methane gas is also applied using open flaring (candle stick flares). The flaring of gas is applied to both pre-drainage and goaf gas with pre-drainage gas normally offering higher concentrations of methane.

It must be noted that at some mines both the pre-drainage and goaf gas is combined into a common underground gas drainage reticulated pipe range and then the gas is extracted to the surface via a common borehole, thus creating a combined mixture of goaf and pre-drainage gas for flaring.

Other operations have the ability, via surface land access, to drill specific pre-drainage surface to seam boreholes (SIS) to specifically drain pre-drainage gas and have separate goaf drainage boreholes to extract goaf gas. Typically, these mines have dedicated surface reticulated gas pipe ranges with the ability to blend gases for either flaring or power generation.

The gas composition and, in particular, concentration of methane gas and oxygen are critical design criteria for a flare manufacture along with gas flow. When sizing a flare and determining the gas composition operating range, the gas nozzle tip pressure and gas mixing velocity ratios must be carefully considered. This becomes even more critical as the levels of methane reduce and the presence of oxygen exists. Figure 2.1 provides an overview of the explosion triangle which is thoroughly considered by flare designers when designing flares for low concentrations of methane.

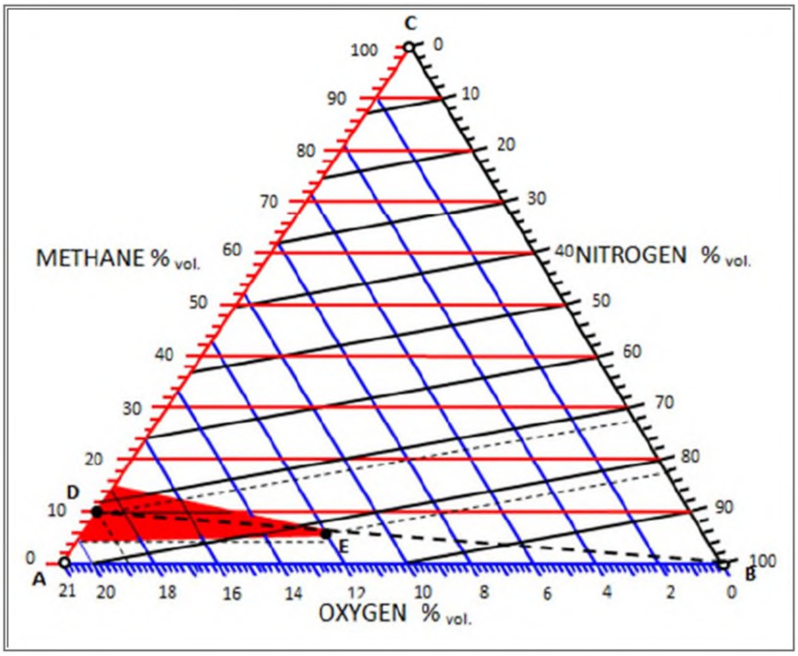


Figure 2.1 Explosive Triangle Flaring (Courtesy Hofstetter)

The explosive triangle indicates an area where gas mixtures become unstable, the lower the concentration of methane and the higher levels of oxygen present create an undesirable condition for the operation of a flare.

Typically, oxygen sensors are installed to detect the presence of oxygen and shut the flare down if they become too high. A typical oxygen shutdown figure for a mobile flare (capacity up to 1,000 l/s) operating with 25% methane would be 5% to ensure the red zone is not encroached and safety margins are maintained.

Within the Australian coal mining industry, it is uncommon for mines to flare when methane contents are less than 30% (using fixed flares), this is primarily due to the inability to maintain a stable atmosphere with fluctuating flows and composition.

A summary of Australian coal mines with flares installed is shown in Figure 2.2, with the typical approximate methane gas operating ranges for each mine shown in respect to the Narrabri Mine. The Project's methane gas operating range is at the lower end of the current industry practices for flaring.

Flaring of Methane Gas in Australian Coal Industry							Gas Utilisation Details
Narrabri	★						Currently free venting
Mine 2				★			Combined goaf & predrainage, power generation & flaring
Mine 3		★					Combined goaf & predrainage, power generation & flaring
Mine 4	★						Recently approved mine extension forecast operating range
Mine 5						★	Combined goaf & predrainage, power generation & flaring
Mine 6					★		Combined goaf only, power generation & flaring
Mine 7							Currently Not Flaring
Mine 8				★			Combined goaf & predrainage, power generation & flaring
Mine 9			★				Goaf and Pre-drainage, flaring only
Mine 10							Currently Not Flaring
Mine 11					★		Combined goaf & predrainage, power generation & flaring
Mine 12					★		Combined goaf & predrainage, flaring only
Mine 13						★	Combined goaf & predrainage, flaring only
Mine 14					★		Combined goaf & predrainage, flaring only with off take 3rd party
Mine 15					★		Combined goaf & predrainage, flaring only with off take 3rd party
Mine 16				★			Combined goaf & predrainage, flaring only
Mine 17							Currently Not Flaring
CH_4%	0-20%	20-30%	30-40%	40 - 60%	60 - 80%	80 - 100%	Operating CH_4 Range for each mine

Figure 2.2 Australian Mines Gas Flaring Summary

Mine 3 and Mine 4 show the closest alignment to the Narrabri Mine.

Mine 3 is currently flaring at low methane compositions predominantly ranging from 25 – 30%. This is possible as the mine has the ability to adjust the “turn down ratio” of their flares and by replacing the burner nozzles can burn the gas conventionally at 25% methane.

Mine 4 is exploring alternatives to assist with flaring at such low concentrations, including methane enrichment technologies, similar to those described in section 2.3.

The forecast methane gas concentration over the Project life is predicted to range between 10% to 40% methane. On this basis, it is considered that flaring could occur at concentrations of 25% methane or above, with the correct technologies (as seen in section 2.3) and low levels of oxygen in the gas mixture (as described in Figure 2.1).

In summary, currently, one mine in Australia is flaring mine gas at concentrations of <30% methane. There is however an approved mine expansion that is exploring alternatives that will enable flaring concentrations of 15 – 20% methane by investigating enrichment technologies to increase the gas concentrations at the flare.

2.2 RFI Item #4

4. What technologies might be applied a) now or b) at some future part of the Project life in order to increase the amount of seam gas that can be effectively pre-drained (i.e., residual gas content to less than 3.5 m^3/t). Please report on these technologies, including whether NCOPL considers that they would be likely to require an amendment to the development application (or modification to any development consent) in order to be implemented

2.2.1 Gas Reservoir and Gas Deliverability (Recovery)

The gas recovery from a coal seam pre-drainage is affected by a number of gas reservoir parameters, primarily:

- Gas saturation
- Seam permeability

Additionally, gas recovery rates will be dependent on time available for pre-drainage, borehole spacing and management practices. With greater time available for gas pre-drainage, it is more likely that the reservoir pressure will approach atmospheric pressure, resulting in maximum gas recovery.

From conceptual modelling, in-seam boreholes at a 20 m spacing for a range of permeability, gas composition, corresponding saturation levels and seam thickness suggest that it is possible to reduce seam gas contents from 5.5 m^3/t to less than 3.5 m^3/t given the appropriate conditions. An example from the modelling (Figure 2.3) assuming permeabilities of 1 millidarcy (mD) and 10 mD result in remaining gas contents of 1.6 m^3/t and 4.1 m^3/t, respectively. The parameters employed are indicative of the situation at the current operation.

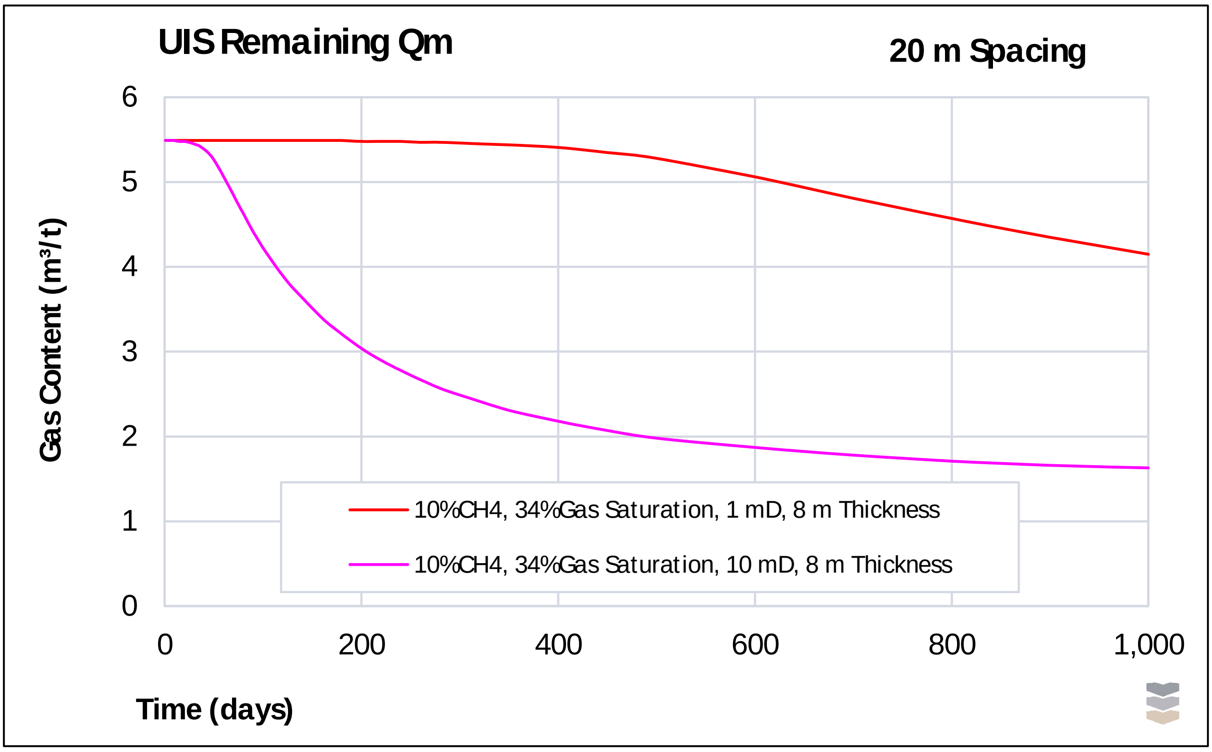


Figure 2.3 - Example of Conceptual Modelling Results

i. Gas Saturation

Gas saturation is defined as the measured gas content of the seam at a given point, expressed as a percentage of the quantity of gas that could be stored by the coal at the specific pressure, temperature and ash defined by the adsorption isotherm for that location (Figure 2.4).

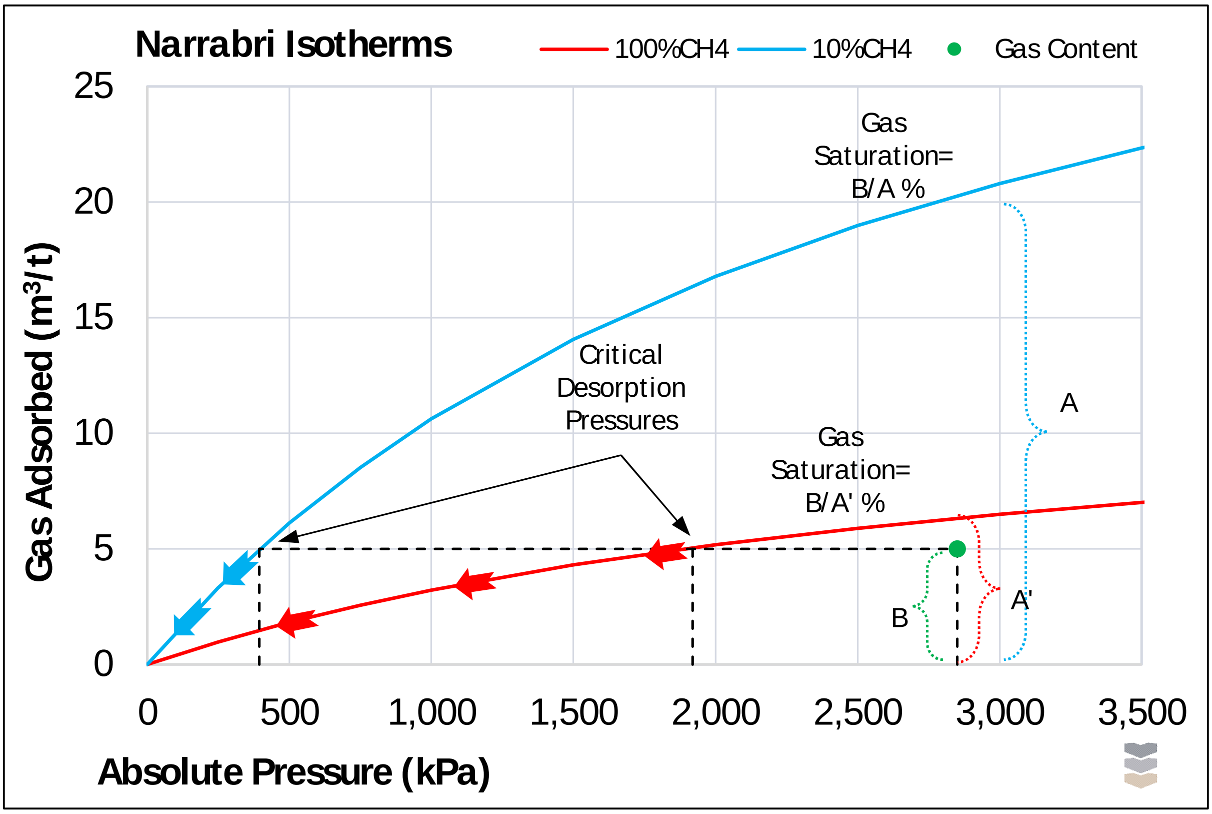


Figure 2.4 - Narrabri Isotherms

Gas drainage is particularly sensitive to gas saturation and gas desorption pressure. Seams with gas saturation levels of greater than 70% are mostly readily drainable given favourable permeability combined with appropriate time and borehole spacing. Increasing levels of CO_2 generally correlate with decreasing saturation levels due to the CO_2 sorption characteristic of coal relative to methane (Palaris, 2020). Gas desorption will not commence until reservoir pressure is reduced to critical desorption pressure.

Gas saturation levels for the Project range between 25 – 45%, which are similar to the values encountered in the current mining domain (Figure 2.5). These low saturation levels are likely to negatively impact the drainability of the Hoskisson (HSK) Seam.

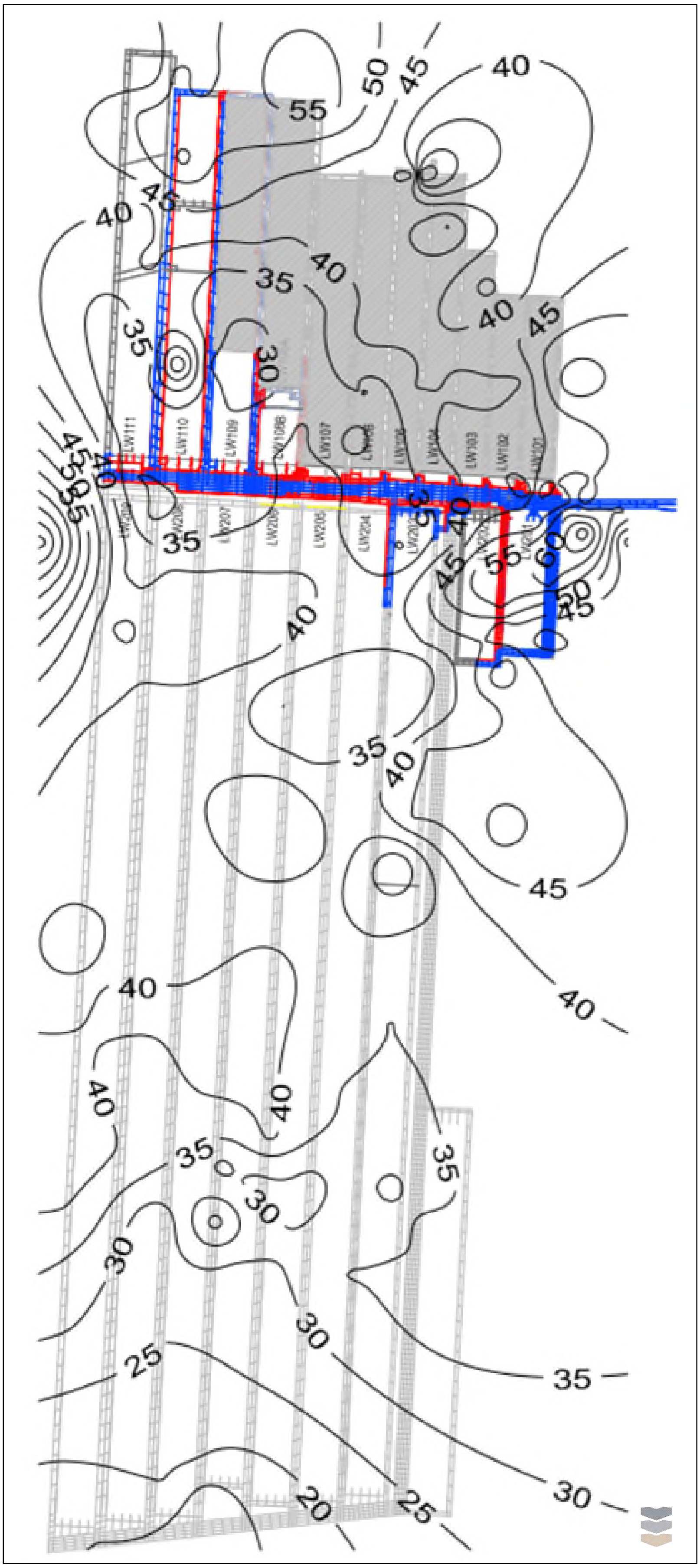


Figure 2.5 – Narrabri Saturation Levels

ii. Permeability

Permeability is a measure of the coal seam and its capacity to allow the movement of gas and fluids through it. High permeability will allow gas and fluids to move through the coal more rapidly. In coal, it is primarily defined by the cleat system, and it is measured in millidarcies (mD). The main factors affecting the permeability of coal include:

- The nature and extent of cleat development and mineralisation of the cleat system
- The Young's Modulus of the coal and imposed stresses

Limited data of the HSK Seam exists for the Project. A total of four permeability tests have been carried out within the northern portion of the 200 series longwalls.

Measurements of seam permeability at the Project are sparse relative to the variability, with no correlation of permeability with seam depth (Figure 2.6). Measured data suggests that HSK Seam permeability in the 200 series longwalls is in the same range as that experienced in the northern longwalls (1 - 23 mD comparted to 1 – 38 mD).

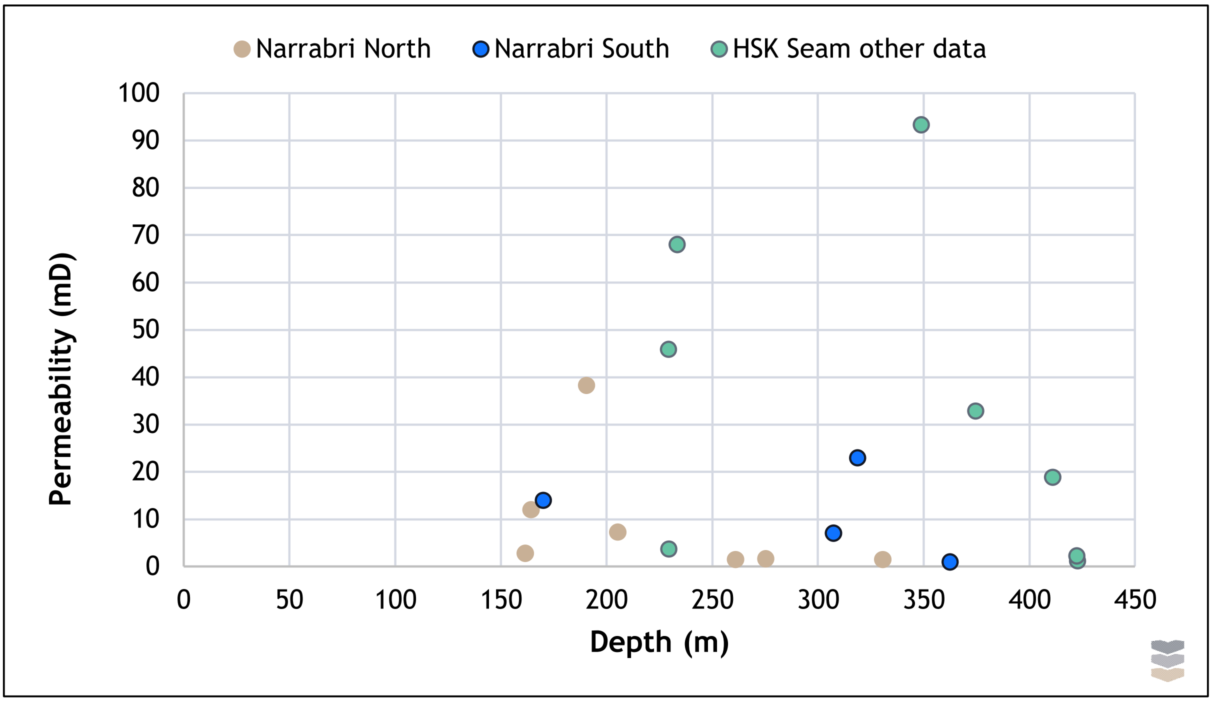


Figure 2.6 - Permeability vs Depth of Cover - Narrabri and the HSK Seam

iii. Gas Reservoir Drainability Benchmarking

Gas drainage rates are a function of gas saturation, permeability, and seam thickness. In order to provide perspective of the drainability of the Hoskissons Seam in the Project area, a comparison with other operating underground coal mines in Australia has been developed.

Rankings are a function of weighting of each the key deliverability parameters, with 35% applied to gas saturation, 50% to seam permeability and 15% to seam thickness. These weightings are based on Palaris' experience in gas drainage performance assessment and modelling. It is arguably subjective and simplistic, particularly given the complex interaction of each of these parameters on gas drainability.

Each mine was then rated from 1 to 10 according to the respective seam characteristics. The Project ranks at the lower end of the scale for the mines assessed due to a combination of low saturation, relatively low permeability and a thick – banded seam (Figure 2.7).

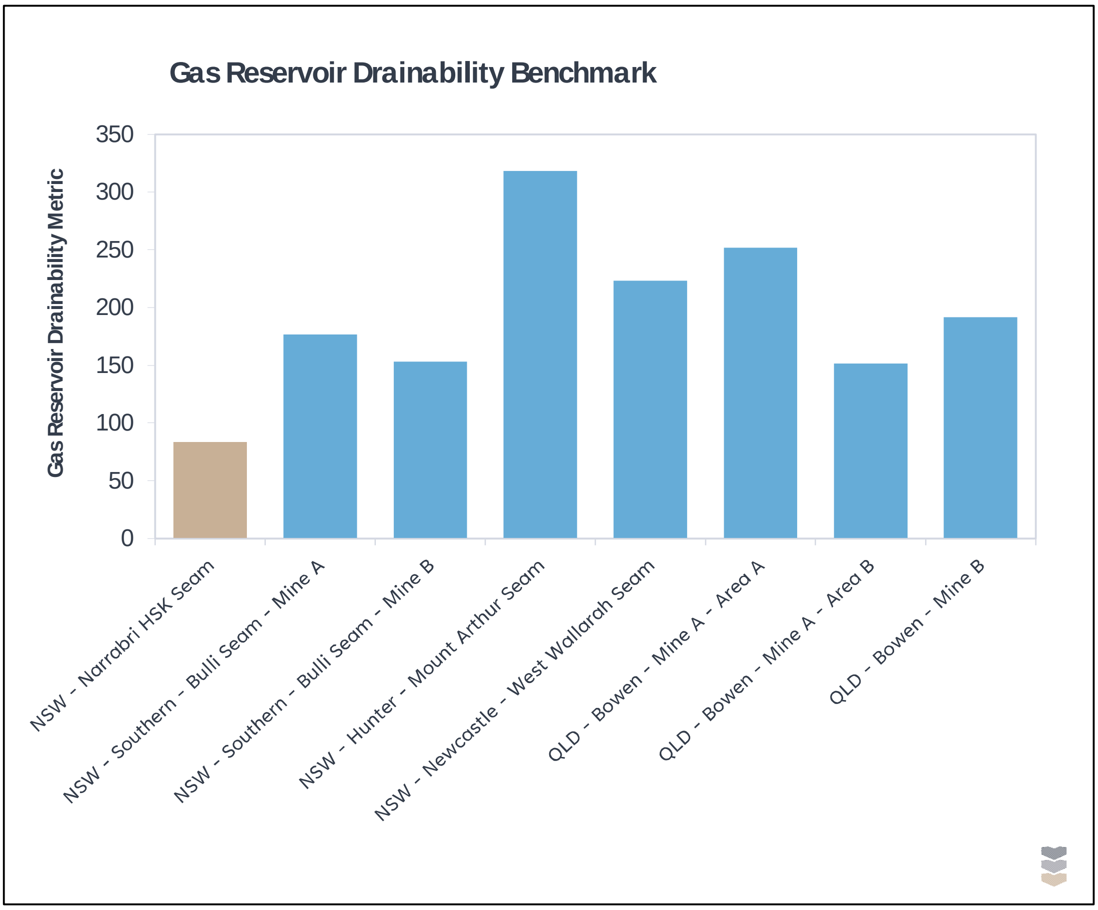


Figure 2.7 – Gas Reservoir Drainability Benchmark

2.2.2 Gas Drainage Practices

Assessing gas content data across the currently operating Longwall 109 at the Narrabri Mine indicates a wide range of gas drainage performance with seam gas content being reduced to between 2.5 – 7.8 m^3/t, for an average of 4.9 m^3/t. Gas recovery rates are quite different along the length of the panel, ranging from 0 - 23% for an average of 13% for almost half of the panel. For the remaining half of the panel, recovery rates are significantly better, ranging from 54 - 74%, for an average of 65%.

Table 2.1 shows that the HSK seam can be a difficult seam to pre-drain, with variances in gas recovery attributable to reservoir conditions, borehole spacing, lead time, borehole managements standards, or a combination of all.

An ongoing detailed investigation is required to better understand pre-drainage performance and in-turn improve future pre-drainage outcomes.

Table 2.1 Compliance Core Data and Drainage Time Estimate for Longwall 109

Horizon	Core #1 Date	Core #2 Date	Drainage Time (Days)	Core #1 Content (m^3/t)	Core #2 Content (m^3/t)	Gas Content Reduction (%)	Hole Spacing	Perm
Upper	27/04/17	19/11/18	571	5.71	5.69	0	20	~1.5
Upper	21/11/17	17/05/19	542	5.38	4.54	0	20	~1.5
Upper	18/8/17	05/05/19	625	5.81	5.23	16	20	~1.5
Upper	18/6/17	17/01/19	578	7.07	5.60	23	20	~1.5
Upper	10/10/18	12/02/19	125	8.97	7.63	10	7.5	~1.5
Upper	03/10/18	16/12/19	439	9.32	3.06	9	5	~1.5
Upper	15/10/18	14/12/19	425	9.61	2.76	21	5	~1.5
Upper	15/12/17	14/12/19	729	9.73	2.52	14	5	~1.5
Upper	21/11/17	22/04/18	152	10.20	7.82	15	5	~1.5
Lower	02/05/17	19/11/18	566	5.61	5.60	16	20	~1.5
Lower	21/11/17	17/05/19	542	5.66	4.34	67	20	~1.5
Lower	18/08/17	05/05/19	625	5.88	5.35	54	20	~1.5
Lower	19/06/17	17/01/19	577	5.70	4.88	71	20	~1.5
Lower	09/10/18	12/02/19	126	9.16	7.69	74	7.5	~1.5
Lower	3/10/18	17/12/19	440	9.18	4.19	74	5	~1.5
Lower	13/10/18	16/12/19	429	9.90	2.59	60	5	~1.5
Lower	14/12/17	14/12/19	730	9.39	3.72	23	5	~1.5
Lower	21/01/18	22/04/18	91	10.74	4.96	54	5	~1.5

Drill pattern optimisation is an important area of gas drainage practices. Areas of focus for the Project may include:

- Design drill patterns to target gate roads as well as longwall blocks
- Pre-drainage of seams adjacent to the working seam for additional pre-drainage gas capture

2.2.3 Future Gas Pre-drainage Technologies

Technologies that could potentially be tested in the future to improve the efficiency of pre-drainage include:

- Nitrogen (N) injection
- Hydraulic Fracturing

It is imperative to point out that these technologies are experimental for underground coal and would require testing and trialling prior to implementation.

i. Nitrogen Injection

Nitrogen injection is a strategy for enhanced recovery where nitrogen (or other gases) is injected into the coal seam and acts to stimulate diffusion of the methane component of the gas through partial pressure differences (Puri and Yee, 1990). Injecting a gas into the reservoir, also increases reservoir pressure, thus increasing the rate of drainage (Packham et.al, 2012).

The method was trialled in Queensland, between 2009 – 2010, at a site with methane as the predominant seam gas. The injection trial indicated that accelerated drainage rates were achieved through the injection of nitrogen. Results showed that residual gas contents below atmospheric pressure (as per the isotherm) could not be achieved.

It is unknown if this technology has been tested in mines with high CO_2 concentrations, such as the Narrabri Mine. The introduction of Nitrogen injection at the Project would require a detailed investigation.

ii. Hydraulic Fracturing

Hydraulic fracturing is a method used to enhance gas production from wells by means of injecting a fluid under pressure into the coal seam so as to open up the cleat network, enhance seam permeability and in-turn gas delivery. These fractures are maintained operational by injecting a solid material such as sand into them. This material is known as a proppant.

Hydraulic fracturing has been trialled in a number of underground coal mines in Australia with generally poor results (Table 2.2). It appears as though stimulation of coal seams at depths greater than ~300 m can be problematic, due to borehole integrity, leading to leakage around the packers used to isolate the fracture sites.

Table 2.2 Summary of Hydraulic Fracturing Trials in Australia

Site	Depth of Cover (if known)	Results
Haenke Colliery, QLD, 1980	N/A	No fractures were successfully created
Central Colliery, QLD, 1996	N/A	No fractures were successfully created
Dartbrook Colliery, NSW, 2002	N/A	Successful initiation of fractures and increased gas production

Site	Depth of Cover (if known)	Results
Tahmoor Colliery, NSW,2005	500 m	High stress conditions caused borehole breakout, resulting in the failure of the trial due to the inability to effectively set the packers
Appin Colliery, NSW, 2007	500 m	Mixed results from 2 boreholes. One achieved a gas production rate more than double that recorded prior to the treatment, the second hole recorded a reduced flow following the treatment
Oaky #1 Colliery, QLD, 2005	N/A	Some increase in gas flow shown, not to the expected magnitude and not sustained
Dendrobium Mine, NSW, 2019	300 – 400 m	Sand stimulation trial completed with inconclusive results
Goonyella Middle Seam Mine, Bowen Basin, 2021	350 m	Indirect stimulation of the working seam from SIS wells underlying the seam. FRAC successfully placed. No discernible change in gas production rates

Whilst hydraulic fracturing has to date been flagged as an option for coal mines with seams identified as having low to ultra-low permeability (< 1 mD), its application at the Project could result in decreased lead times, or increased gas production for the same borehole spacing.

2.3 RFI Item #5

5. What technologies might be applied either a) now or b) at some future part of the Project life in order to safely flare drained goaf gas. Please report in detail on these technologies including whether NCOPL considers that they would be likely to require an amendment to the development application

2.3.1 Flaring of Low Methane Concentration Goaf Gas

For the purposes of this section, low methane goaf gas has been defined as less than 20% methane. A survey of the Australian coal industry identified no specific examples of flaring low methane concentration goaf gas independently. As previously stated, examples of goaf gas being blended with higher methane concentrations of pre-drainage gas existed at several mines.

2.3.2 Technologies Available

The flaring of low methane concentration gas occurs in several industry sectors such as landfill, biogas and oil and gas industries, however, as discussed in section 2.1 of this report, careful consideration must be given to the oxygen levels present when low methane concentrations exist. None of these technologies are currently employed in Australia in the underground coal mining industry.

An accepted practice for significantly reducing risks associated with flaring of low concentration methane gas is known as “Gas Enrichment”, this process involves the separation of the methane gas component from the total gas composition and then flaring predominately the portion of available methane gas.

The three main processes used for gas enrichment include:

i. Pressure Swing Absorption

There are several molecular sieves that process the physical characteristics to adsorb CO_2 and H_2S from natural gas. These desiccants are generally used for Pressure Swing Adsorption systems consisting of two or more towers. While one tower is on-line adsorbing sour gases from the feed gas, the other tower is being regenerated. The towers are switched just before the on-line tower becomes fully saturated with sour gases. This system has an advantage in that its molecular sieve is non-toxic, non-corrosive, and can be selective to the desired gases. An example of a small-scale pressure swing module is shown in Figure 2.8.

Figure 2.8 – Small Scale Pressure Swing Module

ii. Amine Gas Sweetening

The raw gas enters the primary tower and rises through the descending amine solution. The purified gas flows from the top of the tower, the amine solution carrying the absorbed acid gases leaves the bottom of the tower and travels to the heat exchanger. The amine is then heated releasing the acid gases (CO_2, H_2S) and replenishes the amine solution. Figure 2.9 summarises the amine enrichment process.

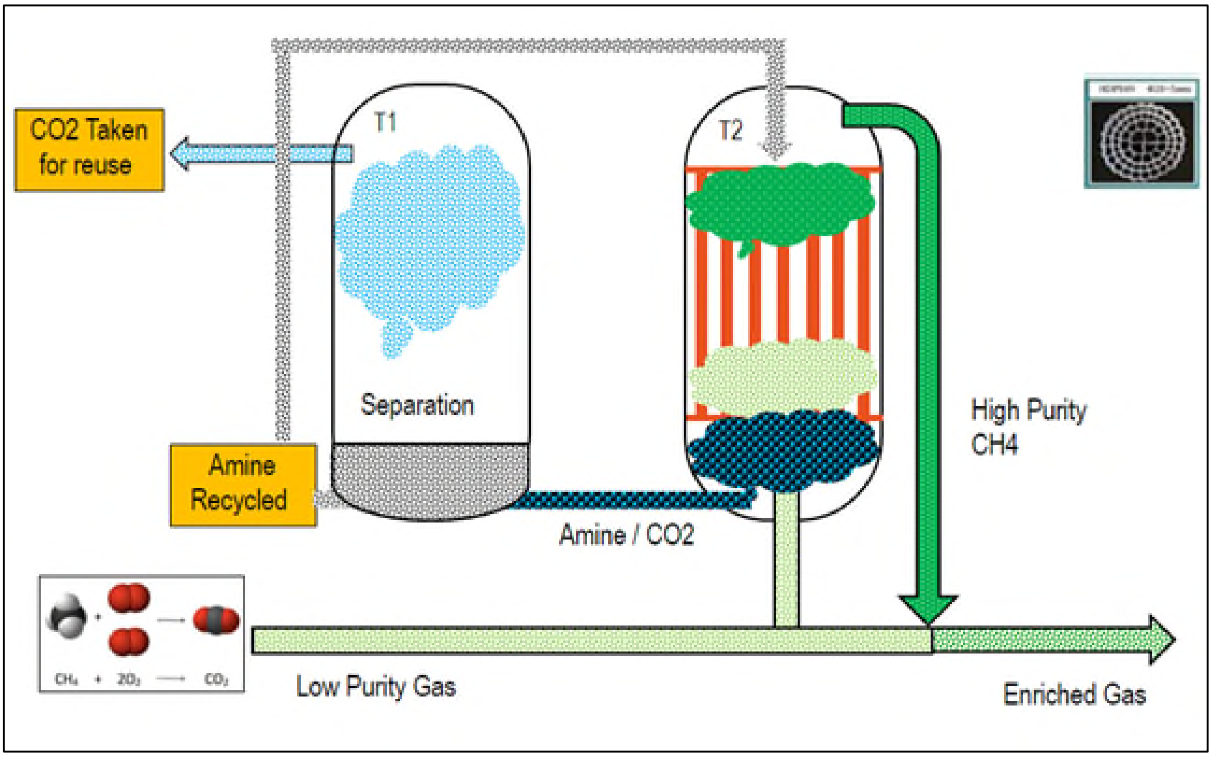


Figure 2.9 – Amine Gas Enrichment Process

iii. Gas Enrichment Using Membrane Separation Technology

Membrane separation technology has been deployed in industrial applications for the reliable separation of gases for the past 30 years and the technology has continually evolved over time. The process involves injecting a gas composition into a series of hollow membrane fibre tubes specifically designed to contain certain gas molecules and allows others to pass through the tube as shown in Figure 2.10 below.

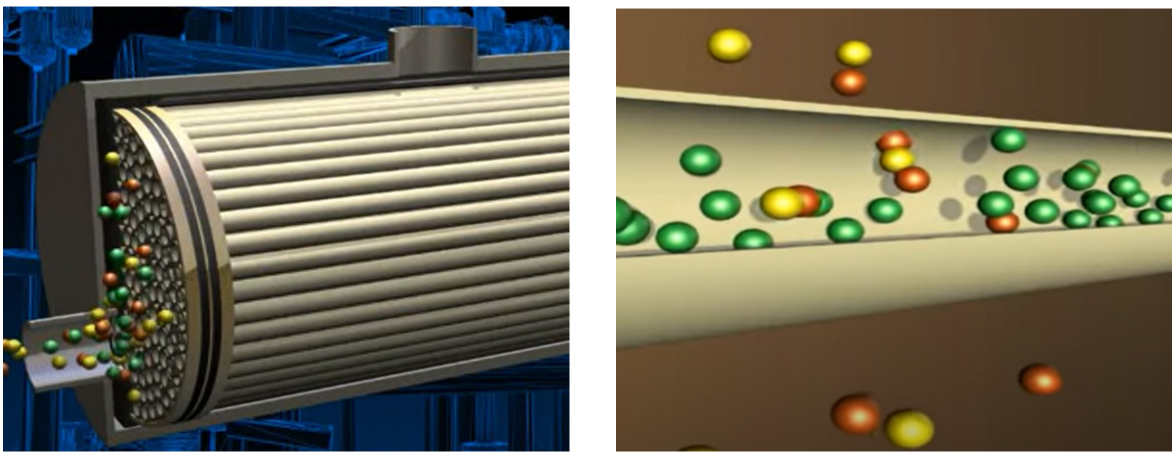


Figure 2.10 - Gas Molecule Separation

The waste gas is allowed to exit the membrane housing via the waste gas port and the process gas exits the end of the membrane housing via the process gas port as show in Figure 2.11 below.

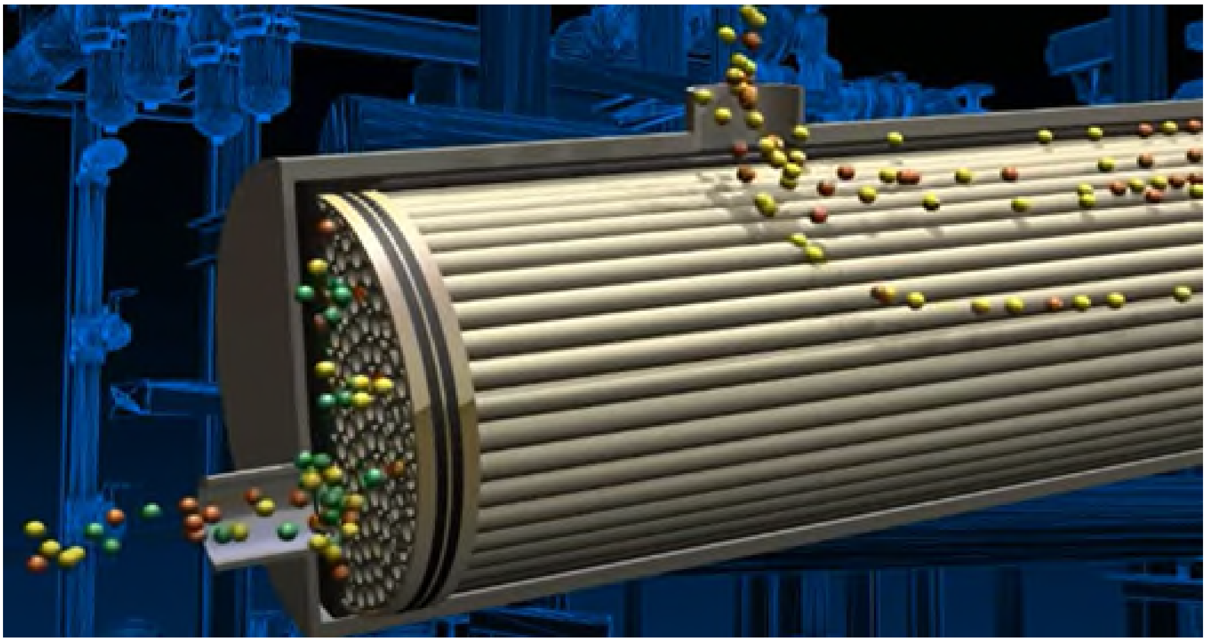


Figure 2.11 – Waste Gas Exiting Membrane Housing

Gas separation membrane modules are built for several industries to be easily relocated the image below in Figure 2.12 shows a gas separation skid configured to separate CO_2 from a gas flow of 2,000 l/s.

Figure 2.12 – Two Stage Gas Separation Module (Courtesy WGR/Generon)

The gas separation process can be summarised into four main groups being:

- Gas extraction and pressurisation
- Gas treatment and conditioning (if applicable)
- Gas separation
- Gas processing and flaring

This technology is the most applicable to the Project. A concept layout for a gas separation module has been developed which could be deployed at the Project due to its ability to be easily relocated.

2.3.3 Existing Narrabri Gas Extraction Process

Presently, Narrabri Mine has several mobile gas extraction units known as (MEU's), of which, two basic designs exist:

- 200 kilowatts (kW), equivalent to 2000 l/s
- 150 kW equivalent to 1500 l/s

The units are powered by diesel generators due to their deployment in remote locations and are positioned in a manner to extract gas from both pre-drainage and goaf inseam boreholes. The gas is extracted from underground via the MEU's and discharged to atmosphere, as shown in Figure 2.13.

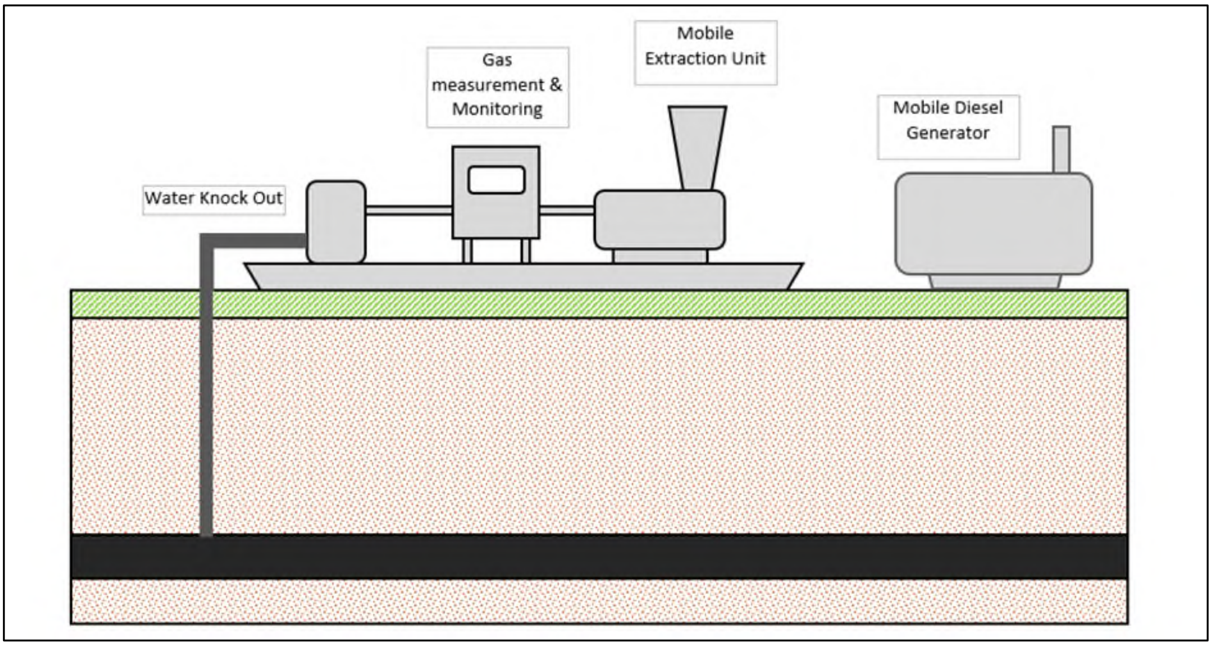


Figure 2.13 – General Configuration MEU Arrangement

These systems have been deployed successfully for many years now at the Narrabri Mine, with all gas currently discharged directly to atmosphere (i.e., vented).

2.3.4 Concept Plant for Gas Enrichment Membrane Separation

i. Plant Configuration and Layout

A likely configuration for the Narrabri site due to the requirement to relocate the equipment from site to site would require a "Plug & Play" module format and would likely consist of:

1. Current MEU skids
2. Gas compression and separation skid
3. Mobile flare
4. Gas / Diesel genset

A conceptual layout for the process is shown in Figure 2.14 and a conceptual use of the equipment, leap frogging MEU's is shown in Figure 2.15.

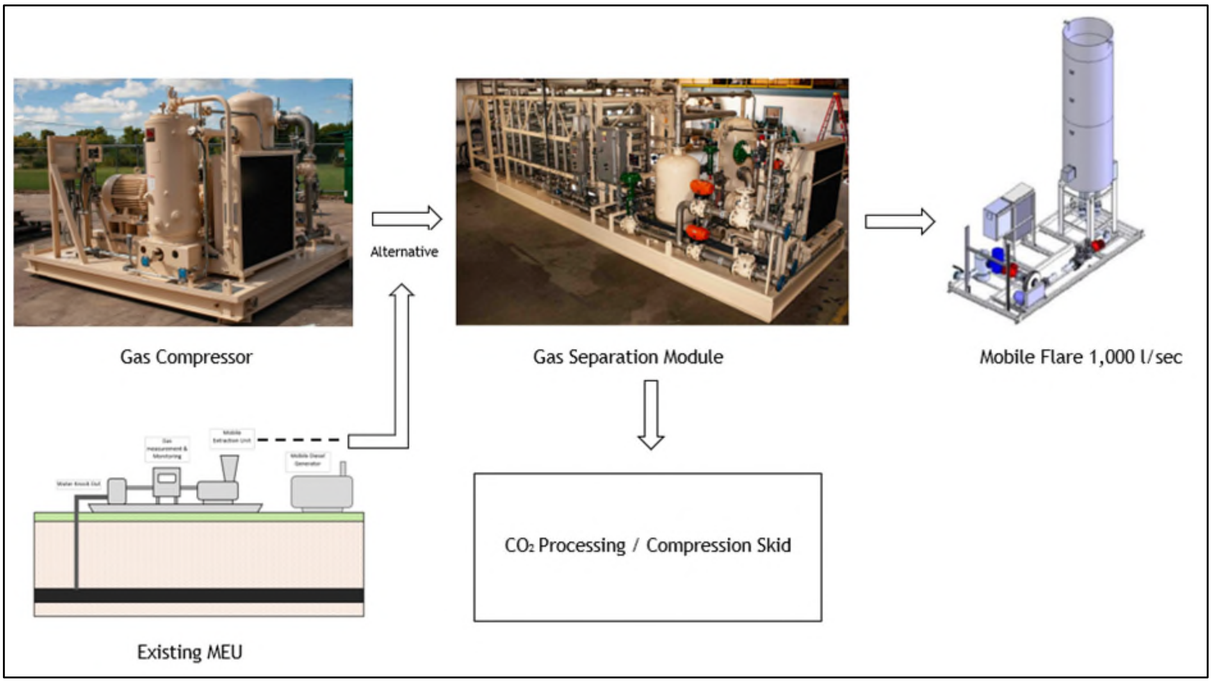


Figure 2.14 – Conceptual Process Layout

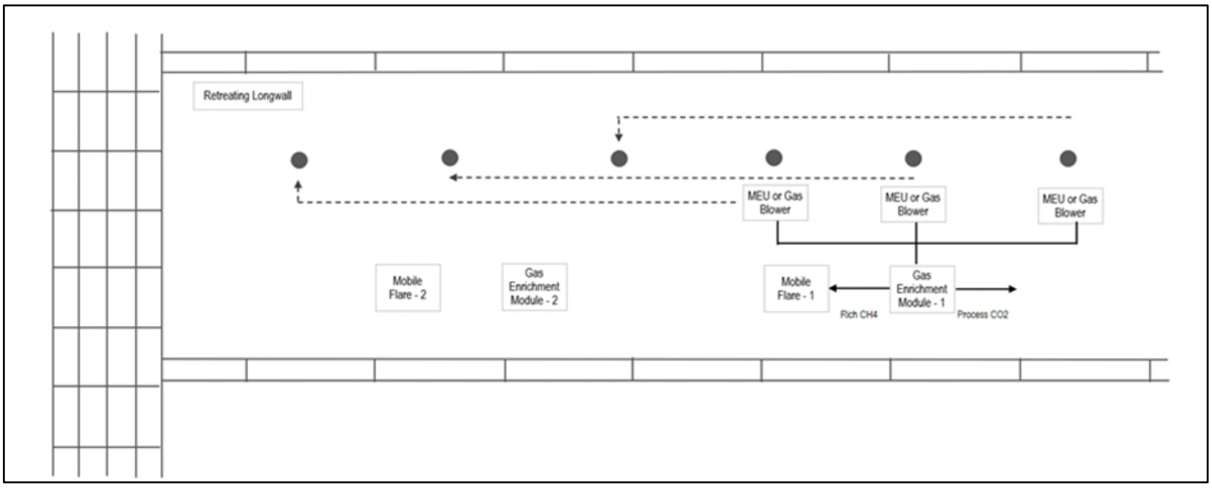


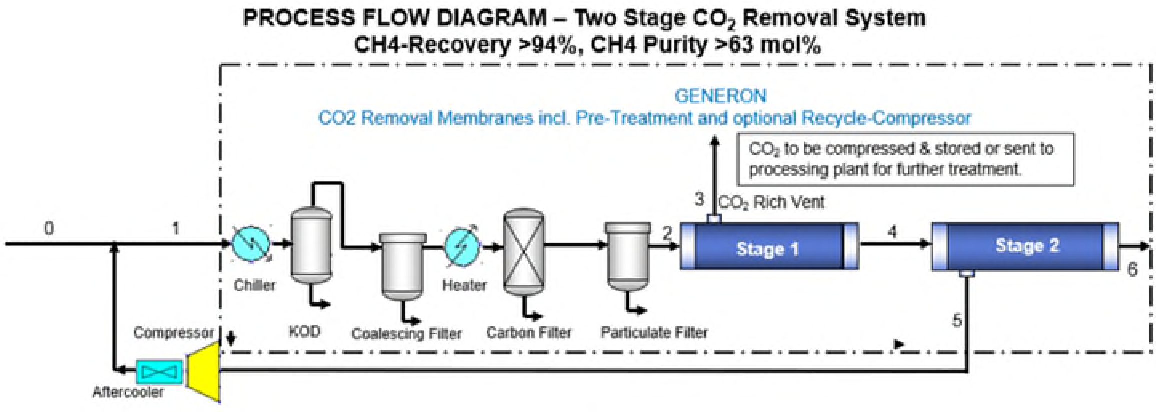
Figure 2.15 – Conceptual Advancing Modular System

ii. Gas Separation Simulation

The predicted methane concentration for the Project has been nominated as 10% - 40% methane. Using this forecast, a simulation was completed with a base case gas flow rate of 1,200 l/s.

The simulation results are shown in Figure 2.16 and concluded using a two-stage membrane separation process 358 l/s of 63% methane would be achieved being adequate for flaring. Further simulations using a three-stage system may deliver a higher purity of methane (approximately 77%).

The high CO_2 purity levels enable the use of the CO_2 for several industrial commercial applications or further treatment would enable further use for the CO_2.



Stream #	0	1	2	3	4	5	6
Description	Raw Feed	Raw Feed + Recycle	Compressed 1st Stage Membrane Feed	1st Stage Permeate Stream	2nd Stage Membrane Feed	2nd-Stage Membrane Perm/Recycle	Product
Flow [SCFM]	2543	3590	3590	1785	1805	1047	758
Pressure [psig]	120.0	120.0	110.0	0.0	100.6	0.3	97.4
Temperature [°F]	68	68	68	68	61.8	61.8	54.3
CH4	20.00	15.60	15.60	1.51	29.54	4.93	63.54
CO2	75.00	80.48	80.48	98.15	63.02	93.80	20.47
N2	5.00	3.91	3.91	0.34	7.45	1.27	15.98
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

**all compositions in Mole Percent*

Figure 2.16 – Process Flow Diagram. Two Stage CO_2 Removal System

2.3.5 Application in Coal Industry

Although gas enrichment technology would be deemed new technology for the Australian coal industry, the process has been proven in other industrial applications, including oil & gas, which has a similar risk profile to the coal industry.

A gap analysis will be required to determine what areas would need to be addressed to ensure a successful transition to meet the compliance requirements of the NSW coal sector. Several suppliers in the USA are supplying equipment into the Australian oil & gas and landfill sectors.

2.3.6 Additional Alternatives

Due to the nature of the mining activities (advancing development and retreating longwall) and the need for modular easily deployed technology, the gas membrane technology would be suitable for the Project.

Other technologies such as Pressure Swing Absorption and Amine Treatment would require a more comprehensive study (for each technology) to determine the best technical and commercially viable option for the Project. However, it is highly likely a solution for low methane gas flaring could be identified for further consideration.

Equally, given the current nature of the technologies in underground coal mining, a small-scale industry demonstration plant could be trialled initially to both prove the concept and quantify the economies of scale. The feasibility of such a trial and subsequent implementation would need to be assessed.

2.4 RFI Item #6

6. Are there any UG coal mines in Australia where the relatively low methane content within mine ventilation air (VAM) is combusted? If so, please report on which mines, whether these are in pilot, demonstration or large-scale operations, what proportion of their VAM is combusted, capex and opex costs and resultant GHGE mitigation

2.4.1 Status of Technology Use in Australia

There are currently no active applications of VAM technology in underground coal mines within Australia. The potential future application of VAM abatement technology in Australia is more challenging than the mature high concentration gas drainage and gas destruction technologies, primarily due to safety risks associated with integration of highly variable ventilation air methane (CH_4) concentrations at large volumetric flow rates with VAM abatement and utilisation equipment. Significant industry research and development effort has been directed towards addressing these integration challenges over recent years.

Palaris is aware of research completed by the University of Newcastle (UON) as part of the Australian Coal Association Low Emissions Technologies Ltd (ACALET)/Commonwealth Coal Mining Abatement Technology Support Package (CMATSP) VAM Abatement Safety Project. The publicly available outcomes of this study are, however, limited to laboratory and small pilot scale research of methane and coal dust ignition. Significant effort is still required to complete the original stated objectives of this project at mine scale.

Other barriers to adoption and deployment of the VAM technology include relatively higher initial capital cost, higher operating costs in both absolute and per CO_2-e tonne abated terms, and large land requirements as demonstrated in Section 2.4.3.

While other VAM abatement technologies such as the CSIRO based VAMCAT and VAMIT have been trialled at pilot scale in NSW, the Vocsidizer™ Regenerative Thermal Oxidizer (RTO) by Megtec/Durr is currently the most developmentally advanced VAM treatment equipment. The operating principles of RTO technology in application to VAM are summarised by Kallstrand (2019) and involves an exothermic oxidation of low concentrations of methane to form carbon dioxide and water vapour. The balance of fuel energy in, energy recovered, and energy exhausted is, however, fundamental to the stable operation of any commercially available RTO technology.

The fluid nature of VAM input parameters highlights several fundamental design principles and advantages of the Vocsidizer™ Regenerative Thermal Oxidizer (RTO) by Megtec/Durr for application to surface based VAM abatement plant:

- Modular and (hence) scalable
- Packaged to minimise site interfaces and services connections

- Relocatable / transportable (within reason)

Proprietary computational fluid dynamics (CFD) models incorporating complex thermodynamic mass and energy balances are used during detailed design phase to optimise the RTO configuration to suit each installation's specific range and distribution of methane concentration. RTO design parameters such as bed cross sectional area, bed height, bed thermal media type, size, and granularity, and bed insulation material properties and thickness, all have an important role in optimal energy balance and, hence determine the lowest possible self-sustaining stable operating concentration.

At concentrations from 0.20% to 0.5% methane, it is economically and technically more efficient to install VAM abatement only equipment without energy recovery. This is to conserve energy within the process chamber and maintain self-sustaining operating temperatures for VAM oxidation. Subject to the site-specific design optimisation described above, the plant is sized by simply dividing the total flow by the capacity of an abatement cube.

At concentrations from 0.50% to 0.8% methane, it is economically and technically more efficient to install VAM abatement equipment with energy recovery. The plant is still sized by dividing the total flow by the capacity of an abatement cube, but the amount of energy recovered reliably is a complex function of methane concentration (fuel energy input) variability and energy exhausted over time. For this reason, drainage gas support is preferred for energy recovery installations to stabilise input fuel conditions.

For short term VAM concentrations above 0.8% methane, it is generally economically and technically more efficient to utilise the fresh-air dilution control, which is included in any standard RTO installation, to temporarily limit fuel energy input and allow some VAM to bypass the RTO unabated. Longer term VAM concentrations above 0.8% methane, are technically treated through the installation of additional VAM abatement cubes and utilising the fresh-air dilution control on all available cubes on a more permanent basis.

However, literature and this study suggest that more optimal economic outcomes for cost per tonne CO2-e abated may be achieved through additional underground gas capture in these circumstances.

Table 2.3 Summary of Typical VAM Abatement Solutions vs CH_4% level

VAM Abatement Type	Low CH_4% Level	High CH_4% Level		Note
NIL Recommended	0.00%	0.19%		Insufficient fuel energy to sustain autoignition temperatures
Site specific abatement only	0.20%	0.29%		Site-specific VAM analysis and optimisation of RTO parameters required to sustain autoignition temperatures
Standard abatement only	0.30%	0.49%		RTO with standard design parameters will sustain autoignition temperatures

Standard energy recovery	0.50%	0.79%		RTO with standard energy recovery design parameters will allow both abatement and energy recovery
Site specific energy recovery	0.80%	1.25%		Dilution of VAM or additional volumetric RTO capacity may be required to prevent excessive RTO unit or exhaust temperatures and allow consistent operation with energy recovery

Considering the likely low levels of methane in the mine return (< 0.3%) and the technical challenges of maintaining the Regenerative Thermal Oxidizer's (RTO) self-sustaining process temperature, as well as the high capital and operating cost, the installation of VAM equipment alone is potentially not economical.

2.4.2 Historical Use of Technology in Australia

BHP Billiton Illawarra Coal established a VAM pilot plant at its Appin site in 2000 to trial the use of the Vocsidizer technology. The success of this pilot led to the establishment of the West Cliff Ventilation Air Methane Project (WestVAMP) at the West Cliff mine with the support of a $6M Australian Government grant under the Greenhouse Gas Abatement Program (GGAP) (Booth, 2008).

WestVAMP was the world's first commercial demonstration of Mine Ventilation Air Methane with energy recovery. The plant used the thermal energy contained in the extremely dilute methane in the ventilation air from West Cliff mine to produce steam in a conventional steam cycle configuration, and then used that steam to continuously generate approximately 5 MW of electricity. Up to 20% of the total mine ventilation air return volume of 340 - 360 m^3/s was captured via ducting placed over one mine fan evase. The total capital cost of the plant, inclusive of all steam plant and equipment, was in the order of AUD $30 M.

The general operational concept and key specifications are otherwise illustrated in Figure 2.17.

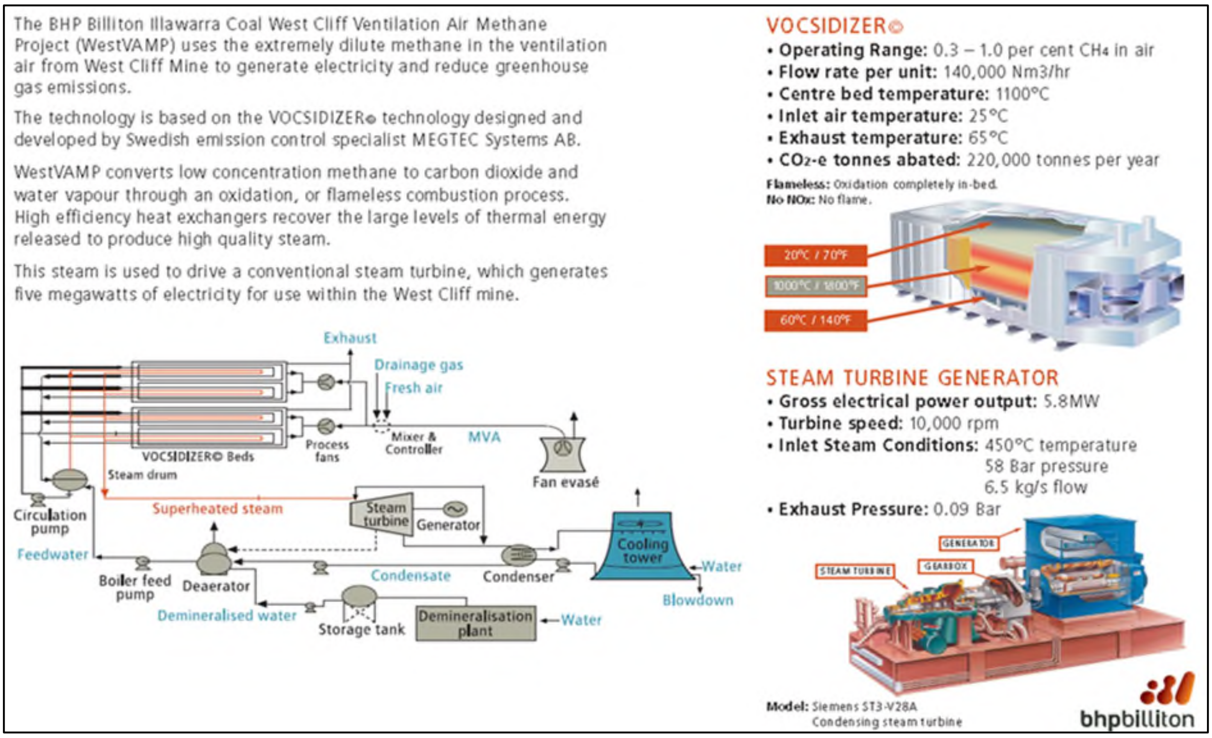


Figure 2.17 - WestVAMP Infographic at Time of Initial commissioning - (BHPB and Booth 2008)

Until decommissioning due to the extinction of West Cliff Bulli seam coal resources in 2017, the West VAMP plant routinely produced in excess of 40,000 MWh of electricity and reduced emissions by over 200,000 tonnes CO_2-e annually (Kallstrand, 2019). Key to the success of the facility, over more than 10 years of safe operation, was the ability to carefully control the fuel gas concentration to Vocsidizer units. This was achieved using either additional higher concentration drainage gas when the VAM concentration was lower than 0.5%, or additional dilution fresh air when the VAM concentration was above 0.9%. Stable fuel gas control resulted in consistent steam temperatures and volumes, hence consistency in electrical output from the steam turbine, as this was configured to operate in boiler follow operational mode.

Other historical uses of VAM as combustion air for gas utilisation include the EDL Appin power station in the 1990's, where a small proportion of the VAM from the adjacent Appin #2 shaft was trialled in the gas engines. Although the trial demonstrated improved energy performance, this was outweighed by the costs associated with VAM cleaning.

A further trial of alternate VAM-RAB technology produced by Corky's at the Centennial Mandalong Mine in the period between 2011 and 2015 were also discontinued due to fouling of the oxidation media.

2.4.3 Other Environmental Considerations of VAM Applications

Currently, the concept of four Vocsidizer™ units combined to form a 'cube', each complete with two process fans, electrical, controls and instrumentation is proposed by Megtec-Durr for supply of multiple units for abatements plants internationally. A configuration of the 'cube' concept is shown in Figure 2.18 below.

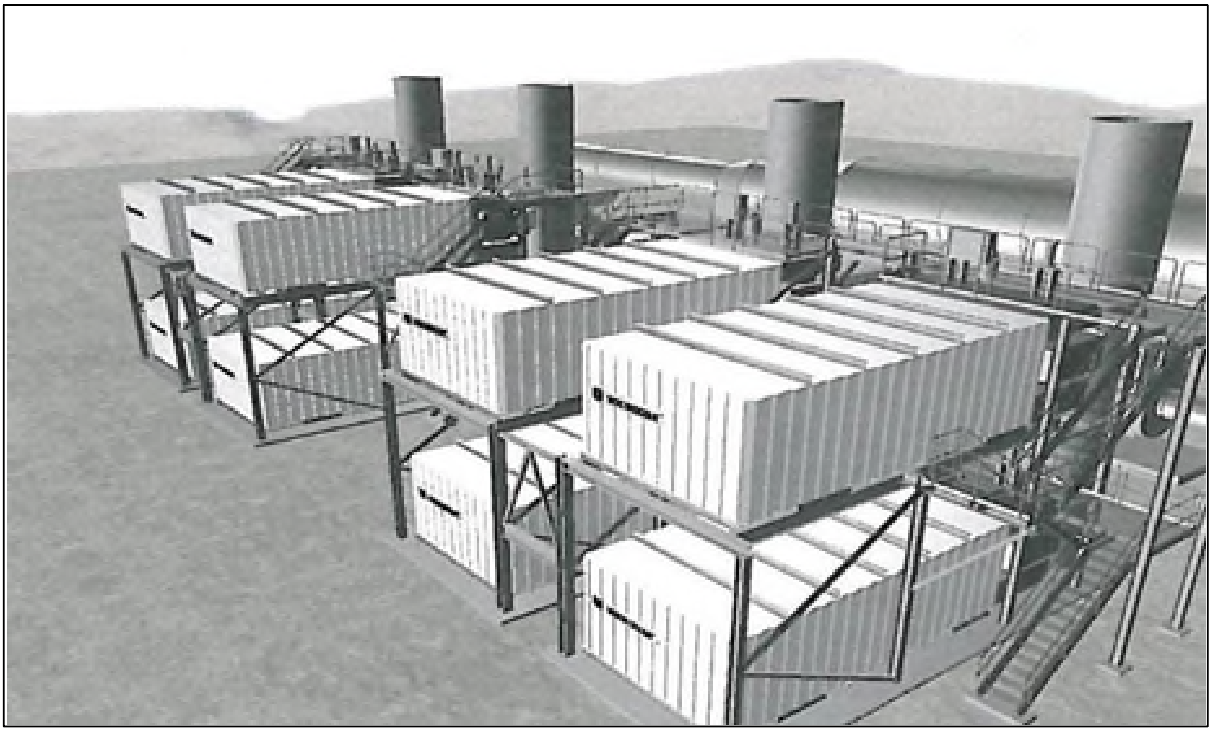


Figure 2.18 – Vocsidizer^{TM} Cube Arrangement Perspective - (Megtec Systems AB)

Each abatement cube has a volumetric flow capacity of approximately 70 m^3/s (250,000 Nm^3/hr) and has overall dimensions of 25 m x 25 m x 10 m inclusive of process air fans (2 off), inlet dampers, exhaust stack, access and supporting structure. Central VAM ducting illustrated in Figure 2.19 would typically occupy a space of 12 – 15 m inclusive of fresh-air dilution inlet. Multiple modular abatement cubes are generally arranged to access a common VAM duct connection from opposite sides. To address the total VAM flow of the order of 500 m^3/sec would occupy a land area of at least 5000 m^2.

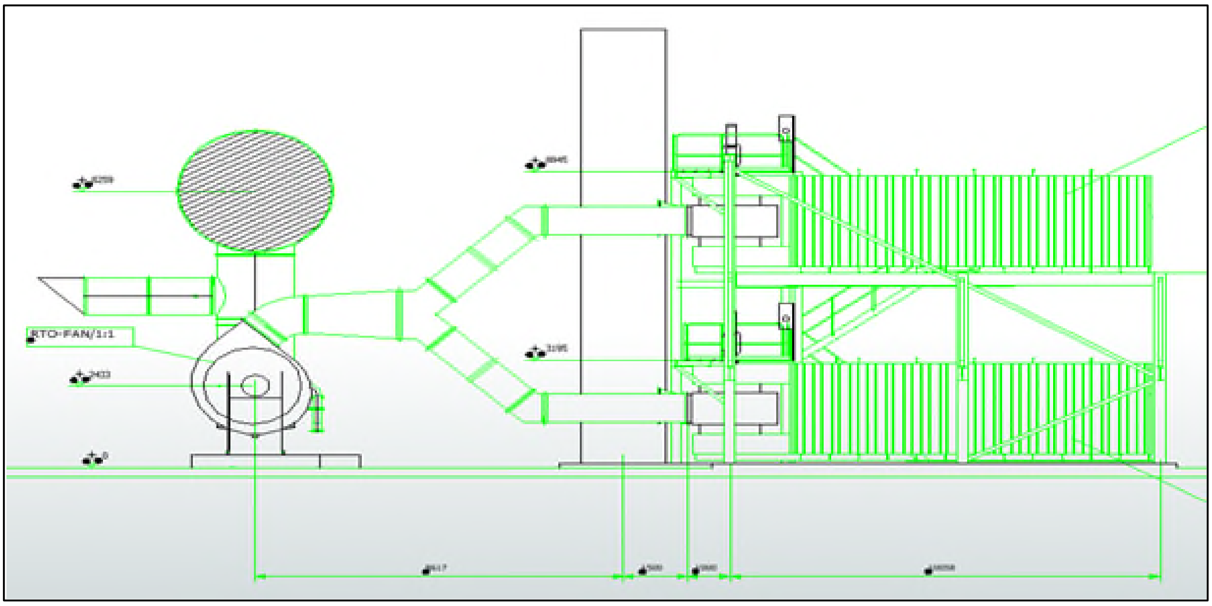


Figure 2.19 – Vocsidizer™ Cube Arrangement Section - (Megtec Systems AB)

The operational energy consumption of VAM equipment is necessarily high due to the quantity of VAM being forced through the oxidation bed. Process air fans in the above arrangement are typically sized in the range between 300 – 350 kW. It is important to consider the effect of this power consumption and effective CO_2 emission elsewhere in assessment of net overall abatement.

3 REFERENCES

Kallstrand Ake 2019, Durr – Megtec Presentation, AMM Utilisation – Low Quality Methane as Energy Source

Packham R, Connell L, Cinar Y, Moreby R, 2012 – Observations from an enhanced gas recovery field trial for coal mine gas management. Published in the International Journal of Coal Geology on 9th July 2012

Palaris 2020, Narrabri South Project – Gas Reservoir and Emission Assessment, Palaris report WHC5175

Puri R,Yee D ,1990. Enhanced coal bed methane recovery. Paper Presented at the SPE 65th Annual Technical Conference and Exhibition, New Orleans. SPE 20732