RFI - LTGA resp. to JSC Inquiry 14 March

1. **The Hon. JACQUI MUNRO:** ***"****Do you have any information about how much that abatement in those seven of eight mines would actually stop, in terms of a volume, by 2030? Or could you point us to some evidence on that?"*

   The Committee also asked for the title of the report, which is Palaris, 27 August 2021, 'Opportunities of fugitive emissions abatement' (Client: Department of Planning & Environment), obtained by LTGA via a GIPA request.

   ANSWER:

   "The principal objectives of this study were to identify potential gas drainage and VAM oxidation abatement opportunities at NSW's gassiest mines and estimate emissions reductions and associated costs. Eight operating underground coal mines and projects were selected."

   The eight mines are not named in the 2021 Palaris report, but the 8 highest emitting underground mines at FY21 in NSW were:

   1. Appin Colliery
   2. Mandalong Mine
   3. Tahmoor Coal Mine
   4. Narrabri Underground Mine
   5. Metropolitan Colliery
   6. Chain Valley Colliery
   7. Dendrobium Colliery
   8. Ashton Coal Mine

   In regard to the question of how much abatement would be possible at 7 of the 8 mines mentioned in the study, Lock the Gate directs the JSC Committee Inquiry to the following statement from NSW DCCEEW in their [NSW greenhouse gas emissions projections 2023 Methods paper]**:**

   > *Opportunities to abate fugitive emissions have been identified for NSW coal mines in recent studies commissioned by NSW Government agencies.* ***In a 2021 assessment of abatement opportunities at NSW's gassiest underground coal mines (Palaris 2021), gas drainage and VAM abatement opportunities were identified at 8 underground coal mines. The study found 80 Mt CO2-e of abatement in mines under BAU, and 110 Mt CO2-e of potential additional abatement over the life of these mines.*** *It recommended a transition to longer term emissions forecasting, mine planning and abatement, maximising CH4 gas capture and utilisation, and/or CH4 destruction through flaring. A key recommendation was for mines to pre-drain CH4 gas from coal seams as early as possible.*

2. **The CHAIR:** There's a footnote here from the Superpower Institute, which is very helpful for the Committee. I'm sure the secretariat could find it, but if you could provide that DCCEEW submission to the Safeguard Mechanism inquiry that would be very useful as well.

   ANSWER:

   Re The Superpower Institute, please see 'Groundbreaking satellite monitoring tool shows significant underestimation of methane emissions from fossil fuel sites', which is a media release published by The Superpower Institute on 9 October 2024.

   Re NSW DCCEEW's statement on on the coal-mine methane underreport issue: *"There is recent evidence that fugitive emissions from coal mining may be significantly higher than currently estimated by the industry."* NSW DCCEEW submission re Safeguard Mechanism reforms, June 2024

   Additional methane underreport statement from Reputex (mentioned in Lock the Gate's submission): *"[m]ultiple independent studies have estimated Australia's coal mine methane emissions to be significantly higher than reported, with the IEA estimating that Australia could be under-reporting coal mine methane emissions by around 90%, while other peer-reviewed studies estimate coal mine methane emissions could be 59-122% higher than reported, with open-cut mines the main source of 'missing' emissions."* Reputex (October 2024):

Report

Opportunities of fugitive emissions abatement (de-identified)

Client	Department of Planning & Environment
Site	NSW
Date	27 August 2021
Doc No.	DPE5704

palaris.com | ABN 13 093 424 867

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Version Management

	Name	Date	Version
Author	Rhys Brett, Felipe Palominos, Bob Dixon, Patrick Booth	6th April 2021	1
Peer Review By	John Pala	27th July 2021	4
Draft Issued To	Bronwyn Isaac	28th July 2021	4
Final Review By	Rhys Brett	27th August 2021	5
Final Issued To	Bronwyn Isaac	27th August 2021	5

Contents

1 KEY CONCEPTS

Fugitive emissions from mining accounted for 9.2% of the 2017-18 NSW total greenhouse gas emissions. Underground coal mines represent approximately 85% of coal mine fugitive emissions and a significant source of coal mine fugitive emissions over coming decades as shown in Figure 1.1[i]. In 2018-19 ventilation air methane (VAM) represented 67% of emissions from NSW coal mines and represents a more technically challenging abatement scenario compared with drainage gas. This emissions background resulted in the project scope equally focussing on emissions abatement through gas drainage (including flaring and power generation) and VAM.

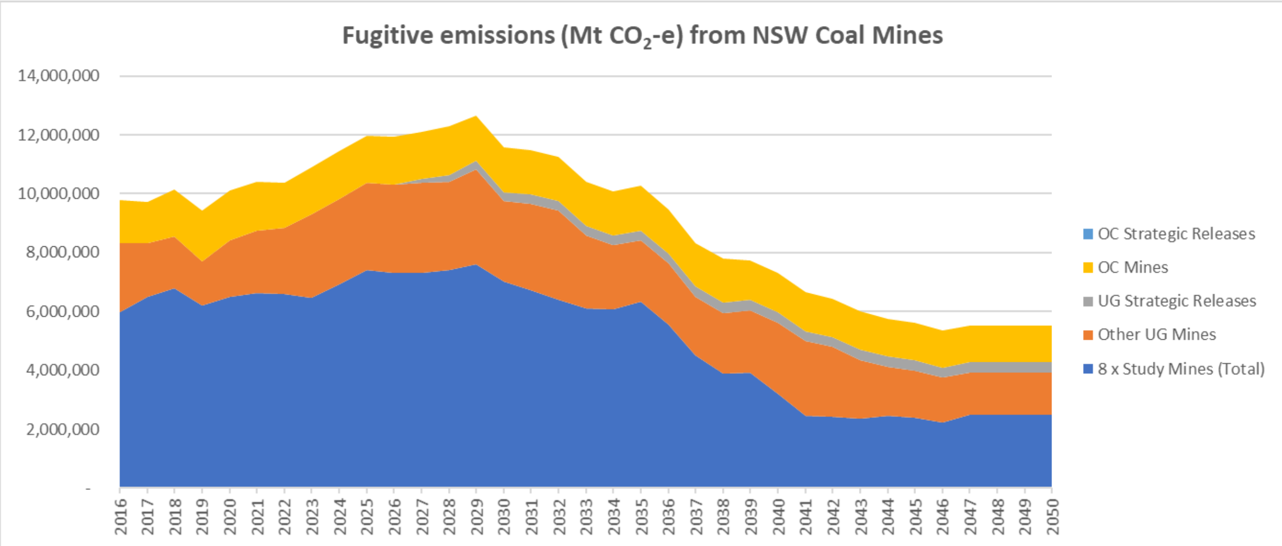

Figure 1.1 NSW Fugitive Emissions Forecast (provided by DPIE)

Gas management in underground coal mines and the associated infrastructure is highly complex and involves specialised equipment, techniques and terminology. Table **1.1** is a glossary of key terms used in this report. Further descriptions of the technology are provided in Chapter 5.

Table 1.1 Glossary of Terms

Term	Explanation
BaU	Business as usual: the current and expected operating condition for the mine
Bleeder Roadway	A roadway located behind a longwall block which receives gas from the sealed and active longwall panels
Directionally drilled	Gas drilling that has a steering motor at the end of the drill string and can be steered to a pre-determined location
DPIE	NSW Department of Planning, Industry and Environment
Flugge model	A Flugge Goaf Caving Model is a technique to estimate the extent of adjacent seam depressurisation from longwall mining
Gas Enrichment	Treatment of the gas that enables the extraction of carbon dioxide from a portion or all the gas stream therefore purifying the methane in the gas stream or increasing the percentage of methane content for gas destruction or utilisation.
Gas Reservoir size	The volume of gas contained over a specified area. Typically measured in m^3/m^2
Goaf	The area /void left after coal is extracted as a result of a mining process allowing gas to build up large concentrations.
Goaf Hole	A borehole that penetrates the goaf and enables extraction of gas to the surface where it can be destructed

Term	Explanation
High Gas Return	The use of an underground roadway which has restricted access due to high levels of carbon dioxide
Horizontal goaf holes	A type of drilling that involves drilling holes in adjacent coal seams or strata to capture gas emissions from depressurisation caused by longwall extraction
Inbye	The general working area towards the active coal face. Generally extending to a point 300m on the air intake side active working coal faces.
LOM	The time frame a mine is forecast to remain in operation before likely closure
Longwall specific gas emissions	The total gas emissions from the extraction of longwall mining. This includes the working seam and adjacent seams that are depressurised. This is measured in m^3/t
Maingate	The roadways on the side of a longwall block that typically contain the conveyor and service equipment
MEU	Mobile exhaust fans: A portable fan unit that can be placed over a goaf hole or gas extraction borehole and exhaust the mine gas to atmosphere
NGER	National Greenhouse Gas Reporting requirements nominated by the clean energy regulator
Outburst	An outburst is the sudden and violent ejection of coal, gas and rock from a coal face and surrounding strata in an underground coal mine. When outbursts occur, they can be very serious events, possibly even resulting in fatalities
Outburst thresholds	The upper limit of gas concentration in coal allowed during mining
Outbye	The roadways and tunnels extending from the surface entry to the intersection of the defined inbye locations of the mine
PDCE	Post drainage capture efficiency used to express the amount of gas captured as a result of a gas drainage process
Plies	Layers of varying coal properties within the overall coal seam
Post drainage	The drilling and drainage of gas from depressurised seams and voids after the extraction of coal
PPA	Power Purchase Agreement, an agreement between two parties (power generator and consumer) for an agreed amount of energy under an agreed pricing structure
Pre drainage	The drilling and extracting of gas from coal prior to its extraction
Rotary drilled	Gas drainage drilling that is not steered
Sealed mining areas	Mining areas that have been completed and the connecting open roadways are sealed. Gas can still be emitted from sealed mining areas through the coal and the seals
SIS	Surface in seam coal seam gas extraction: Involves boring into the coal seam from the surface. This borehole is then connected to a pipeline and under suction the gas is extracted to be utilised, destructed, or vented
STG	A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power
Tailgate	The roadways on the side of a longwall block that typically contain the return (polluted) ventilation air
UIS	Underground in seam coal gas extraction: Involves drilling directly into the coal seam from underground and extracting and capturing the majority of the gas through a range of pipelines, conveying the gas to the surface under suction to be utilised destruction or vented to atmosphere
Underground reticulation system	The system of connected pipes that is designed to remove gas from pre and post drainage to the surface

1.1 Key Financial Assumptions

The financial estimation methodology used database costs and factored estimates for specific elements. The estimate for all assets was prepared under the following assumptions (Table 1.2). Other assumptions were made specific to each asset; these are outlined in each of the asset specific report sections.

Table 1.2 Key Assumptions - All Assets

Area	Assumption
Order of accuracy	Conceptual analysis; ±40%
Discount rate (Base Case)	Real discount rate; 7%
Valuation date	01 July 2020
Base date for financial estimation	January 2021
Financials	All financials are in real 2021 dollars on a 100% ownership basis, with no allowance for structuring, joint venture or other commercial arrangements All financials are at the asset level and do not consider costs associated with financing or tax deductions for interest payments Sunk costs as at the valuation date and any expenditure to date have not been considered for valuation purposes
Currency	Australian dollars, unless otherwise stated
Cash flow periods	Cash flow periods are expressed annually in Australian financial years ending June 30
Taxes and depreciation	Pre-tax basis: tax and depreciation not considered in the analysis
Improvements and disruptions	No consideration is given to future productivity improvements, technological advances, force majeure conditions or industrial relations disruptions
Units	Quantities stated are metric (SI units)
Battery limits	Analysis includes costs associated with gas drilling and drainage, gas venting, gas utilisation and VAM. Analysis excludes all other costs such as site mining costs (including gas and ventilation staff), overheads and all ex-mine costs
ERF ACCU	Utilising the ERF ACCU mechanism requires overcoming certain barriers and has additional requirements to enter the auction. This includes fulfilling method requirements which may be difficult to adhere to. Not all cases have used the ERF ACCU mechanism
Abatement	CO_2-e abatement has not been discounted in the financial modelling or MAC curves
Land ownership and acquisition	It is assumed that all land is owned and available for VAM and gas utilisation infrastructure. No costs associated with land acquisition have been included in the modelling

1.2 MAC Curves

MAC curves have been utilised in this report. The figure below (Figure 1.2) explains the MAC curve formats. A MAC curve presents multiple abatement scenarios. In the chart below these scenarios are relative to the business-as-usual (BaU) case. The combination of all options is presented by the hatched horizontal line to derive a cumulative abatement quantity of CO_2-e (Mt) and a weighted average abatement cost ($/t CO_2-e)

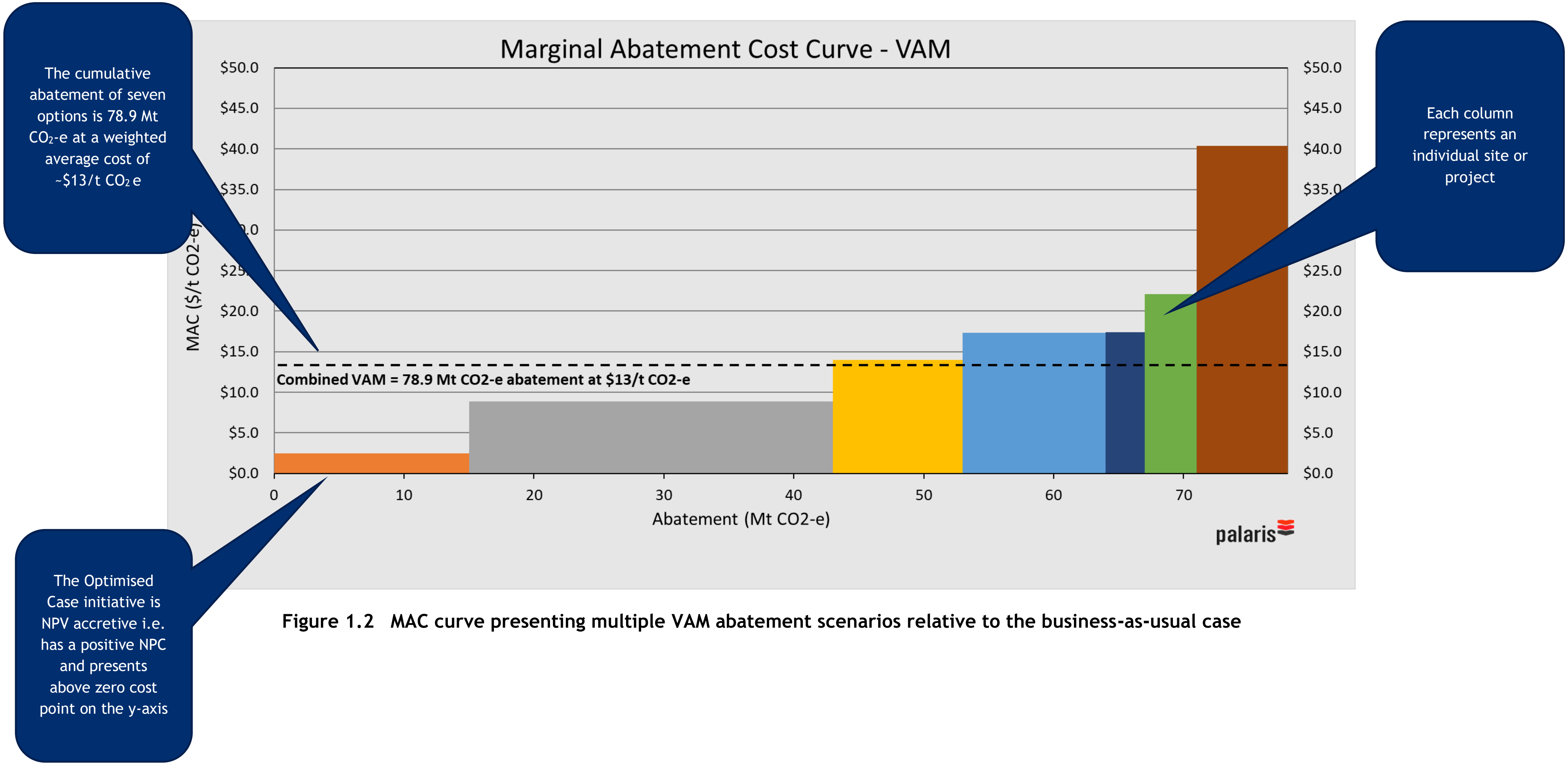

Figure 1.2 MAC curve presenting multiple VAM abatement scenarios relative to the business-as-usual case

2 EXECUTIVE SUMMARY

The principal objectives of this study were to identify potential gas drainage and VAM oxidation abatement opportunities at NSW's gassiest mines and estimate emissions reductions and associated costs. Eight operating underground coal mines and projects were selected. Abatement technologies specified in the scope included gas drainage (including flaring and power generation), VAM oxidation and potential new technologies.

The methodology established a "Business as Usual" case, with information provided from each mine. This was validated using existing emissions and plans for future abatement with a particular focus on gas destruction and ventilation air methane (VAM). An "Optimised Case" was then developed by refining gas drainage practices, gas destruction and VAM technology options. The work was undertaken at a conceptual level (+/-40%) with financial evaluation completed for each case.

The study established the marginal cost of implementing each abatement technology under a range of scenarios shown in Figure 2.1. It identified that abatement technologies including electricity generation (VAM RTO + STG and power generation units) as a revenue stream or cost-offset were relatively lower marginal cost than abatement technology that does not include power generation.

Whilst flares are higher marginal cost, their significant lower capital cost relative to the VAM RTO installations and the ability to add incremental capacity has led to them being widely installed throughout NSW gassy mines.

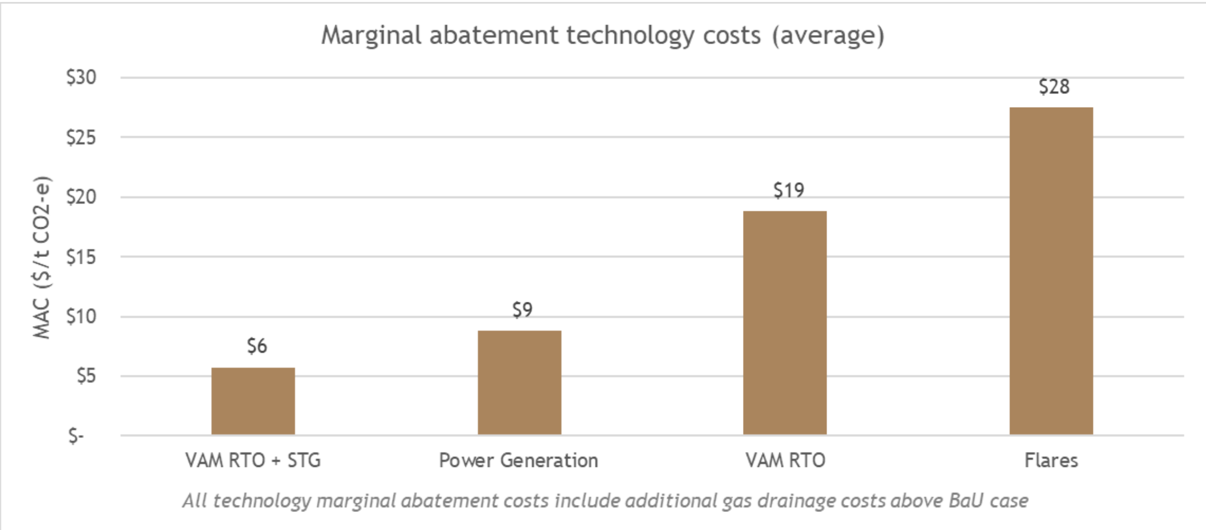

Figure 2.1 Marginal abatement technology costs (average) for 8 study sites

The study additionally optimised the technology configuration of abatement technologies for each site to identify the lowest marginal abatement costs that could be achieved at each site - shown in Figure 2.2. The study clearly identified that where existing gas drainage activities are occurring and supporting infrastructure is already in place, increasing gas drainage and expanding the existing gas abatement infrastructure is a significantly lower-cost option for reducing emissions.

These costs are further reduced where power generation is included which offsets mine site electricity costs. This applies to multiple technology combinations considered which were <$10/t CO_2-e in all cases.

The costs of establishing new gas drainage practices and constructing new supporting infrastructure or constructing VAM RTO infrastructure is significantly higher - between $23/t CO_2-e and $30/t CO_2-e.

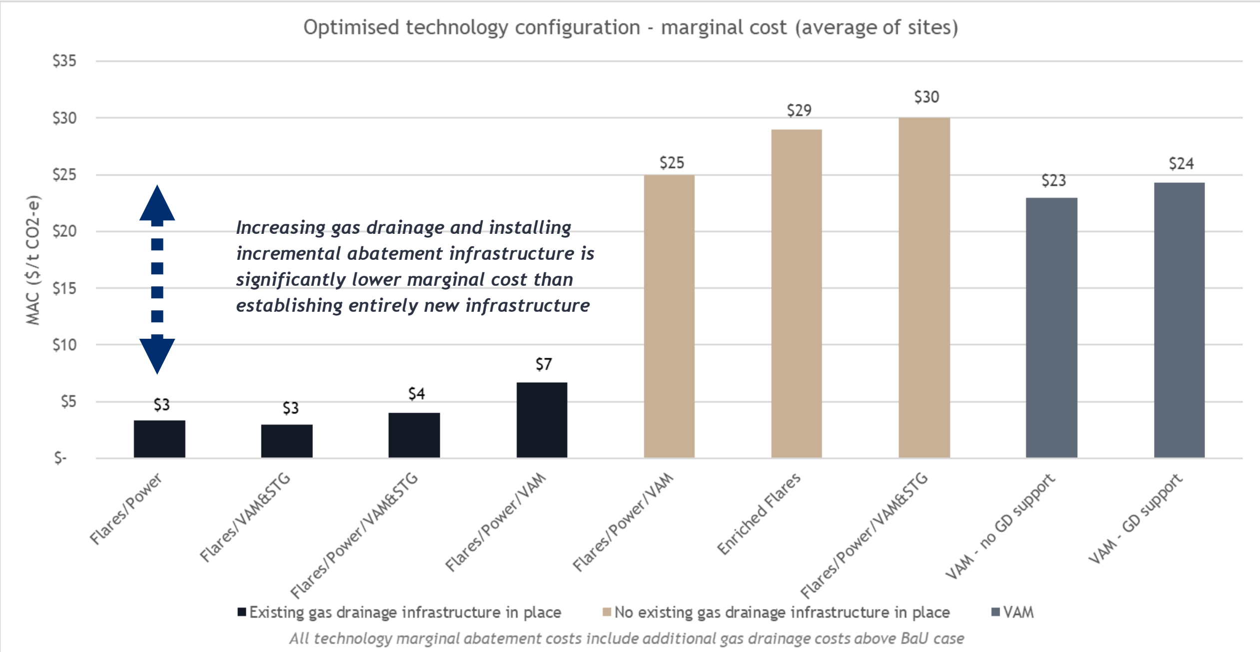

Figure 2.2 Optimised technology configuration – marginal costs

Technology Configuration	Description
Flares / Power	The use of gas fired power generation supported by the use of gas flaring for the remaining CH_4 which is unable to be used in the power generation process
Flares / Power / VAM	The use of gas fired power generation supported by the use of gas flaring for the remaining CH_4 which is unable to be used in the power generation process. Additionally, VAM RTO units are installed to oxidise the CH_4 into CO_2 utilising the surface exhaust mine ventilation air
Flares / Power / VAM & STG	The use of gas fired power generation supported by the use of gas flaring for the remaining CH_4 which is unable to be used in the power generation process. Additionally, VAM RTO units are installed to oxidise the CH_4 into CO_2 utilising the surface exhaust mine ventilation air coupled with power generation through energy recovery with a gas and a steam turbine
Enriched Flares	Extraction of a portion of gas drainage gas and removing most or all the CO_2 (enrichment) and injecting it back into the main pipeline downstream to increase the overall CH_4 concentration to allow efficient flaring of CH_4
VAM – No GD Support	The use of VAM RTO units to oxidise the CH_4 into CO_2 utilising the surface exhaust mine ventilation air without the support of higher purity gas drainage gas. No other flaring or power generation.

VAM – GD Support	The use of VAM RTO units to oxidise the CH_4 into CO_2 utilising the surface exhaust mine ventilation air which are supported with the injection of high purity CH_4 from drainage gas. This allows consistent operation of the VAM unit during periods of low CH_4 concentrations in the mine ventilation air. No other flaring or power generation.

Gas Drainage and Utilisation

At gassy underground mines, drainage of CH_4 is carried out prior to and during mining to keep CH_4 concentrations below the explosive range. Drained CH_4 can be flared and converted to CO_2. If quantities are sufficient, drained methane can be used for onsite power generation.

Improved gas drainage practices, beyond what is required for safety compliance, would reduce VAM emissions and increase potential for onsite generation. Some improvements modelled in the study included:

- Drainage and capture of gas from adjacent coal seams which are depressurised during mining
- Increasing gas recovery through increasing drainage density; and
- Use of additional drainage techniques including surface drainage drilling and hole stimulation

A number of additional gas utilisation opportunities at participant sites were identified in this study. These were identified by Palaris modelling improvements in gas drainage combined with assessing the existing capacity of installed gas drainage infrastructure which resulted in large abatement increases at relatively low marginal cost. Improved gas drainage practices also increase gas purity, which increased the number of potential projects for flaring where the gas would otherwise be vented. For all sites, the weighted average cost of gas utilisation opportunities was \$5/t CO_2-e for 113Mt CO_2-e of potential additional abatement across all study sites.

VAM Destruction

VAM represents 67% of fugitive emissions and the largest opportunity for potential abatement. It also represents significant technical challenges as CH_4 released to the atmosphere through mine ventilation air is at very low concentrations and cannot be easily captured or flared.

Regenerative thermal oxidisers (RTOs) are currently the only commercially available technology to directly abate VAM in large volumes. An RTO operated at West Cliff Coal Mine near Appin between 2007-2016 without incident. As RTOs operate by igniting the low concentrations of CH_4 in the mine ventilation stream, the industry has indicated that modern safety systems required for safely controlling this risk of an explosion propagating back into the mine are still to be fully developed.

Other constraints on the use of RTOs include limited land available at ventilation shafts for large VAM equipment, not all mines have appropriate methane concentrations in VAM of > 0.2% and the technology has relatively high capital costs. No Australian mines are currently using RTOs to abate VAM.

An industry investigation into safety issues of VAM RTOs and associated technologies has recently been carried out by ACARP and Low Emissions Technology Australia. Coal Innovation NSW is planning to provide funding to support a demonstration RTO plant in NSW to test new safety equipment and procedures.

If this demonstration project and other similar projects are successful and the safety concerns of the industry are resolved, there could be significant further scope for deployment of RTOs at NSW mines.

This study carried out a preliminary investigation of feasibility of VAM RTO deployment. Based on minimum concentrations of 0.2% CH_4 concentration and sufficient ventilation volumes, the potential for VAM destruction through RTOs was identified for 7 of the 8 sites, including associated power generation at 3 sites where CH_4 concentrations were >0.5% CH_4 (combined with gas drainage gas supplement). Across all sites, the weighted average cost of VAM opportunities was $13/t CO_2-e for 79Mt CO_2-e of additional abatement across all study sites.

Post-mining CH_4 containment

Following completion of mining in an area, the area (goaf) is sealed and gas concentrations are typically kept high to minimise any explosion risk. Significant CH_4 leakage from these areas occurs during normal atmospheric changes due to the permeability of the coal seams and seals. This leaked CH_4 becomes VAM and is more difficult to capture.

A key insight from the study is for five out of six operating mines, emissions from sealed workings represented some 50% of total VAM emissions. Despite current ventilation management techniques being available (e.g. pressure balancing) to lower goaf leakage, currently there is little awareness or incentive to manage this gas as a resource or abatement opportunity. A low risk, high yield solution is encouraging the capture of mine gas from sealed areas and increasing the amount of capture from the active goaf, which can be subsequently destructed or used for electricity generation.

More broadly, mining companies maintain a “just in time” strategy to gas management consistent with removal of gas for safety and productivity reasons ahead of mining. This current approach is not compatible with long term emissions forecasting, planning and abatement. Gas management practices are typically short term – primarily focussed on the next 2 to 3 years. Current legislation does not require detailed longer-term forecasting. Employing long term gas drainage practices reduces CH_4 entering mine ventilation where it becomes more difficult to capture.

Incentives and Funding

Based on an initial mine technology assessment, a number of projects may be eligible for ERF / CSF Funding – specifically for VAM, flaring and power generation. This is subject to further investigation. Given the current limited availability of ACCUs relative to the potential size of some projects and some costs higher than historical ACCU prices, it is likely additional funding may be required for some eligible projects.

To assist the DPIE in developing incentive mechanisms and levels, several assessments were completed. These were for different incentive mechanisms including direct financial (direct investment and lower cost loans) and indirect financial. Studies demonstrated the importance of:

- Incentivising early gas capture - once gas is in a pipeline, many more abatement options are available
- Maximising the scale of gas capture to be able to complete power generation – the additional revenue stream from this significantly improves the abatement economics

Additional incentives were identified regarding removal of artificial geographic boundaries, lowering administrative costs, building larger scale regional infrastructure and research and development.

New Technology

In addition to gas flaring, power generation and VAM technologies, a number of developing technologies being commercialised are potentially able to provide additional abatement opportunities in the near future were assessed. An assessment of technologies was completed as follows:

Table 2.1

Technology Assessment	Small-Scale LNG Production	Compressed Natural Gas (CNG) Production	Methanol Production Technologies	Green Hydrogen	Virtual Pipelines	Hazer Process
Safety	7	3	5	5	7	7
Development Phase	10	10	7	7	10	7
Time to Commercialisation	10	10	10	3	10	3
Scalability	1	1	2	5	10	1
Industry Acceptance & Experience	7	7	7	3	10	3
Harmful Products / Waste	10	10	7	7	10	7
Process Efficiency & Emissions	5	5	7	7	5	7
TOTAL SCORES	50	46	45	37	62	35

A full assessment of technologies against key parameters that will determine the likelihood of future development was completed. Both virtual pipelines and small-scale LNG production were both identified as having high potential for further R&D and funding.

3 PURPOSE OF THE REPORT

The NSW Department of Planning, Industry and Environment (DPIE) commissioned Palaris Australia Pty Ltd with this study on fugitive emissions abatement opportunities at NSW's gassiest coal mines. The aims of the study report are:

i. Make indicative findings regarding potential fugitive abatement projects at NSW mines and build a picture for the NSW Government of the broad type, scale and cost of abatement opportunities in order to inform potential incentive programs, and
ii. Give mines a useful starting point for identifying and further investigating potential abatement projects, and potentially participating in government programs to abate fugitive emissions. The report is not intended to inform consent authorities as it would not be appropriate for them to rely on its content given findings about potential fugitive abatement opportunities at mines are indicative only.

The background for the study is the NSW Government's Net Zero Plan Stage 1: 2020-2030 (https://www.environment.nsw.gov.au/topics/climate-change/net-zero-plan) which commits the government to invest in our scientists, entrepreneurs and businesses to deliver the next wave of technologies, goods and services for our consumers, workforce and the environment. The Plan aims to incentivise, commercialise and deploy technologies to reduce greenhouse gas emissions from the extraction, preparation and use of coal, and is based on empowerment and support rather than regulation.

4 MINING INDUSTRY APPROACH TO GAS MANAGEMENT

4.1 Current Approach

Gas management in underground coal mines is currently carried out to control the risks associated with gas contained within coal seams and other lithological units. Risks associated with gas include outbursts, explosion, asphyxiation, and fire. To manage such risks, coal mining legislation in NSW is prescriptive and sets out the maximum allowable gas levels for different areas of the mine. With methane (CH_4) being explosive, statutory limits are set well below the lower explosive limit (typically 2% CH_4 or lower) with production to stop, electrical power to be removed and personnel withdrawn if certain levels are exceeded. Additionally, effective gas drainage has helped deliver higher productivities – annual mine output has increased from some 1.5Mtpa to over 10Mtpa over the last 35 years. Improvements in gas drainage effectiveness have been a key contributor.

The three primary methods currently employed for gas management include:

i. Pre drainage of the working seam or adjacent seams (completed prior to mining)
ii. Post drainage (capturing gas during longwall mining as the strata is relaxed and gas is released from other coal seams / lithology)
iii. The use of ventilation to dilute the gas to below prescribed statutory levels

The gas pre drainage strategies employed across most NSW mines are generally limited to the working seam, underground based, and generally focus on a “just in time” basis. Strategies are centred around the gas pre drainage requirements (with regards to outburst) for the next gateroad and longwall block (~1 – 2 year outlook).

Post drainage strategies tend to be more intensive in mines where CH_4 is the predominate seam gas, focusing on the capture of the surplus CH_4 that the longwall ventilation system cannot dilute to legislative limits, to allow unimpeded production at planned production rates.

For mines with carbon dioxide (CO_2) as the dominant seam gas, the explosion risk is lessened. Whilst pre-drainage is still required to manage the outburst risk (an outburst being a “burst” of coal causing a safety risk), CO_2 levels in underground roadways may be allowed to run at ~3 - 5 times that of methane (with sufficient controls to manage asphyxiation risk) thus reducing the need for post drainage.

At the completion of mining a longwall panel, blocks are sealed and isolated from the rest of the mine’s workings. Gas will continue to desorb within the sealed environment (often for years) after the completion of mining. Gas in sealed areas tends to be a mix of CH_4, CO_2 and excess Nitrogen (N_2). Most of that gas eventually reports to the mine’s ventilation system. The rate at which it leaks from the sealed areas is a function of seal and strata integrity, gas buoyancy pressure and applied ventilation pressures. For five of the six operating mines assessed as part of this study, this component of the total ventilation emissions varies between ~ 50 - 60%, increasing for the older, more established mines (as more areas are mined and sealed).

Gas drainage infrastructure is generally designed based on the forecast gas flows (plus a contingency factor) that will result from the pre and post drainage activities, with excess gas (beyond the capacity of the plant) released to the atmosphere.

Whilst the gas risk and the need to remove the gas for management of those risks is well understood, the actual gas is largely seen as a by-product of the coal mining process. While there are many examples of NSW mines taking steps to abate fugitive emissions due to their climate impact, there is scope for an increased focus on this issue.

4.2 Alternate Approach

Adopting a different view of gas would potentially require mine operators to be given the correct incentives to encourage capture and utilisation or destruction rather than venting. Incentive design would need to address the main drivers for the current approach which include:

- Routine - It is generally more convenient and less technically complex to implement additional ventilation capacity than it is to install the required infrastructure to capture gas into a reticulation system for use in power generation or flaring
- Motivation – There are few incentives to encourage mine operators to capture and utilise mine gas rather than venting it to the atmosphere
- Cost – Drilling and gas drainage infrastructure is CAPEX and OPEX intensive depending on required volumes to drain. Sites are under constant pressure to keep operating costs to a minimum
- Risk – Early drainage of areas not required in the near future (~1 - 2 years ahead) can have a number of risks associated with it including:
    - Approvals – The mine operator may not have formal approval to mine areas beyond such a time frame and is likely to be reluctant to incur a cost (due to drilling) with an uncertain financial return
    - Resource definition – This is based around risks to achieving the plan beyond 2 – 5 years associated with geological or geotechnical considerations. It is less likely that gas drainage will take place in areas that are not well defined and may not be mined in the future

The current GHG Clean Energy Regulator baseline reporting requirements do not change these drivers.

Additionally, the guidelines require a baseline to be set for three years, which does not fully encompass a “life of mine” view. This was evident in the data supplied by the sites where emission forecasting beyond 2023 had not been done or was not well developed. A comprehensive strategy to support utilisation might in fact consider drainage 4 - 7 years ahead of mining.

Based on the data examined, it is evident that the two key targets for a low risk, high yield solution is encouraging the capture of mine gas from sealed areas and increasing the amount of capture from the active goaf, which can be subsequently combusted or used for electricity generation. Ideally, suitable mines would have the necessary gas drainage infrastructure (gas reticulation system, extraction units, flares, power plant, etc) and would require minimum CH_4 purity in the mine gas to enable combustion (for example, 40% CH_4 is required for power generation) with low oxygen content (<6%).

Supplementary to this would be pre-draining the gas across a mine plan far in advance of mining (5 – 10 years ahead), to allow for maximum and consistent gas recovery. Similar practices are currently followed in Queensland where electricity producers and coal mine operators target areas as gas fields prior to mining. This practice will be limited in NSW due to surface access restrictions (such as steep terrain, private land or conservation areas), which would require an underground based concept to be developed, and more mixed seam gas (combination of CO_2 and CH_4) compositions, which may not be suitable for electricity generation.

5 ABATEMENT TECHNOLOGY

The scope of this project was to study the potential application of abatement technologies and practices to the sites and projects including gas drainage, gas destruction and VAM abatement.

5.1 Gas Drainage

Gas drainage in underground coal mines is currently carried out to control the risks associated with gas including, outburst, explosion, asphyxiation and fire. Effective gas management allows for higher equipment productivities.

The current techniques of gas management include pre drainage of the working seam or adjacent seams (completed prior to mining – see Figure 5.1) and post drainage (capturing gas during longwall mining as the strata is relaxed and gas is released from other coal seams – see Figure 5.2).

In this project, industry best practices that were applied to gassy mines to reduce ventilation air methane included:

- Pre or post drainage of adjacent seams currently not drained
- Applying Surface to Inseam (SIS) drilling to increase pre drainage recoveries and reduce surface impacts
- Increasing density of vertical holes or use of horizontal goaf holes to increase post drainage efficiency
- Increased pre-drainage of working seams
- Introducing pressure balancing of older sealed mining areas and capturing gas from these sealed areas
- Gas hole stimulation to increase gas flows

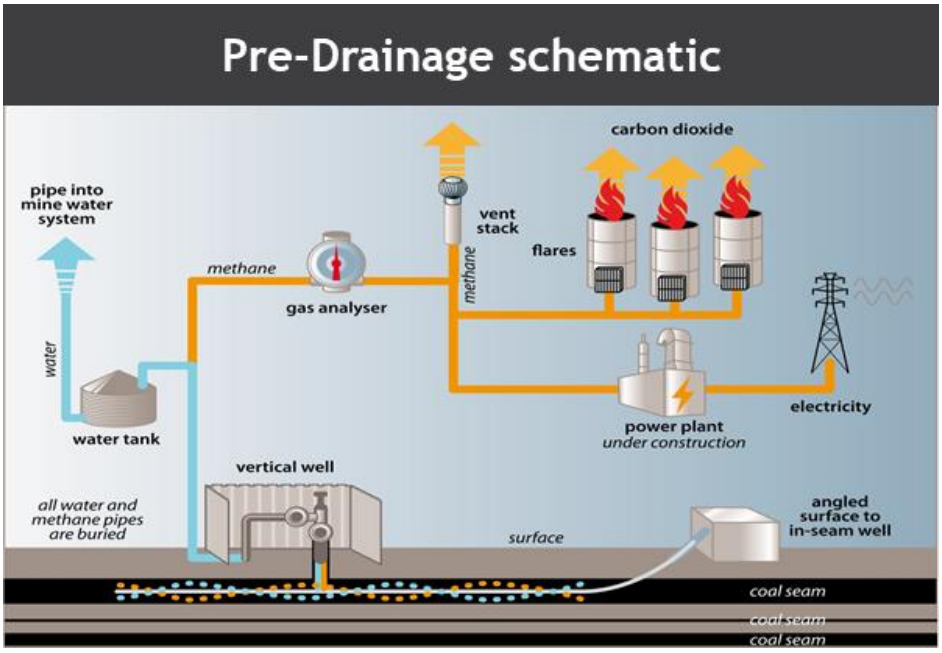

Figure 5.1 Pre Drainage Schematic

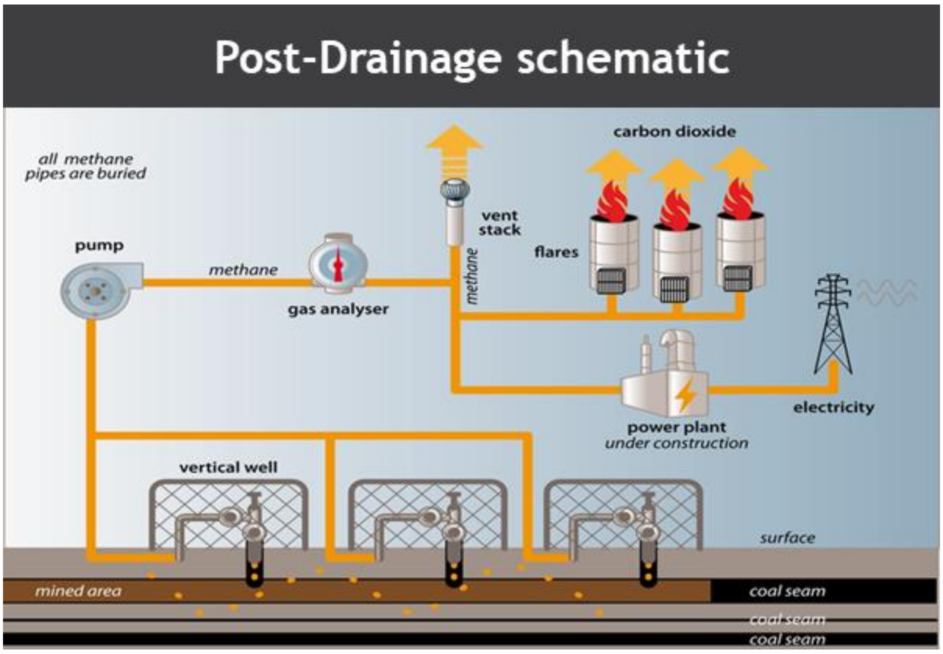

Figure 5.2 Post Drainage Schematic

5.2 Gas Destruction

A number of technologies are available for the destruction of methane:

Fixed Enclosed Flare

The function of an enclosed flare in an underground mine is to efficiently destruct the captured methane extracted through goaf, SIS and UIS gas drainage processes. This method of gas destruction is commonly used throughout Australian mines. The enclosed flare is a fixed piece of plant primarily used for larger flows of gas between 1000 – 3000 l/sec per flare and with a working composition range of 25% to 90% CH_4. Typically, suppliers aim for 99.7% destruction of all CH_4.

Operation

The flare is controlled by the burner management system which is the safety management system for the flare. Prior to gas being passed into the enclosed flares the gas must be filtered and dewatered to ensure effective combustion. The vacuum pumps deliver the gas to the flare typically at pressures between 12 – 20 kpa.

The methane mine gas mixture is injected into the plume stack through the burner manifold mixing tubes with a pilot ignition probe providing a source of ignition. Once ignited the temperature probe and sensory system tracks the status of the burning methane and adjusts the air feed, to ensure complete gas destruction and constant temperature.

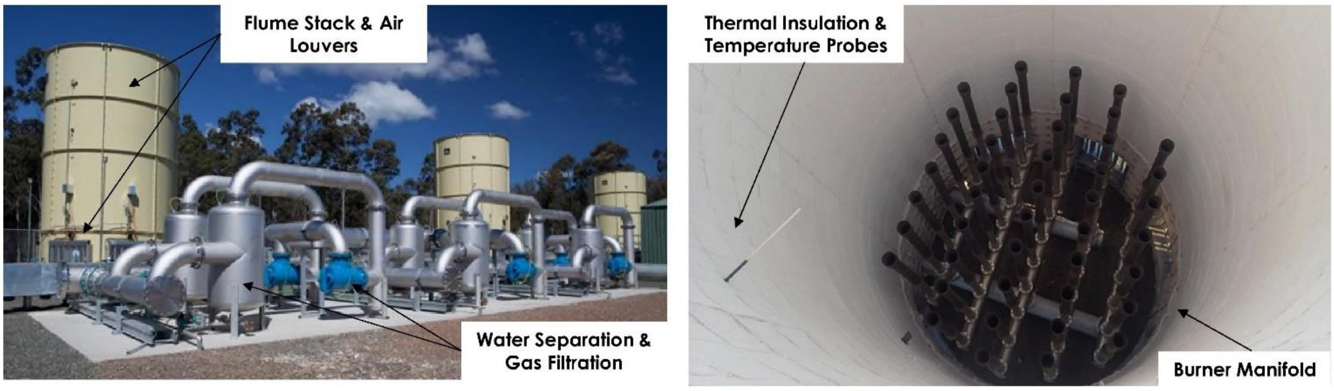

Figure 5.3 Picture of flare (Left) [Courtesy of Tahmoor Mine], Internal Flare Layout with Burner Manifold (right)

Mobile Flare

The function of a Mobile Enclosed Flare as the name suggests is to be relocatable and rapidly deployed across various locations. As with the enclosed flare the mobile flare efficiently destructs the captured methane extracted in locations that are not financially or geologically viable for extensive overland pipelines, or in remote areas. It allows gas to be flared directly at the goaf, UIS or SIS borehole, by design its ability to collapse allows for easy transportation and deployment. The mobile flare skid assembly includes a water knockout, vacuum pump, gas monitoring and flare. The range of flow required for these flares is 80 l/s-1000 l/s with a CH_4 composition of 20%- 95% governed by the percentage of oxygen mixture in the gas stream.

The mobile flare is placed on a cleared patch of land and erected prior to connection to the mine system. The gas source is connected to the inlet of the water knockout. Gas is drawn through the water knockout and filter using the vacuum pump and injected into the enclosed flare. The ignition and thermal process is the same as the fixed enclosed flare. The feed oxygen to maintain flare ignition is drawn into the base as required, the nozzle design and gas pressure creates the mixing effect.

The gas can be powered by a 60kw gas generator however, solar / battery versions are currently being trialled. The flares are presently not operating in Australia but are used extensively in Europe, presently Australian mine have opted for the use of candlestick flares.

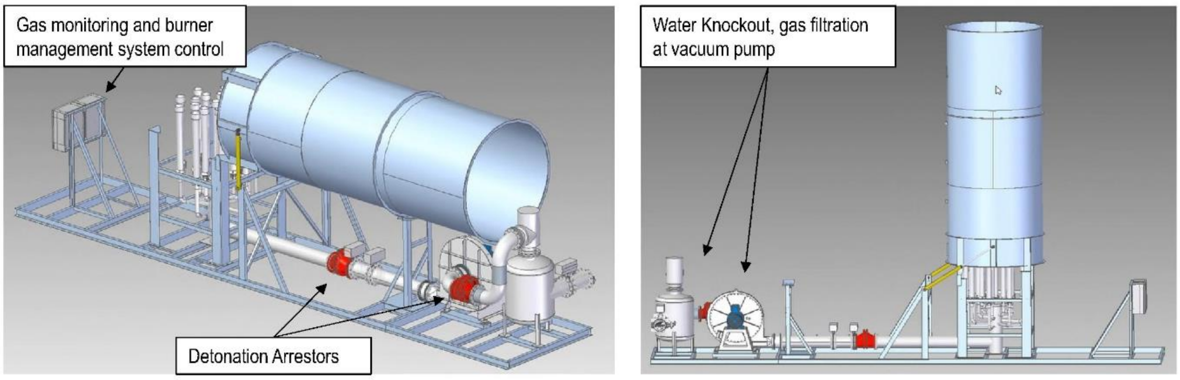

Figure 5.4 Undeployed Flare and Deployed Flare

Gas Fired Power Station

The function of a gas fired power station is to convert the methane extracted from the mine into electricity and potentially offset electricity costs where possible. Specially designed gas gensets are available in numerous capacities to accommodate the predicted amount of the gas feed throughout the mine life. The gensets range in size from 1 MW, 3.3 MW, 5MW and 10MW. Power stations usually include singular or multiples of the same powered gensets for ease of maintenance, system redundancy, and overall cost purposes.

Figure 5.5 Typical Gas Genset

Installation footprints of power station are governed by the size of the plant the example below shows a 16MW plant with the ability to be expanded to 22MW the overall dimensions of the proposed installation footprint being 100m x 80m.

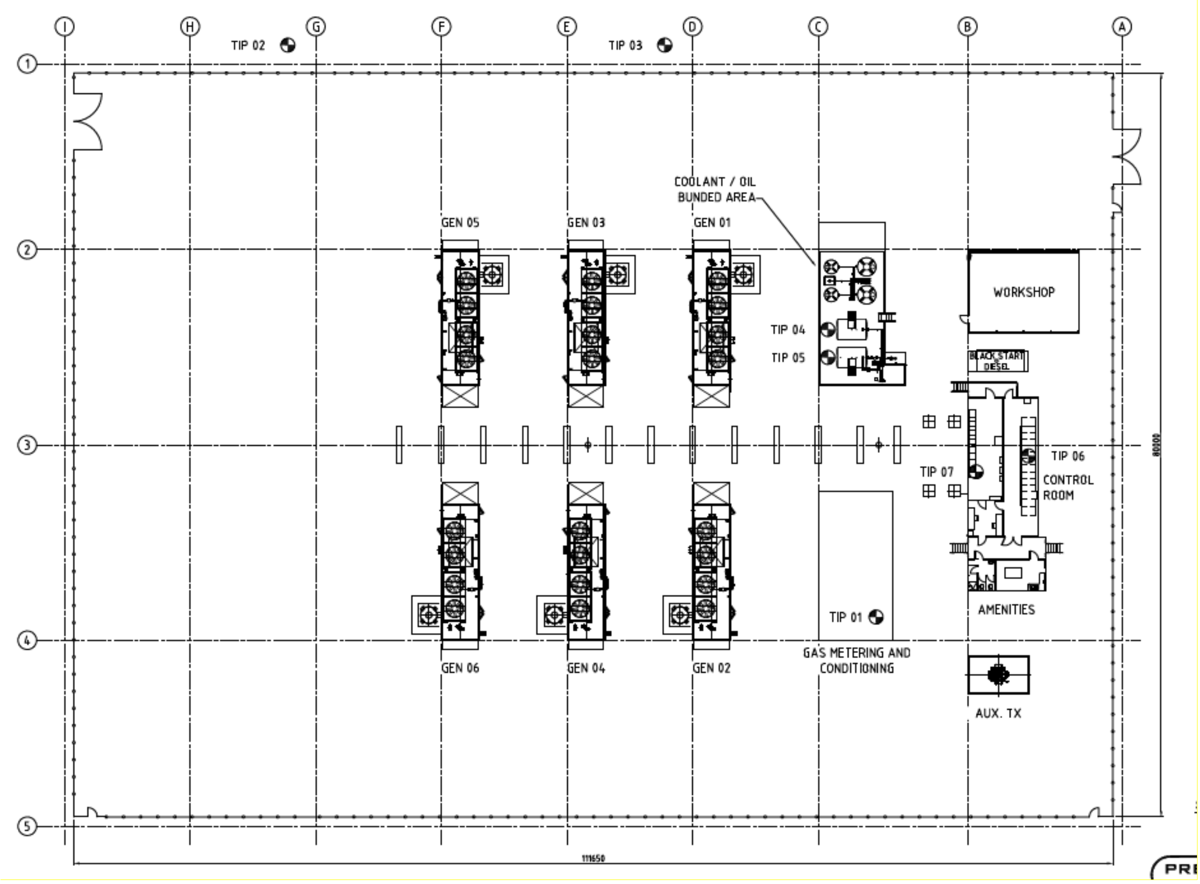

Figure 5.6 16MW Power Station Layout

Power stations can be configured to supply power behind the meter directly to the mine site or can be configured to also export power into the grid. The clean energy regulator and AEMO as well as state bodies have numerous regulatory requirements for this type of application.

Figure 5.7 10 MW power station – 3 x 3.3 MW Gas Gensets

Vacuum Extraction Plant

The purpose of a Vacuum Extraction Plant is to always maintain effective suction on the underground gas pipe range to ensure the underground gas is extracted to the surface where it can then be utilised or destructed. Typically, underground extract pressures for larger mines can be around -35kpa at the pump station to maintain -5kpa suction pressure at the individual drill holes underground.

A vacuum extraction plant typically consists of either blowers or liquid ring vacuum pumps connected in series. The capacity of the plant is driven by the number of pumps and the predicted life of mine gas forecast. Given the criticality of the plant, mines will always look to maintain system redundancy to ensure sufficient capacity exists. Gas treatment and conditioning is typically installed along with water treatment for the liquid ring pump installations in these plants. Most plant will be configured to maintain a target suction pressure, with pumps circuits featuring recirculation systems.

Figure 5.8 Gas Extraction [Courtesy of Yancoal], Gas Extraction Plant [Courtesy of South 32]

Gas Enrichment

Gas enrichment in this circumstance is essentially the extraction of a portion of gas out of the mine surface captured gas pipeline, removing most or all the carbon dioxide, and injecting it back into the main pipeline downstream to increase the overall CH_4 concentration. The increased CH_4 content allows mines with a lower percentage CH_4 operating range to maintain destruction of gas, or in some cases the enriched gas is used to boost the gas provided to the power station. This process is widely used in Europe in landfill and Biogas applications.

Amine gas enrichment is a common method used to capture carbon dioxide in a mixed methane stream. It involves using an Amine chemical solution to scrub and capture the carbon dioxide with the exiting gas stream becoming a significantly higher concentration of CH_4, around 95-98%. The amine solution is then passed through a closed system and heated to produce steam to separate the carbon dioxide and Amine chemical and the carbon dioxide is then captured to utilise elsewhere. The Amine chemical is then condensed and reused again and if required substituted with more Amine solution to compensate for the small amounts lost during the steam separation process. These range in 500 l/s and 1000 l/s rated plants. Currently this technology is not utilised in the Australian mining industry. However, it has been extensively utilised in industrial gas and biogas industries. Other enrichment process is available and utilised in biogas and industrial gas industries. Noted methods include pressure swing absorption, membrane separation, cryogenic separation and physical (water or organic) scrubbing.

Figure 5.9 Typical Gas Enrichment (Amine) Plant in Biogas

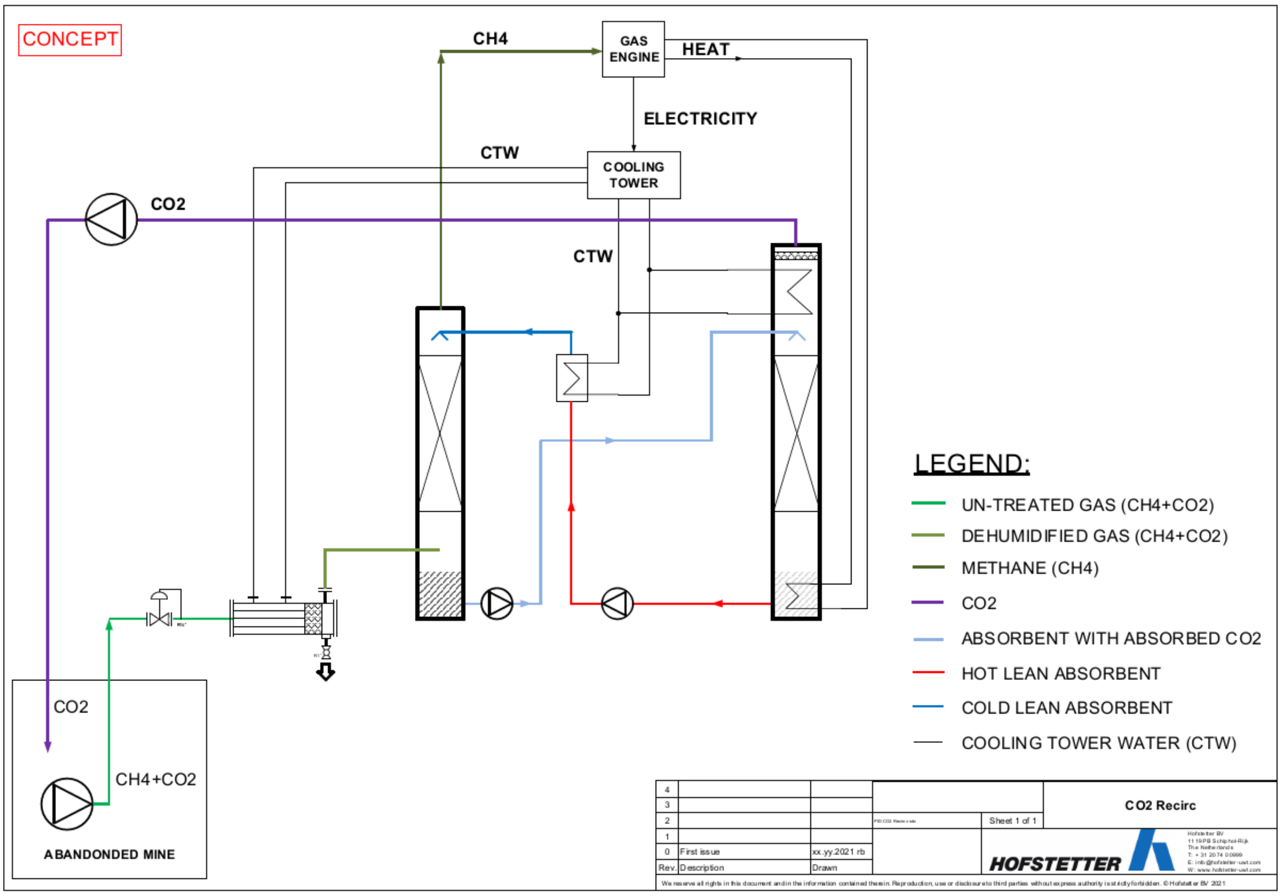

Figure 5.10 Gas Enrichment Process Flow Diagram [Courtesy of Hofstetter]

5.3 VAM Abatement

The potential application of VAM abatement technology in Australia is more difficult than gas drainage and gas destruction technologies due to safety control system issues (currently the subject of significant research and development), higher relative capital costs and large land requirements.

The Vocsidizer$_{TM}$ 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.

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. However, all the above design parameters may be accommodated within the order of accuracy of the capital estimates provided.

At concentrations from 0.20% to 0.5% CH_4, 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% CH_4, 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 CH_4 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% CH_4, 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% CH_4, 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 CO_2-e abated may be achieved through additional underground gas capture in these circumstances.

The fluid nature of VAM input parameters highlights several fundamental design principles and advantages of the Vocsidizer$_{TM}$ 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)

Application of Selected Technology and Vocsidizer^{TM} Cubes Concept

Currently the concept of four Vocsidizer^{TM} 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. A configuration of the 'cube' concept is shown in Figure 5.11 below.

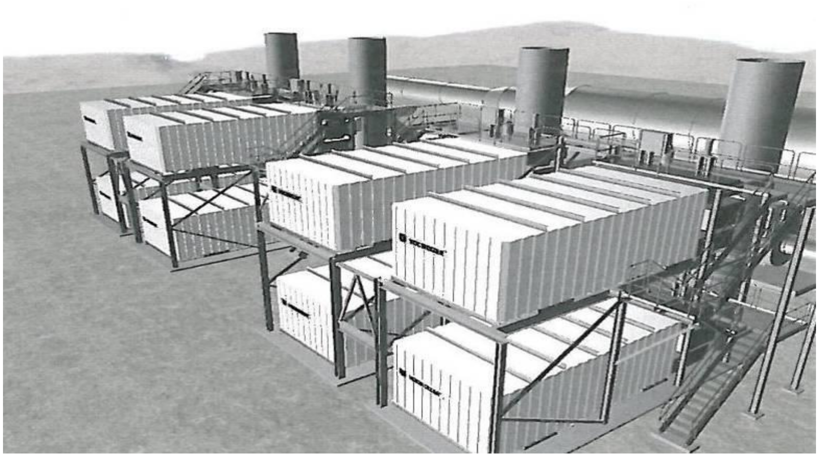

Figure 5.11 Vocsidizer^{TM} 'Cube' Arrangement perspective (Courtesy: Megtec Systems AB)

Each abatement cube has a volumetric flow capacity of approximately 70m^3/second (250,000 Nm^3/hr) and has overall dimensions of 25m x 25m x 10m inclusive of process air fans (2 off), inlet dampers, exhaust stack, access and supporting structure. Central VAM ducting illustrated in Figure 5.12 would typically occupy a space of 12-15m inclusive of fresh-air dilution inlet. Multiple modular abatement cubes are generally arranged to access a common VAM duct connection from opposite sides.

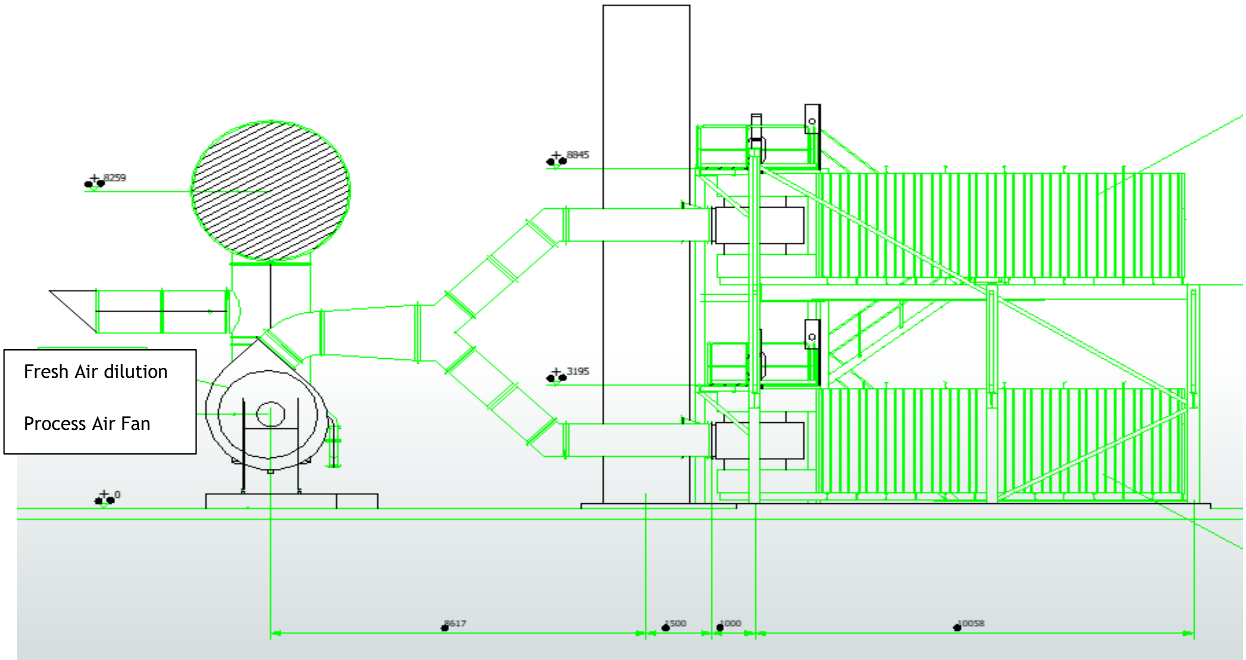

Figure 5.12 Vocsidizer^{TM} 'Cube' arrangement section (Courtesy: Megtec Systems AB)

Application of Selected Technology and Vocsidizer^{TM} Steam Cubes Concept

Currently the concept of four Vocsidizer^{TM} 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. A configuration of the ‘steam cube’ concept incorporating feedwater deaerator and steam drum is shown in Figure 5.13 below.

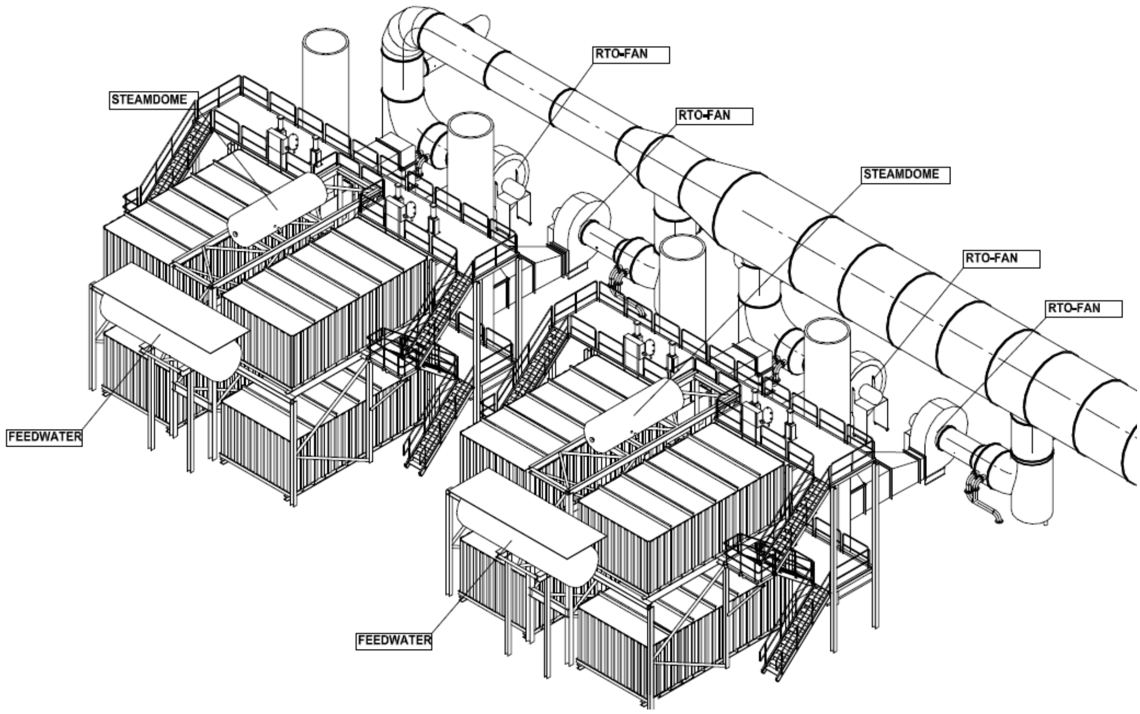

Figure 5.13 Vocsidizer^{TM} ‘Steam Cube’ Arrangement (Courtesy: Megtec Systems AB)

Table 5.1 Summary of typical VAM Abatement solutions vs CH_4% level

VAM Abatement Type	Low CH4% Level	High CH4% Level	Colour	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

6 ERF AND CSF ELIGIBILITY

6.1 Emissions Reduction Fund

The Emissions Reduction Fund (ERF) is a voluntary scheme that provides incentives for a range of organisations and individuals to adopt new practices and technologies to reduce emissions. A number of activities are eligible under the scheme and participants can earn Australian carbon credit units (ACCUs) for emissions reductions. One ACCU is earned for each tonne of carbon dioxide equivalent (tCO_2-e) stored or avoided by a project. ACCUs can be sold to generate income, either to the government through a carbon abatement contract, or in the secondary market.

The ERF was established in 2015 transitioning from the Carbon Farming initiative. With new funding provided by the government the ERF was renamed the Climate Solutions Fund (CSF) in 2019 building on the ERF initiative.

Duration

An ERF Crediting Period is the period a project is able to apply to claim ACCUs. Crediting periods vary depending on the type of project and range between 7-25 years. For Coal Mine Waste Gas projects, this period is generally limited to 7 years. Where the Coal Mine Waste Gas project abates more than 250,000 t CO_2-e per year, and uses a custom method, it may be classified as a large project and have access to a 10-year crediting period.

Project Type

Projects that can be eligible under the ERF/CSF are called methods. Eligible Methods include:

- Generic method for emissions reductions at facilities reporting under the National Greenhouse and Energy Reporting Scheme
- Capture and destruction of coal mine fugitive emissions
- Reductions in emissions-intensity of transport
- Commercial, industrial, and aggregated energy efficiency
- Capture and combustion of landfill gas and agricultural waste
- Alternative treatment of organic waste
- Capture and combustion of biogas from wastewater, and
- Methods for the land sector, including increasing soil carbon, reducing livestock emissions, expanding opportunities for environmental and carbon sink plantings, and re-forestation

To expand on the above definitions, the ERF/CSF further elaborates on the applications of coal, oil and gas. “Mining oil and gas projects redirect and destroy waste emissions from coal, oil and gas facilities. Activities could include capturing, destroying or converting methane gas from coal mines or reducing fugitive emissions from oil and gas operation.”

Prior to registration of a Project the below activities must not have taken place:

- Signing a contract to undertake project activities
- Acquiring or leasing equipment
- Construction

- Making final investment decisions

The Coal Mine Waste Gas Method applies when:

- The facility is an underground coal mine which will destroy or convert some or all of the waste mine methane drawn from the mine by installing a flaring, flameless oxidation or electricity production device. (*Clean Energy Regulator, <http://www.cleanenergyregulator.gov.au/ERF/Pages/Choosing%20a%20project%20type/Opportunities%20for%20industry/Mining,%20oil%20and%20gas/Coal-mine-waste-gas.aspx>)*

Table 6.1 ERF/CSF Technology Eligibility

Technology	ERF / CSF eligible	Reference
Direct Venting	No	
Process Vent	No	
Flaring	Yes	Carbon Credits (Carbon Farming Initiative - Coal Mine Waste Gas) Methodology Determination 2015
Power Station	Yes	Carbon Credits (Carbon Farming Initiative - Coal Mine Waste Gas) Methodology Determination 2015
VAM	Yes	Carbon Credits (Carbon Farming Initiative - Coal Mine Waste Gas) Methodology Determination 2015
Gas Enrichment	No	
LNG	No	
CNG	No	

6.2 Technology Assessment & Funding Eligibility

The information in Table 6.2 below summarises the results of the technology assessment completed for the eight nominated mines. The following observations should be noted:

- Direct venting infers the gases are emitted directly to atmosphere with no application of abatement technologies
- Process venting infer the site has or intends to install vent stacks as part of the abatement technology designed to operate when system spikes or over capacity events occur
- Several mines have the ability to expand their existing abatement infrastructure capacity
- Several mines have the ability to further explore opportunities to further utilise the fugitive gas or add to their existing infrastructure with different of new technology

Table 6.2 shows the number of sites identified where a technology is eligible for ERF / CSF funding based on the Mine Technology Assessment, where the technology is already in place and where the technology was not being considered at all.

Table 6.2 Mine Technology Assessment

Technology	Technology already in place	Technology potentially eligible for ERF / CSF funding	Technology not being considered	Not Applicable
Direct Venting	2	0	5	1
Process Vent	3	2	2	1
Flaring	3	3	1	1
Power Station	2	2	3	1
VAM	0	6	2	0
Gas Enrichment	0	2	6	0
LNG	0	2	6	0
CNG	0	1	7	0

6.3 Funding Eligibility

The Carbon Credits (Carbon Farming Initiative – Coal Mine Waste Gas) Methodology Determination 2015: Part 3 – Project Requirements, outlines the project requirements for eligibility to claim carbon credits for offsets project. In particular, for new projects, there must have been no prior material abatement from the conversion of the methane component of coal mine waste gas from the mine at application time. For expansion projects, some of the methane must have been converted at application time, and a statement must be provided as to the recognised capacities of existing flaring, flameless oxidation and/or electricity production devices, as specified.

The applicable technologies with the potential to qualify for funding are discussed in Section 6.1 and Table 6.1 which identifies the potential mines and qualifying technologies.

7 INCENTIVE DESIGN CONSIDERATIONS

Operators may need direct or indirect strategic incentives to conceptualise and implement increased levels of emissions abatement. Critical to the success of an incentive achieving the goals of increasing emissions abatement are the incentive mechanism design, the financial level that the incentive is offered at to ensure mine operator take-up, and that the incentive creates the best emissions abatement outcomes for the NSW Government.

7.1 Direct Fiscal Subsidy

Direct Capital Investment

The use of direct capital investment by Government into emissions abatement projects to assist companies meeting internal investment hurdles is a well-established incentive mechanism.

Government may also co-invest to allow the project to become a “demonstration project” allowing the learnings of the project to be leveraged throughout broader industry.

Mining companies may seek government co-investment for the following reasons:

- To lower the capital cost of the project for the company
- To lower the perceived risk of the investment by having a large stable entity involved
- If government co-investment is early in the project cycle, this lowers the risk of poor project outcomes - early proof on concept and pilot plants are more frequently funded by government

Mining companies in NSW are increasingly taking more action on emissions abatement due to updated emissions targets in line with the Paris Agreement 2015. This will likely result in increasing capital being allocated to emissions abatement projects. Another incentive for companies to act is the avoidance of the purchase of carbon credits to offset exceedances of emissions baselines NGERs something.

Within the project cycle, there are different opportunities for investment including:

- Feasibility Studies (about 5% of project value)
- Pilot Plants (about 5-15% of project value)
- Total Project (100%)

Earlier investment in an abatement project would increase the opportunity for project risks to be resolved which could otherwise stop further mining company investment. As the capital costs of the VAM abatement projects considered in this study range from $70M to $140M, early studies and pilot plants can still incur significant costs.

Low Cost Loans

Typical costs of capital for mining companies range from 7% for large mining companies to 9-10% for smaller companies. Due to their financial positions, governments can typically provide debt funding at a lower cost of capital than mining companies are able to access. To provide further incentive, the NSW Government could consider loans that are at a lower cost of capital.

Sensitivity analysis on the cost of capital was completed for all 8 mines/project abatement solutions at 3% and 10% to provide a quantification of the potential impact of lower cost loans.

The conditions of the loan could also be structured in a way to incentivise greater than planned abatement efficiency by further innovation and optimisation of the abatement facility by the mining company.

7.2 Improved Regulations

Artificial geographical barriers

Methane gas that is produced as part of the coal mining process within a mining lease is generally limited to on site use only. Mines located in relatively close proximity, for example:

- South Coast – Appin and Tahmoor
- Hunter Valley – Mount Thorley Warkworth underground, Maxwell, Wambo
- Narrabri North and Santos Pilliga CSG project

The value of the conceptual abatement projects assessed for each site may increase if gas supplies and infrastructure was shared between existing mines. This could increase scale and lower costs of abatement, lower variability of gas supply and potentially make connecting gas network infrastructure more affordable – supporting manufacturing and other gas users.

An incentive to be considered by government is improvement of government policy and regulations to accommodate these opportunities as they are identified.

Lower Administrative Costs

Coal mining is a highly regulated industry in NSW with extensive safety and engineering legislation in place. Whilst much of the legislation has been designed around equipment that has developed over many decades, much of the decarbonisation technology solutions are either in early development or are new to the coal mining industry. Much of the current Australian legislation does not reference decarbonisation technology that is available and in operation globally.

To overcome issues of poor alignment between Australian and global engineering standards, increased awareness and the availability of expert resources to validate that the technology is legal to use needs to be completed to allow this new technology to be used on sites. Currently it can be difficult for recognised bodies to be able to certify that equipment is able to be used.

For example, an analysis of the implementation of a mine site gas utilisation power plant indicated that receiving all technical approvals would take 32 months to be completed.

Whilst new decarbonisation technology is being developed and commercialised in different sectors within Australia, many decarbonisation technologies that have been developed internationally and are further along the development curve are now also available in Australia. To increase the speed of take-up of decarbonisation solutions, improved regulation around licensing and technology agreements into Australia (particularly where current solutions are unavailable) would lower technology costs and likely increase local manufacturing of these technologies.

7.3 Infrastructure Development

As stated in Section 7.2, many of the potential abatement projects assessed in this study may benefit from increased scale and lower costs by combining with other nearby projects. More broadly, other regional infrastructure solutions may provide synergies between different abatement projects.

Different examples and concept solutions include:

- The QLD Government is currently assessing the feasibility of and options for new gas transmission pipeline infrastructure to connect the Bowen Basin's gas resource to the eastern Australian gas market
- Redbank Power Station was initially constructed to utilise tailings and although is currently not operating, supply of mine gas from adjacent mine sites could improve the economics of the project
- The Hunter Valley contains many open pit mining voids, some of which are being considered for stored hydro power solutions. Gas power generation could be deployed alongside stored hydro
- Existing Industrial Areas (e.g. Mount Thorley Industrial Area) could benefit from having access to low cost bulk gas sources which could provide potential for new manufacturing opportunities

7.4 Research and Development

The application of VAM technologies is a significant fugitive abatement opportunity for underground coal mines. Whilst a number of units are operationally globally, the industry has identified that further research and development is required to address safety concerns, lower costs and increase the operating range of the technology.

For many underground coal mines in Australia, the remaining coal to be extracted is located in increasingly deeper areas which are often characterised as being increasingly difficult to drain gas from due to issues such as lower permeability. If coal is extracted with less than optimised drainage having been completed, more gas is released when the coal is extracted and reports to the ventilation air stream.

Gas well stimulation is a well utilised method of increasing the flow of gas from coal from surface gas drilling and has had some limited application in underground gas drilling. General industry results indicate that 4x as much gas is released after well hole stimulation than would otherwise have been the case. Incentives for further research into making this technology available and effective to underground gassy mines could improve gas drainage performance across the industry.

8 ALTERNATE TECHNOLOGIES

Although some of these alternatives are not core to coal mining specifically, they offer the potential to align or encourage offtake style agreement for the use of the gas and offer up other applications with the potential to lower carbon emissions or make productive use of the gas.

8.1 Small-Scale LNG Production

This technology is used to process gas obtained from the coal seam into a more efficient and clean fuel which is stored for later use. The process involves the filtering, dewatering and compression of the gas into a liquid allowing more effective storage, for use in machinery and other applications. The gas must be cryogenically stored (at low temperatures) to maintain its liquid form. This method is commonly used in the United States coal seam gas operations and large industrial land fill sites in Europe. Applications also exist in USA, Canada, and Russia with large open-cut mining machinery converted to run on LNG gas.

The compressed gas is either sold via injection into the LNG pipeline network, transported by truck as a virtual pipeline system or utilised within the plant. Training and specialised safety equipment must be used when transferring between storage sources due to the low temperatures e.g. refuelling machinery. LNG can be utilised throughout the gas industry and in mining as a compact fuel source and for transportation.

Table 8.1 Small-scale LNG Production Pros and Cons

Pros	Cons
Plant design provides for modular construction	High degree of complexity requiring skilled staff to maintain
Process gas for plant machinery or commercial use, lowering emission of tradition diesel engines	Cost of production may outweigh wholesale price of gas
Easily transportable & relocatable	Specialised storage must be used to maintain liquid form
Product is readily available	Training and specialised safety gear is needed for storage transfer
Emissions offset from harnessing the gas instead of bringing it allows additional funds due to Carbon Credits	Plant is capital intensive and would rely on minimum capacity to be commercially viable
All gases are separated and have the ability to be harvested and hence there are no by-product emissions	Would best suit take off agreement as it is not core to core mining companies

8.2 Compressed Natural Gas (CNG) Production

This technology follows a similar process of filtration and dewatering of the extracted coal seam gas to the LNG production, however the gas is instead compressed into a high-density gaseous form. In this form it can be stored in compressed gas cylinders and used directly in machinery without extra conversion processes with minimal training needed for storage transfer.

The gas is either sold via injection into the CNG pipeline network, transported by truck as a virtual pipeline system or utilised within the plant. This process is commonly used in the gas industry with pipelines throughout Australia as, like LNG, limited applications exist presently in the mining industry.

Table 8.2 Compressed Natural Gas (CNG) Production Pros and Cons

Pros	Cons
Design provides for modular construction reducing installation time and smaller equipment or relocation infrastructure. Also, it allows for incremental expansion	Design has an increased complexity requiring a high degree of competence to maintain equipment
Processes gas for plant machinery or commercial use	Cost of production may outweigh wholesale price of gas
Product can be directly used in machinery	Difficult to transfer excessive amounts of fuel
Minimal training needed for storage transfer	Larger storage vessels required to store the gas compared to LNG
Product is readily available	
Emissions offset from harnessing the gas instead of bringing it allows additional funds due to Carbon Credits	

8.3 Methanol Production Technologies

Methanol is a broadly used alcohol which is the base chemical for many derivative chemicals that are utilised in many industrial applications. Its derivative chemicals are used in products such as plastics, paint, adhesives and is also a main additive in unleaded petrol. It can also be used as a partial or whole marine fuel and diesel fuel replacement.

The most common method of producing methanol is via steam methane reforming, processing natural gas into syngas and lastly methanol. Renewable methanol, via the method of carbon dioxide hydrogenation, is a more recent production method requiring a hydrogen source and carbon dioxide source to produce the methanol. It utilises an energy source, green hydrogen and an industrial source of carbon dioxide.

Currently green methanol is an expensive process due to the cost of renewable power and the source of green hydrogen. Currently work is being performed to decrease the cost of renewables and green hydrogen technologies and production.

In terms of application to a mining operation methanol is deemed preferable as it is able to be mixed at concentrations up to 15% with existing diesel, reducing fuel costs and exhaust emissions with minor engine modifications.

Table 8.3 Methanol Production Technologies Pros and Cons

Pros	Cons
Commonly used steam methane reforming method is widely used in industry and proven	Steam methane reforming produces waste gas and carbon dioxide
Methanol industry is heavily developed and there is a current demand	Green methane method is still premature and is waiting on technology advancements to bring down costs
Product is able to be transported easily	Requires a constant carbon dioxide/monoxide source and hydrogen source
Green option able to produce carbon neutral fuel source	Green hydrogen industry and technology is premature in Australia
Has potential to be used currently in mine haul fleet with minor modifications to decrease emissions	

8.4 Hydrogen

Hydrogen can be produced from many sources. Brown/Grey hydrogen utilises fossil fuels such as brown/black coal or natural/mine gas with no method of capturing the GHG emissions in the process. Common methods include steam methane reforming and coal gasification. Most of these methods result in syngas production and additional purification is required to capture the pure hydrogen for further use.

Blue hydrogen is able to utilise the same methods of production mentioned in Brown/Grey hydrogen production, however, includes a form of carbon capture technology to prevent carbon dioxide and other harmful greenhouse gasses being released into the atmosphere.

Green hydrogen relies on renewable energies such as solar or wind to produce electricity for hydrogen production. Currently, the main method utilised to convert the electricity produced from renewables to hydrogen is via electrolysis. There are two types of electrolysis hydrogen production methods commonly used in industry, including Polymer (Proton) Electrolyte Membrane (PEM) Electrolysis and Alkaline Electrolysis. Hydrogen can be utilised in a range of applications for example to create heat, serve as long term energy storage, blended with natural gas or mine gas to create a cleaner fuel source, and used as a fuel.

Table 8.4 Hydrogen Pros and Cons

Pros	Cons
Variety of potential commercial and industrial applications	High degree of complexity requiring skilled staff to maintain
Brown/Grey and Blue hydrogen production methods are mature and proven technologies in a number of global applications.	Cost to produce green hydrogen is currently not viable for commercial use
Green Hydrogen is a production method that does not emit GHG emissions.	Training and standards are still relatively immature
	Brown/Grey hydrogen production results in GHG emissions

8.5 Virtual Pipelines

A virtual pipeline is a system that allows for natural gas transportation in the form of compressed or liquified gas via trucks, boats and/or rail. Essentially the purpose of this is to allow sites that are unable to access a physical gas pipeline source to be connected to industrial facilities, institutions domestically or internationally. This also acts as an alternative as actual pipe infrastructure can be a costly and complex exercise. This application may apply to mine clusters potentially allowing mine gas from the surrounding mines in close proximity to each other to be dispatched to a common processing facility allowing the gas to be treated and dispatched or incorporated into the state gas supply system.

Table 8.5 Virtual Pipelines Pros and Cons

Pros	Cons
Virtual Pipeline systems have been utilised	Requires extensive transportation network
Cost in comparison in production of a physical pipeline is a substantial difference short and long term.	Transportation vehicles emit carbon dioxide
Process can be undertaken internally or in contractors in the relevant industries	

8.6 Hazer Process

The Hazer Process is a production method developed by the University of Western Australia and commercialised by the Hazer Group. The main feed source natural gas, and a catalyst of iron ore, are input into a reactor. The reactor is heated resulting in a reaction between the natural gas and iron ore to extract the carbon from the methane and capturing it around the iron ore particles. As a result, hydrogen and graphite are an output. Currently Hazer group are in the process of constructing a demonstration plant in Woodman Point with engineering and acquisition commencing in 2020.

Table 8.6 Hazer Process Pros and Cons

Pros	Cons
Ability to produce hydrogen at a decreased cost compared to green hydrogen	High degree of complexity requiring skilled staff to maintain
Carbon is captured as graphite and able to be utilised in other applications	Currently no commercial plant constructed only a demonstration plant

8.7 Available technology / table fatal flaws

To determine the implementation status of the above defined technologies an assessment was performed. High level critical assessment criteria were developed accompanied by a numerical ranking process to gauge the level of applicability and current readiness this technology for the mining industry.

The assessment criteria sections are outlined below:

- Safety
- Technology Development Phase
- Time to Commercialisation
- Scalability
- Industry Acceptance & Experience
- Harmful Products / Waste
- Process Efficiency and Emissions

The critical assessment criteria and its relevant ranking definitions are outlined in Appendix A

The Table 16.7 below, includes the results of the assessment on the alternative technologies in section 8. It is observed that the highest-ranking technology is the virtual pipeline. This technology has been progressively introduced into the mining industry and is now a service provided by many gas services and equipment providers to mines that both produce and not produce gas as part of their production process to provide energy or a means of exporting excess gas. The safety case for this operation is easily adaptable from other industries and operations such as oil and gas, and transportation. The other technologies are currently still in the process of development or have not yet been proven in the mining industry. The assessment criteria used for Table 16.7 is outlined in Appendix A .

Table 16.7 Alternative Technology Assessments

Technology Assessment	Small-Scale LNG Production	Compressed Natural Gas (CNG) Production	Methanol Production Technologies	Green Hydrogen	Virtual Pipelines	Hazer Process
Safety	7	3	5	5	7	7
Development Phase	10	10	7	7	10	7
Time to Commercialisation	10	10	10	3	10	3
Scalability	1	1	2	5	10	1
Industry Acceptance & Experience	7	7	7	3	10	3
Harmful Products / Waste	10	10	7	7	10	7
Process Efficiency & Emissions	5	5	7	7	5	7
TOTAL SCORES	50	46	45	37	62	35

9 CONCLUSIONS AND RECOMMENDATIONS

i. The current "just in time" approach to gas management is not compatible with long term emissions forecasting, planning and abatement. This challenge will require a change in mindset to a holistic, long term view of emissions with better abatement outcomes. This should be supported through education and targeted incentives including literacy of the use of tools such as marginal abatement cost curves.

ii. The early capture of gas into a pipeline is better than later gas emitted through VAM which becomes significantly more difficult to capture and abate. Incentives should be designed strongly in favour of early gas capture up to 10 years ahead of mining.

iii. Typically, VAM comprises up to 67% of emissions for an underground coal mine and represents the largest remaining opportunity to reduce emissions by area. Whilst there are well established technologies for flaring and power generation, the application of VAM technology has not been at the same rate of development. Further incentives and funding should prioritise the use of existing and developing VAM technologies where opportunities are available for deployment.

iv. The analysis completed in this project is that up to 50% of emissions comes from existing mined out areas which have been sealed and represents a significant opportunity to reduce emissions through ventilation techniques such as pressure balancing, improving seal quality etc. Within the industry, however, the focus on managing already extracted areas including emissions is limited. An increased focus on the management of emissions in previously mined areas will be required to achieve significant emissions reductions.

v. The growth of abatement technology solutions globally that can be applied to the mining industry will support the reduction of emissions towards net zero. With many administrative and technical hurdles slowing the adoption of these technologies, there needs to be a fast tracking of the assessment and adoption of these technologies to maximise abatement.

vi. Marginal Abatement Cost Curves and their use for identifying optimal emissions abatement projects is a new concept to the mining industry. The mining industry would significantly benefit from the education of key stakeholders and decision makers of the development in NSW Government Policy and Programs and the use of abatement planning tools such as the MACC.

vii. More detailed engineering analysis (including site visits by engineering personnel) and requests for site specific budget quotes/costs is recommended to increase the order of accuracy of the estimates provided in this report to a Pre-Feasibility level.

viii. Analysis of the potential revenue streams such as mine/CHPP power cost offsets and ERF ACCU eligibility specific to each site is recommended to be undertaken in more detail in the next study stage.

Appendix A Critical Assessment Criteria

Safety		Technology Development Phase		Time to Commercialisation		Scalability	
Known events have occurred with multiple fatalities, major plant damage, Global negative media exposure for organisation	1	Research Phase Only	1	10 years to commercialisation	1	Fixed plant output requires complete duplication to increase capacity	1
Known events have occurred with single fatality & major injuries, major plant damage, and negative media exposure	3	Concept Prepared Only	3	8 years to Commercialisation	3	Plant sizing has some level of capacity sizing based on min and maximum variables to design within	3
Known events have occurred incurring major business interruptions and potential safety risk and exposure to workers	5	Prototype Being Tested Only	5	5 years to Commercialisation	5	Certain items of plant are modular allowing capacity increase as long as key process inputs are sized for the maximum expected capacity requirement	5
Only minor events only identified in industry search	7	Small scale Industry Testing Commenced	7	3 years to Commercialisation	7	Modular in construction and plug and play to allow capacity increase	7
No major events recorded or identified within industry search	10	Product has been in market commercially for a number of years	10	Product was released prior to 2020	10	Self contained units capacity is a multiple of the number of units, before fixed plant becomes more economical	10

Industry Acceptance & Experience			Harmful Products / Waste		Process Efficency & Emmssions	
Presently no commercial example available / operating within industry	1		Process requires strict access conditions with specialist safety equipment to minimise exposure to harmful waste or toxic gases	1	Process creates greenhouse gasses however is difficult to implement carbon capture or other technology to prevent	1
Commercial example operating in other industries Global	3		Process / product produces by products requiring specific treatments to make safe before disposal or exposure to humans or animals	3	Process creates greenhouse gasses however efficiency losses occur when implementing carbon capture or other technology to prevent	3
Commercial Example operating in Coal Industry Global	5		Process / product is monitored within specific guidelines and if maintained present no significant risk to humans or the environment	5	Produces greenhouse gasses but is easily able to impliment another technology or carbon capture to offset or eliminate the emission	5
Commercial Example operating in Australian industry	7		Process / product gives of no harmful products or gases at limits to be harmful to humans, animals or the environment	7	Produces Greenhouse Gasses but green alternative produced can be utilised	7
Commercial Example operating in Australian industry and specifically Coal	10		Process general by products or waste that is friendly to the environment and promotes growth or food products	10	Green alternative is produced and is financially viable	10

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