



**CLEAN DEVELOPMENT MECHANISM  
PROJECT DESIGN DOCUMENT FORM (CDM-PDD)  
Version 03 - in effect as of: 28 July 2006**

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**SECTION A. General description of project activity****A.1. Title of the project activity:**

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The Capture, Destruction and Utilisation of Mine Methane at the Beatrix West Shaft in South Africa  
Version 1.0

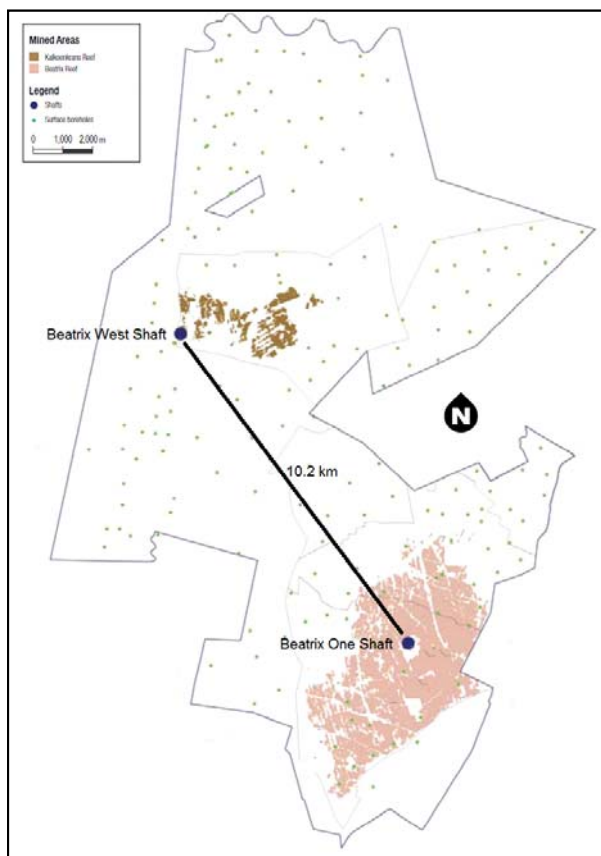
Date: 04 April 2012

**A.2. Description of the project activity:**

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**Purpose:**

The proposed project activity is to reduce greenhouse gas emissions through the capture, destruction and utilisation of mine methane from the West shaft of the Beatrix Gold Mine. The Beatrix Gold Mine (hereafter referred to as “Beatrix”) is owned and operated by GFI Mining South Africa, a wholly owned subsidiary of Gold Fields Ltd. The Beatrix West shaft is located 10.2 km North-West of the Beatrix One Shaft where CDM project 4728 was registered on 10 June 2011.



**Figure 1: Project location relative to Project 4728**



Methane is released by mining activities in the Beatrix West shaft. The gas is released when mining activity intersects methane carrying geological faults. Currently, the methane is diluted with ventilation air to below its explosion limits and released into the atmosphere through ventilation shafts.

The proposed project will install structures underground to capture the methane and pipe it to the Beatrix West ventilation shaft where it will be piped to surface. Once at surface, the methane will be flared and used to generate electricity.

Electricity will be generated in internal combustion engines. Waste heat from the internal combustion engines will be used in absorption chillers. The excess methane that cannot be handled by the engines will be flared in an enclosed flare.

The electricity generated in the project activity will be used as captive capacity to displace grid electricity at the Beatrix West shaft. The refrigeration produced by the absorption chillers will replace refrigeration from compressor chillers using grid electricity.

The baseline scenario for this project activity is the continuation of the current practice, which is to dilute and vent the mine methane and import electricity from the grid.

#### **GHG Reduction:**

The project will reduce greenhouse gasses in three ways:

- The flaring of methane will reduce the amount of methane released into the atmosphere to below that of the baseline.
- The use of methane to generate electricity will reduce the amount of electricity Beatrix needs to import from the South African grid. South African grid electricity is generated predominantly from low grade coal.
- The use of waste heat in absorption chillers will further reduce the amount of electricity imported from the grid by displacing chilling capacity from electrically driven compressor chillers.

#### **Contribution to Sustainable Development:**

The project makes positive contributions to sustainable development. The South African Designated National Authority (DNA) evaluates sustainability in three categories: Economic, environmental and social. The contribution of the project towards sustainable development is discussed in terms of these three categories:

- **Economic:** The project will contribute to foreign reserve earnings for South Africa via the carbon credit sales revenue.
- **Environmental:** At a regional level, the project will have a positive impact on the environment. This positive impact relates to a reduction in the generation of coal-based electricity and its associated environmental consequences. These consequences include: the impact of coal mining, the utilisation of scarce water resources, SO<sub>2</sub> emissions and the impacts associated with the disposal of coal ash.



The project will result in a reduction of greenhouse gas emissions by eliminating the release of methane; which has a global warming potential of 21 times that of carbon dioxide.

- **Social:** The project will create jobs in both the construction and operations phase.

GFI Mining South Africa have committed to contributing a percentage (R0.20 per ton of CO<sub>2</sub>e and 0.5% of pre-tax profit) of their carbon credit revenue to The Gold Fields Foundation. This is similar to the contribution GFI Mining South Africa makes out of gold mining revenue in terms of its social sustainable development obligations as dictated by the South African mining legislative framework relating to sustainable development.

The Gold Fields Foundation is involved in a number of projects aimed at the social wellbeing of the local communities. These projects target local economic development with a positive environmental impact. Examples of these projects include:

- Golden Oils – a community based, indigenous plant essential oil project
- Bulk water supply to the Lejweleputswa District
- Land and housing project in Masilonyana
- Beatrix day-care facilities

### **A.3. Project participants:**

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<b>Name of Party involved (*) ((host) indicates a host Party)</b>	<b>Private and/or public entity(ies) project participants (*) (as applicable)</b>	<b>Kindly indicate if the Party involved wishes to be considered as project participant (Yes/No)</b>
Republic of South Africa (host)	GFI Mining South Africa (Pty) Ltd	No

### **A.4. Technical description of the project activity:**

#### **A.4.1. Location of the project activity:**

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##### **A.4.1.1. Host Party(ies):**

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The host party is the Republic of South Africa.

##### **A.4.1.2. Region/State/Province etc.:**

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The project is located in the Free State Province.

##### **A.4.1.3. City/Town/Community etc.:**

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Beatrix mine is situated south of Virginia in an area known as the “Welkom Gold Fields.” Beatrix mine is in the Theunissen district of the Free State. Beatrix falls under Masilonyana Local Municipality and Lejweleputswa District Municipality.

**A.4.1.4. Details of physical location, including information allowing the unique identification of this project activity (maximum one page):**

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The project activity will be implemented at the Beatrix West shaft. The GPS coordinates of the shaft are:  
28° 11.172'S  
26° 43.309'E

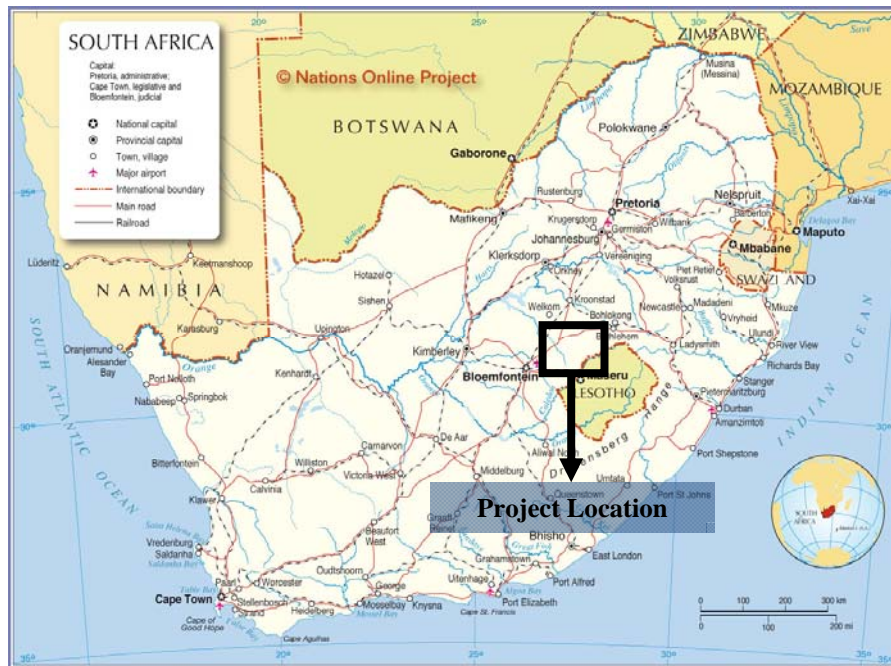


Figure 1: Map of Southern Africa

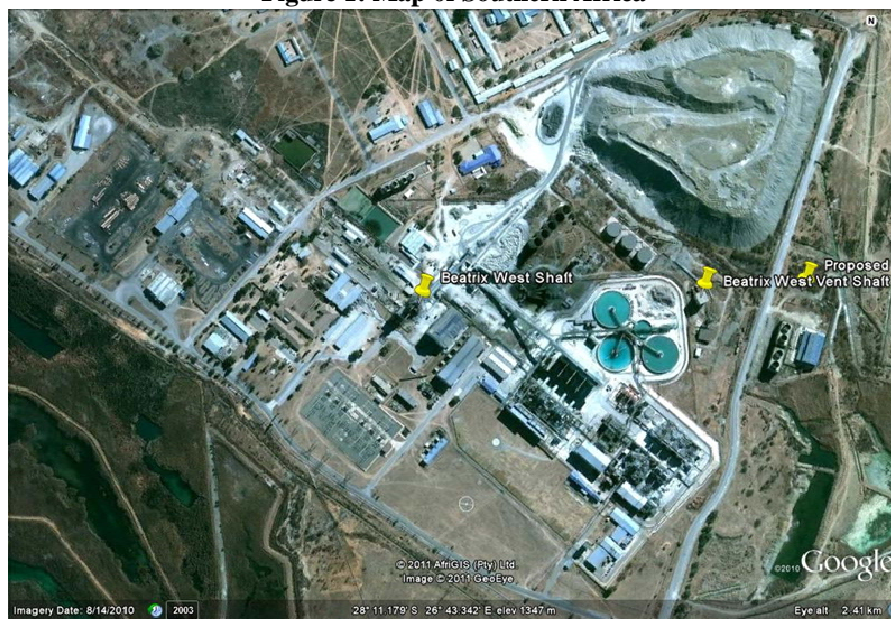


Figure 4: Beatrix West site layout

**A.4.2. Category(ies) of project activity:**

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The project category is:

Sectoral Scope 10: Fugitive emissions from fuels (solid, oil and gas)

**A.4.3. Technology to be employed by the project activity:**

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The methane is found in geological faults in the Freestate goldfields where the Beatrix Gold Mine is situated (Hugo, 1963). This methane is liberated when a methane carrying fault is intersected during the mining operations.

The methane will be captured by sealing off areas into which the methane is released by geological faults. Pipes will be installed to transport the methane from these areas to the vent shaft and up the vent shaft to surface.

The implementation of this project results in a transfer of environmentally safe and sound technology, and know-how to be used, to the Host Party. The technology implemented is proven technology (a similar project has been implemented at another shaft on the Beatrix mine) adhering to international standards. The Gold Fields employees will be trained to have the required know-how of the technology and the functioning of the project activity.

Methane is released by mining activities in the Beatrix West shaft. The gas is released when mining activity intersects methane carrying geological faults. Currently, the methane is diluted with ventilation air to below its explosion limits and released into the atmosphere through ventilation shafts.

The proposed project will install structures underground to capture the methane and pipe it to the Beatrix West ventilation shaft where it will be piped to surface. Once at surface, the methane will be flared and used to generate electricity.

Electricity will be generated in internal combustion engines. Waste heat from the internal combustion engines will be used in absorption chillers. The excess methane that cannot be handled by the engines will be flared in an enclosed flare.

The electricity generated in the project activity will be used as captive capacity to displace grid electricity at the Beatrix West shaft. The refrigeration produced by the absorption chillers will replace refrigeration from compressor chillers using grid electricity.

The baseline scenario for this project activity is the continuation of the current practice, which is to dilute and vent the mine methane and import electricity from the grid.

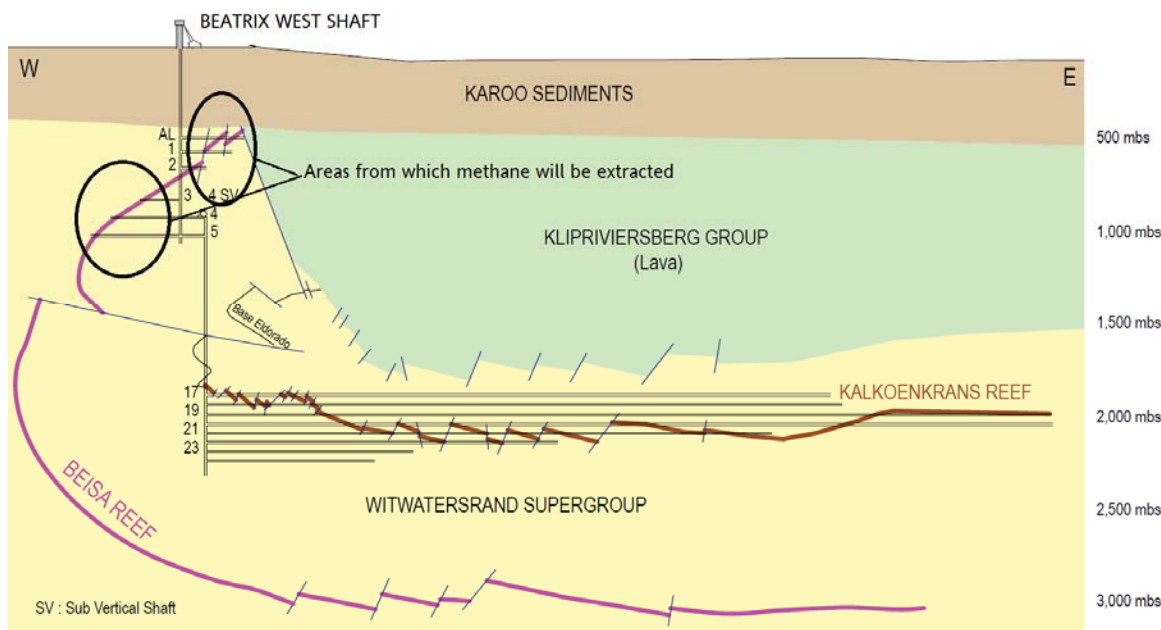


Figure 6: The underground areas for mine methane extraction.

The Beisa mining area, having a number of methane gas emitters will be sealed off, allowing in the order of 500 l/s of methane gas being emitted to accumulate, captured and be piped to surface from A level, the uppermost level of the Beisa mining area. The initial installation will consist of one monitoring station underground to monitor the condition of the methane gas which will include the flow rate of the gas. The pipeline to capture the methane gas will be constructed on A level.

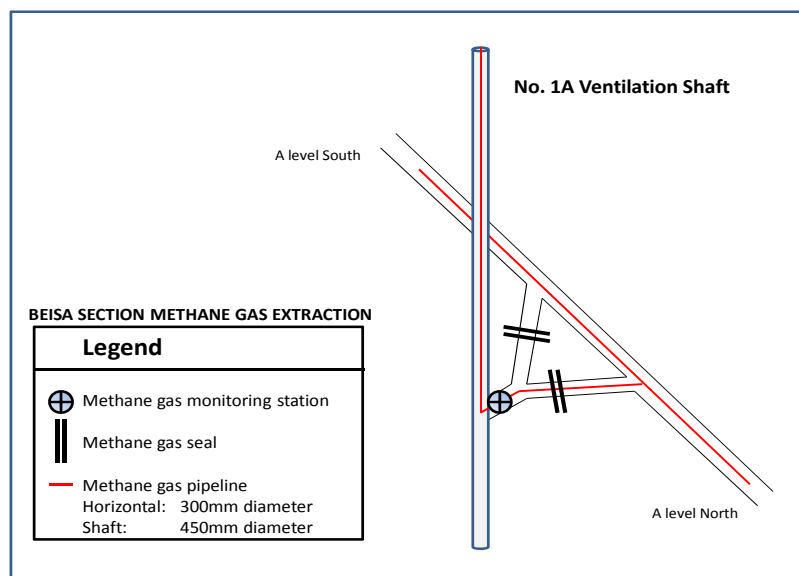
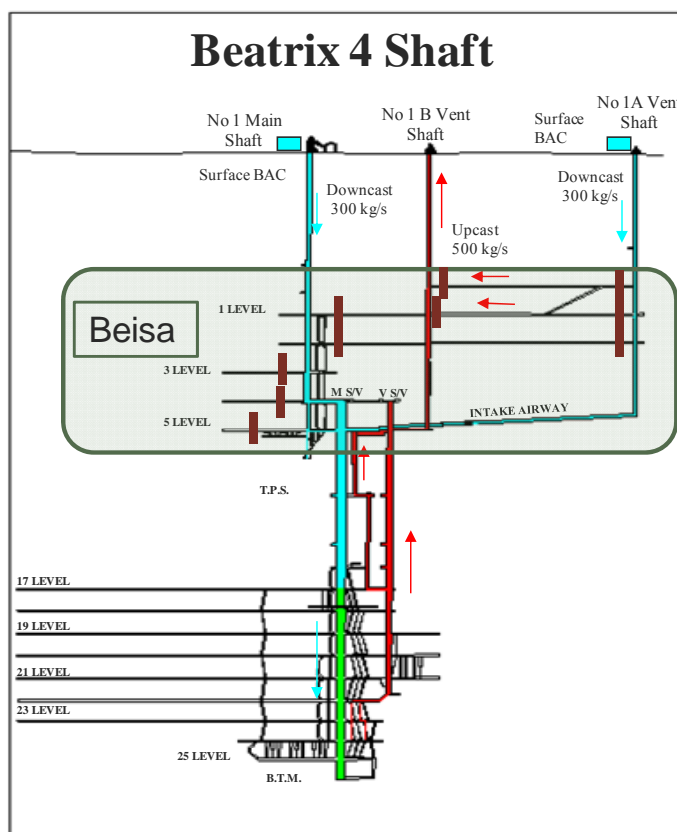


Figure 7: The underground piping and monitoring system for the mine methane extraction



**Figure 2: Sealing plan for Beisa section**

Due to the nature of the methane source, it is not possible to accurately predict the volume of methane that will be released in the mine. However, based on experience, GFI Mining South Africa is comfortable that they will be able to deliver a maximum of 500 l/s (100% methane at atmospheric conditions) of pure methane from the mine. Once the extraction piping and flaring facility are complete, accurate measurements can be taken and there will be more certainty of the amount of gas available.

For the purposes of the ex-ante calculation of the emission reductions, a total methane flow rate of 400 l/s (100% methane at atmospheric conditions) was used to be conservative.

Initial gas analysis of the methane containing gas had the following composition:

Propane	Carbon Dioxide	Ethane	Oxygen	Nitrogen	Methane
<50ppm_vol	2764ppm_vol	240ppm_vol	4.72%	24.18%	70.8%

The gas composition is however subject to change. A gas composition of 70.8 volume % methane was assumed for the ex-ante calculation of the emission reductions.

**Electricity generation from mine methane:**



The captured mine methane will be combusted in internal combustion engines to generate electricity. This will be done after a first phase during which the methane will be flared to more accurately establish amount of methane emitted.

The plan is to install 4 internal combustion engines each with an electrical generation capacity of 1.345 MWe. The plant will produce roughly 44 772 MWh per year. Owing to the variability in the methane flow rate, engines may be decommissioned or more engines may be installed at a later stage.

#### **Flaring of mine methane:**

During the first phase of the project all the methane will be flared in order to accurately determine the amount of methane available for power generation. This phase will last a minimum of 6 months.

The mine methane that is not consumed by the engines will be flared in an enclosed flare. None of the captured methane will be released back into the atmosphere. The flare will have a minimum flowrate of 7l/s. It will be desirable to keep the flare running at a very low capacity even when the engines are running at full load. This will ensure that the flare is alight and will be able to immediately burn any additional gas should an engine trip.

When the internal combustion engines are offline for maintenance or unforeseen circumstances, all the captured methane will be flared. The flare will have a capacity of 700 l/s.

#### **Waste heat recovery:**

Waste heat from the internal combustion engines will be used in absorption chillers. The initial installation will consist of 1 chiller with a cooling capacity of 4.6 MW<sub>thermal</sub>, reducing grid electricity consumption by 7 428 MWhr per year.

#### **A.4.4. Estimated amount of emission reductions over the chosen crediting period:**

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The estimated amount of emission reduction over the chosen crediting period is represented below:

**Table 1: Summary of emission reductions**

<b>Years</b>	<b>Annual estimation of emission reductions in tonnes of CO<sub>2</sub>e*</b>
1	76 264
2	171 128
3	171 128
4	171 128
5	171 128
6	171 128
7	171 128
8	171 128
9	171 128
10	171 128
<b>Total estimated reductions (tonnes of CO<sub>2</sub>e)</b>	<b>1 616 416</b>
<b>Total number of crediting years</b>	<b>10</b>



<b>Annual average over the crediting period of estimated reductions</b> (tonnes of CO <sub>2</sub> e)	<b>161 642</b>
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Due to the variation of mine methane, the emission reduction figures in the table above were calculated based on measurements and estimates taken during the development of the project. There is no guarantee that the underground methane emission rate will stay constant. The methane emission rate may increase or decrease, depending on changing geological conditions. Should this happen, the emission reduction by the project will vary accordingly.

**A.4.5. Public funding of the project activity:**

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No public funding has been used or will be used in the development and implementation of this project.



**SECTION B. Application of a baseline and monitoring methodology****B.1. Title and reference of the approved baseline and monitoring methodology applied to the project activity:**

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This PDD is compiled using the approved baseline and monitoring methodology AM0064:

**“Methodology for methane capture and utilization or destruction in underground, hard rock, precious and base metal mines”** Version 02, EB 42

This PDD refers to the following tools:

- “Tool to calculate baseline, project and/or leakage emissions from electricity consumption” Version 01;
- “Combined tool to identify the baseline scenario and demonstrate additionality” Version 4.0.0;
- “Tool to determine project emissions from flaring gases containing methane” Annex 13, EB28;
- “Tool to calculate the emission factor for an electricity system” Version 02.2.1.

No fossil fuel is used to capture, transport or use the mine methane. Hence, the “Tool to calculate project or leakage CO<sub>2</sub> emissions from fossil fuel combustion” Version 02 is not used in the PDD.

**B.2. Justification of the choice of the methodology and why it is applicable to the project activity:**

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AM0064 was developed by Promethium Carbon (Pty) Ltd specifically for the registered project “The Capture and Utilisation of Methane at the GFI Mining South Africa owned Beatrix Mine in South Africa”. The latter registered project is very similar to this project activity.

A discussion of the applicability of AM0064 as applied to this project follows:

**Table 2: Discussion of the applicability of AM0064 for mine methane**

<b>Discussion of the Applicability conditions of AM0064 for mine methane capture and utilization or destruction as applied to the Beatrix Underground Methane Capture Project</b>		
<b>Applicability criteria as in AM0064</b>	<b>Project activity at Beatrix mine</b>	<b>Was the Applicability condition of AM0064 met?</b>
<i>The applicability conditions apply to project activities that involve capture, utilisation or destruction of methane from any operating mine, excluding mines where coal is extracted.</i>	The Beatrix West shaft is an operating mine. Methane will be captured, utilized and destroyed. Beatrix West is not a coal mine.	Yes
<i>Mine methane can be captured from the following:</i> • <i>Underground boreholes in the mine, where mine methane can be captured from:</i> - <i>Development ends including shafts, access drives,</i>	Methane will be captured from underground boreholes, gas drainage galleries and sealed areas	Yes



<p>ore passes or other developments;  - Existing infrastructure such as shafts, access drives, raises and winzes;  - Working areas including working stopes and worked out stopes; or  - Any other area opened up for the development of the mine or the extraction of ore;</p> <ul style="list-style-type: none"> <li>• Surface wells drilled into sealed off areas where the mine methane is accumulated;</li> <li>• Gas drainage galleries or other infrastructure using mine methane capture techniques, including capture of gas from sealed areas;</li> <li>• Ventilation air.</li> </ul>	<p>as described.</p> <p>Surface well drainage from sealed off areas where mine methane is accumulated could be considered if future methane sources are identified due to continued mining.</p> <p>Ventilation air methane will not be used.</p>	
<p>The mine methane can be removed from the mine, in which the project activity is implemented, in two ways:</p> <ol style="list-style-type: none"> <li>1. By sealing off an area into which the methane is released and piping it from that area, and/or</li> <li>2. By piping the methane from underground boreholes.</li> </ol>	<p>Both these removal methods will be used in this project.</p>	<p>Yes</p>
<p>For the purposes of this component, drainage to surface boreholes is only allowed in the following cases:</p> <ul style="list-style-type: none"> <li>• Where a hole is drilled from the surface to an underground mining area where mine methane is allowed to accumulate. For safety reasons, such an area will be isolated (sealed off) from the rest of the workings by walls. Methane will be drained into these areas with the purpose of taking it to the surface via the borehole.</li> <li>• Where a hole is drilled from the surface to an underground mining area and a pipe into which mine methane has been collected is connected to the opening of the borehole where it intersects the mining area. In this case the borehole is used to convey mine methane to surface rather than to install a pipe column in the shaft.</li> </ul>	<p>Depending on future mine development, methane may be drained to surface through boreholes drilled into underground mining areas where methane is allowed to accumulate.</p> <p>Methane extraction, from surface boreholes, that does not comply with the requirements of AM0064 will not be done.</p>	<p>Yes</p>
<p>The methodology is applicable under the following conditions:</p> <ul style="list-style-type: none"> <li>• The captured mine methane is utilised to produce electricity, motive power and/or thermal energy and/or destroyed through flaring;</li> <li>• Prior to the start of the project activity all mine methane was released into the atmosphere or partially used for heat generation;</li> <li>• The methodology applies to both new and existing mining activities;</li> <li>• Project participants must be able to supply the</li> </ul>	<p>Captured methane will be flared, used for electricity generation and the generation of thermal energy.</p> <p>No prior use of the methane exists and all methane is diluted in the ventilation air.</p>	<p>Yes</p>



<i>necessary data for ex-ante projections of methane demand in the case where part of mine methane was used for the heat generation prior to the start of the project activity.</i>	Beatrix West is an existing mining operation.	
<i>This component of the methodology does not apply to project activities that:</i> <ul style="list-style-type: none"> <li>• Operate in coal mines;</li> <li>• Operate in open cast mines;</li> <li>• Capture methane from abandoned or decommissioned mines;</li> <li>• Capture/use methane from surface boreholes that do not intersect mining areas/developments underground;</li> <li>• Use CO<sub>2</sub> or any other fluid/gas to enhance methane drainage.</li> </ul>	Beatrix mine is not a coal mine and is not an open cast mine.  Beatrix West is, furthermore, an operating mine and not an abandoned or decommissioned mine.  Future surface borehole methane extraction will only be done for mining areas/developments underground.  No CO <sub>2</sub> will be used for enhanced methane drainage.	Yes
<i>In addition, the applicability conditions included in the tools referred to above apply.</i>	All tools that AM0064 refers to were adhered to.	Yes
<i>Finally, for mine methane capture and utilization or destruction, this methodology is only applicable to project activities where the identified baseline scenario is a partial or total atmospheric release of mine methane. In case of a partial atmospheric release, some mine methane is flared and/or used for the heat generation only.</i>	The baseline selection section will illustrate that atmospheric methane release is the baseline scenario.	Yes

**B.3. Description of the sources and gases included in the project boundary:**

&gt;&gt;

The spatial extent of the project boundary comprises:

- All equipment installed and used as part of the project activity for the extraction of the methane at the project site.
- Flaring and captive power facilities installed and used as part of the project activity.
- Power plants connected to the electricity grid, where the project activity exports or imports power from the grid, as per the definition of an electricity system in the latest approved version of the “Tool to calculate the emissions factor for an electricity system.”

The boundary for the capture of mine methane includes:

- Piping of the methane to the surface

- Underground monitoring stations for the methane

A diagram of the boundary for the capture of mine methane can be seen below:

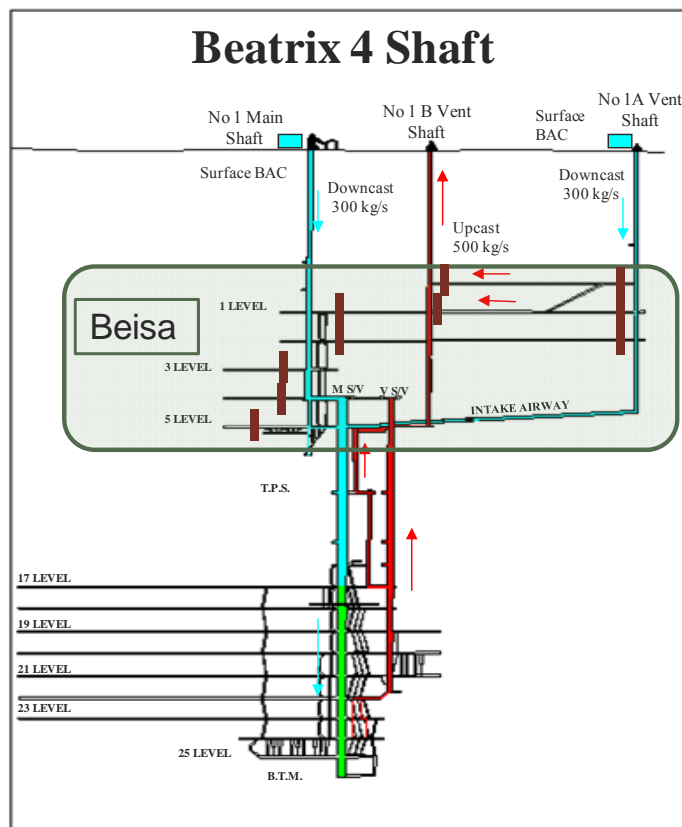
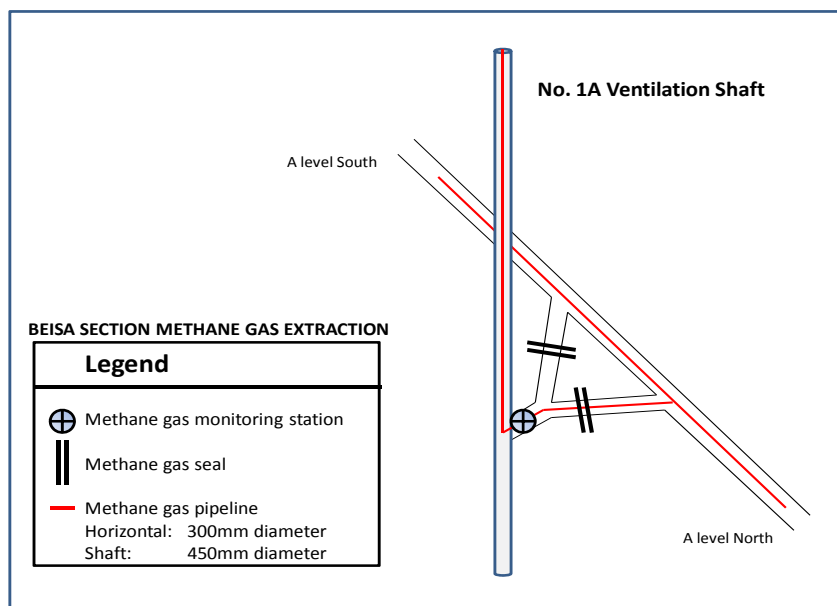


Figure 3: Beisa section



**Figure 7: The underground piping and monitoring system for the mine methane extraction**

The boundary for the destruction and utilisation of mine methane includes:

- The piping of methane on the surface to the flare (Phase 1) and internal combustion engines (Phase 2)
- The fan on the surface used to increase the pressure of the methane (Phase 1)
- The flare (Phase 1)
- The internal combustion engines (Phase 2)
- Absorption chillers (Phase 3)
- The instrumentation on the surface, which is in place for monitoring (Phase 1)

A diagram of the boundary for the destruction and utilisation of mine methane can be seen below:

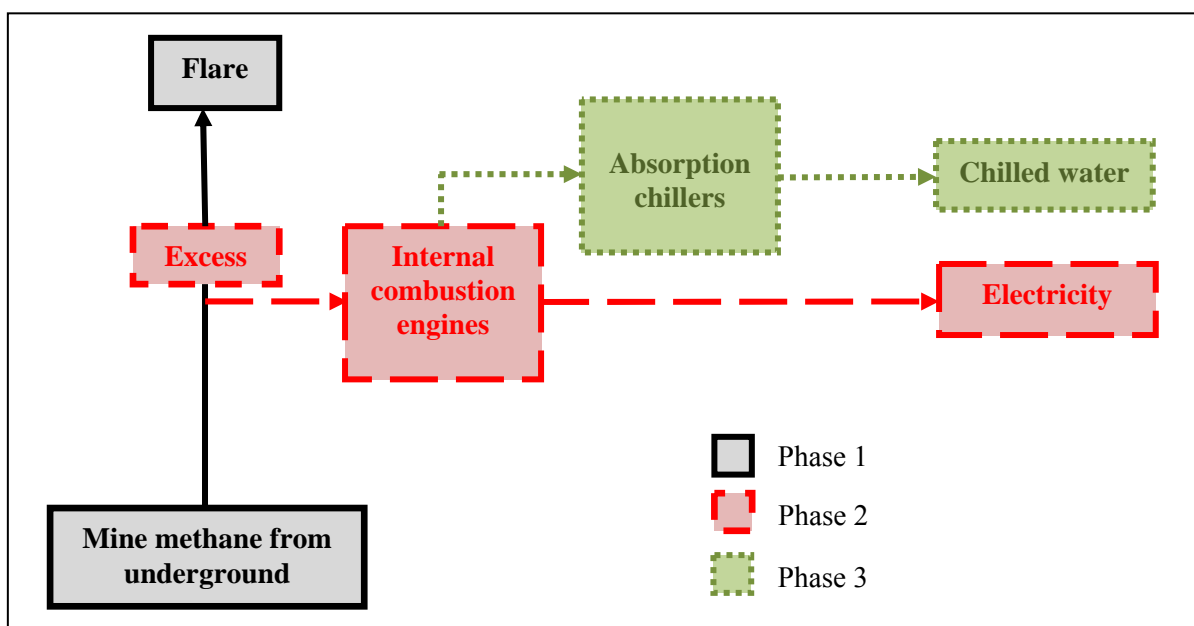


Figure 4: Destruction and utilisation of mine methane (3 phases indicated in one diagram)

Table 4 illustrates which emissions sources are included and which are excluded from the project boundary for determination of both baseline and project emissions.

Table 4: Overview on emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Venting of methane	CO <sub>2</sub>	No	Excluded.
		CH <sub>4</sub>	Yes	Emissions from the venting of mine methane are included in the project boundary.
		N <sub>2</sub> O	No	Excluded. There is no N <sub>2</sub> O in the gas.
Baseline	Emissions from use or destruction of methane in the baseline	CO <sub>2</sub>	Yes	Emissions from any flaring or use for heat generation in the baseline scenario are included in the project boundary. However, no methane was flared or used in the baseline.
		CH <sub>4</sub>	No	Excluded for simplification. This is conservative.
		N <sub>2</sub> O	No	Excluded for simplification. There is no N <sub>2</sub> O in the gas.
	Emissions from electricity generation in the grid	CO <sub>2</sub>	Yes	Included in the project boundary as the project will generate electricity from the mine methane through engines.
		CH <sub>4</sub>	No	Excluded for simplification. This is conservative.
		N <sub>2</sub> O	No	Excluded for simplification. This is conservative.



Source		Gas	Included?	Justification / Explanation
	Emissions from captive power and/or heat generation, and vehicle fuel use	CO <sub>2</sub>	Yes	Included in the project boundary as the project activity includes power generation from the mine methane.
		CH <sub>4</sub>	No	Excluded for simplification. This is conservative.
		N <sub>2</sub> O	No	Excluded for simplification. This is conservative.
Project activity	On-site fuel consumption due to the project activity, including transport of the gas	CO <sub>2</sub>	Yes	The electricity used by the equipment in the project activity will be included in the project boundary. Apart from electricity, no other fossil fuels are used in the project activity.
		CH <sub>4</sub>	No	Excluded for simplification. This emission source is assumed to be negligible.
		N <sub>2</sub> O	No	Excluded for simplification. This emission source is assumed to be negligible.
	Emissions from methane combustion	CO <sub>2</sub>	Yes	Emissions from the combustion of mine methane in flares and engines will be included in the project boundary.
		CH <sub>4</sub>	No	Excluded for simplification.
		N <sub>2</sub> O	No	Excluded for simplification.
	Emissions from NMHC destruction	CO <sub>2</sub>	Yes	If NMHC accounts for more than 1% by volume of extracted mine methane then the emissions from the combustion of NMHC in flares and engines must be included in the project boundary. The NMHC content of the gas will be monitored in the project activity.
		CH <sub>4</sub>	No	Excluded for simplification.
		N <sub>2</sub> O	No	Excluded for simplification.
	Fugitive emissions of unburned methane	CO <sub>2</sub>	No	Excluded.
		CH <sub>4</sub>	Yes	Small amounts of methane will remain unburned in flares and power generation. This methane will be accounted for and included in the project boundary.
		N <sub>2</sub> O	No	Excluded.
Fugitive methane emissions from on-site equipment	CO <sub>2</sub>	No	Excluded for simplification. This emission source is assumed to be very small.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Fugitive methane emissions from gas supply pipeline or in relation to use in vehicles	CO <sub>2</sub>	No	Excluded for simplification. However other leakage effects are taken into account in the project.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Accidental methane release	CO <sub>2</sub>	No	Excluded for simplification. This emission source is assumed to be very small.	
	CH <sub>4</sub>	No		



Source	Gas	Included?	Justification / Explanation
	N <sub>2</sub> O	No	

**B.4. Description of how the baseline scenario is identified and description of the identified baseline scenario:**

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The “Combined tool to identify the baseline scenario and demonstrate additionality” Version 4.0.0 was used to identify the baseline scenario in the following manner:

**STEP 1: Identification of alternative scenarios**

***Sub-Step 1a: Define alternative scenarios to the proposed CDM project activity***

The identified alternative baseline scenarios are:

- A. Diluting the methane to safe and acceptable levels with ventilation air is technically feasible. The ventilation air methane (VAM) can then be:
  - i. Vented to the atmosphere as VAM.
- B. Capturing of methane and extraction from underground boreholes or sealed off areas. The captured methane can then be:
  - i. Captured and vented above ground in a safe location;
  - ii. Flared above ground;
  - iii. Used for electricity and thermal energy generation with the excess flared; or
  - iv. Used for electricity and thermal energy generation with the excess flared without being registered as a CDM project activity. This is the proposed project activity for the destruction and utilisation of mine methane without CDM.

The baseline scenario alternatives include all possible options to generate electricity and/or heat:

- C. For the generation of electricity and/or heat:
  - i. Electricity can be imported from the national grid;

***Sub-Step 1b: Consistency with mandatory applicable laws and regulations:***

All options comply with the mandatory applicable laws and regulations.

**STEP 2: Barrier analysis**

***Sub-step 2a: Identify barriers that would prevent the implementation of alternative scenarios:***

A list of the alternative scenarios and the investment, technological barriers and barriers due to prevailing practice that they face is presented below:

***Scenario Ai: The VAM can be vented to the atmosphere***



The mine currently dilutes the methane with ventilation air and releases it into the atmosphere. This is common practice for mine methane from gold mines.

According to Hugo (1963) when referring to methane in the Orange Free State Gold-Field, “...as much gas as possible is allowed to escape through surface bore-holes or via the exhaust ventilation systems in order to reduce the methane hazard in the mines”

This is illustrated in more detail in a report by Cook (1998), “*The normal means of dealing with accumulations and emissions are well documented (various including Greig, 1989; Eschenburg, 1980), although a part of this is based on the assumptions that gases separate depending on relative densities. The methods include ventilation, cementing or plastering fissures, water infusion of fissures, drainage and compressed air.*”

And, “*It is generally considered that the relatively small methane volumes can be controlled by good ventilation practice and proper detection procedures (Jackson, 1957; Kidd ,1997), and that other procedures are additional for particular circumstances.*” (Cook, 1998)

Hence, there are no barriers to this scenario and it can be considered a possible baseline scenario for the mine methane.

***Scenario Bi: The mine methane can be captured and vented above ground in a safe location***

The mine methane is vented as VAM. Venting the mine methane not as VAM would require capturing the mine methane in its concentrated form then piping it up the shaft and finding a safe location in which to vent it. Firstly, the capturing and piping of concentrated methane would pose a safety risk to the mine. In addition, it is very difficult to find a safe location away from the mine and farms in the area, where this gas with a methane concentration above 85 volume % can be vented.

The dangers of methane are elaborated: “*Methane can be dangerous because the mixture of methane and air in a confined area can create explosive conditions! If the amount of methane in the air reaches 5 to 15 percent, an explosion can occur. If the amount of methane in the air increases even more, it can be flammable...Higher concentrations of methane in the air can also be dangerous because there is not enough oxygen for people to breathe.*” (Study Hall Webmaster, 2004)

Methane poses a huge safety risk to the mine and this option would increase the risk to safety at the mine. Finding a location to vent the methane is not an option as there is still a safety risk associated with the methane unless it is diluted below its explosion limits in air. This scenario is not an alternative baseline scenario.

***Scenario Bii: The captured mine methane can be flared above ground***

The captured mine methane can be flared above ground. This would require capturing the concentrated methane before it is diluted with ventilation air. This is not current practice in the mine. The capturing of the mine methane and piping it to surface increases the safety risk associated with the methane. It is much safer to dilute the methane at source to below its explosion limits in air and transport the VAM; which is current practice. The methane is diluted with ventilation air in the baseline. The methane is not captured and flared above ground. As there is no safety and no financial incentive to install a methane capturing and flaring system, this is not an alternative baseline scenario.



***Scenario Biii: The mine methane can be used for electricity and thermal energy generation with the excess flared***

The variability and unpredictability of the mine methane make it difficult to be used for additional reliable power generation. The mine needs a reliable power source in order to keep the miners safe underground. The variability and unpredictability of the methane is cited by Cook (1998), “*Uncertainty as to the origins and transport mechanisms of gas within the strata make emissions difficult to predict, so although the ventilation is adequate to control the normal situation, sudden emissions do create problems*” and “*The distribution of gas is across almost all mines, but to variable degrees. There is no distinct correlation between reefs, mines, depths or regions, making prediction difficult to generalise. Many individual mines and people have their own opinions where the chances of gas emissions are greater.*”

The use of methane poses a safety risk to personnel and will require adequate training on the risks associated with methane gas. According to Cook (1998), “*There is a general lack of awareness of the hazards of methane on mines, with only four mines considering combustible gases to be a problem*” and “*Methane ignitions have long been acknowledged as a hazard in South African gold and platinum mines, but the origins and transport mechanisms of the gas have not been well understood. This lack of understanding has contributed to the hazard, making gas emissions difficult to predict and prepare for.*”

Owing to the unpredictability of the mine methane flow and the hazardous nature of mine methane, this can be eliminated as a potential baseline scenario.

The generation of electricity in equipment such as an internal combustion engine would require training of personnel to operate and maintain the equipment. A service level agreement would need to be signed with the manufacturer of the engine to ensure that the engines were properly serviced.

***Scenario Biv: The mine methane can be used for electricity and thermal energy generation with the excess flared without being registered as a CDM project activity. This is the proposed project activity for the destruction and utilisation of mine methane without CDM.***

Owing to the unpredictability and uncertainty of the methane resource, this can be eliminated as a plausible baseline scenario. Please see Scenario Biii; which discusses the uncertainty of the methane resource and safety issues related to the use of mine methane. The variability of the methane makes it impossible to justify the installation of the methane extraction system and a power plant. This scenario is therefore not an alternative baseline scenario.

***Scenario Ci: The electricity can be imported from the national grid***

The mine already receives all of its electricity from the national grid and only has emergency generators on site. Sourcing all the electricity from the national grid is common practice and, hence, this option is a plausible baseline scenario. The mine already has all equipment in place to receive electricity from the grid. In addition, historically, grid electricity has always been cheap.

***Sub-step 2b: Eliminate alternative scenarios which are prevented by the identified barriers:***

This has been done in the analysis of the scenarios above. The only scenarios that are not eliminated as a result of the barriers are:

- A i. The mine methane is vented to the atmosphere as VAM
- C i. Electricity can be imported from the national grid



The alternative scenario that does not face any barriers is the baseline scenario. Hence, the baseline scenario for Beatrix is the continuation of the current practice, which is to dilute and vent the mine methane and import electricity from the grid.

Simply continuing with this practice has the following advantages:

- It conforms to all legal requirements provided that the mine methane is diluted sufficiently;
- No technological barriers exists as this is the accepted industry practice;
- No capital expenditure is required since the ventilation system currently in use at the Beatrix mine adequately dilutes the methane to an acceptable level; and,
- It is common practice to source electricity from the national grid.

#### Step 4: Common practice analysis

Globally, various projects are at different stages of development to utilize coal mine methane (CMM) for power generation. These projects are being developed as CDM projects. At least six of these projects are being executed in China. The proposed Beatrix West project is a deviation from these projects since Beatrix is a gold mine and the methane released is not related to the amount of gold mined.

The only similar project is the CDM registered project “The Capture and Utilisation of Methane at the GFI Mining South Africa owned Beatrix Mine in South Africa”. However, according to the “Combined tool to identify the baseline scenario and demonstrate additionality” (Version 4.0.0) it does not need to be included in this analysis seeing as the latter project is a CDM project activity.

The Beatrix mine is still the only gold mine planning to use the methane for electricity generation in South Africa. All methane from South African gold mines is simply diluted and vented. This is referenced in a letter from the Chamber of Mines of South Africa. This letter can be seen in Annex 5.

<p><b>B.5. Description of how the anthropogenic emissions of GHG by sources are reduced below those that would have occurred in the absence of the registered CDM project activity (assessment and demonstration of additionality):</b></p>
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Date	Milestone
26 Jan 2011	Proposal to develop CDM project submitted to Gold Fields by Promethium Carbon.
30 Aug 2011	CDM “Notice of Prior Intent” form submitted to CDM executive board and South African DNA.
21 Dec 2011	Letter of no objection received from DNA

The “Combined tool to identify the baseline scenario and demonstrate additionality” (Version 4.0.0) was used to demonstrate that the proposed project activity is additional.

Section B.4. lists the alternatives scenarios and the barriers that these scenarios face. Apart from the identified baseline, the alternatives scenarios, including the proposed project activity, face barriers. Therefore, all the other alternative scenarios, including the proposed project activity, are additional.



The additionality of the proposed project activity is further illustrated by the complete list of barriers listed below:

**Investment barriers *inter alia*:**

- Codes such as the SAMREC code (THE SOUTH AFRICAN MINERALRESOURCE COMMITTEE (SAMREC), 2011), the mineral resource quantification code of the JSE Securities Exchange (where Gold Fields is listed) or other international codes such as JORC are required by the investment community. When considering these codes, it is clear that the investment of capital in the available methane resources is not justifiable. This is because of the unpredictable nature of the methane occurrence. The proposed project, which involves the use of methane, therefore, is impossible to fund in terms of conventional mining finance.
- The unquantifiable and unpredictable nature of the mine methane makes debt funding of the proposed project impossible.
- The proposed project will require capital expenditure that would not be required in the continuation of the baseline.
- The importance of resource estimation in investment decisions can be seen from “*The mining industry depends on financial investments that, in turn, depend on how well investors understand the risks involved in estimating mineral resources or ore reserves. Professional organizations in several different countries have published codes that set minimum standards for public reporting of mineral resources and ore reserves.*” (Ramcharan & Moser, 2010)

**Technological barriers, *inter alia*:**

- The unpredictability of methane supply is a barrier to the project activity. The flowrate of the methane is expected to vary and the continuation of the release of methane is not a certainty. This poses risks in terms of plant capacity and investment. According to Head and Kissell (2006), “*Unlike coal mines, methane emission rates in metal/non-metal mines are not consistent. This irregularity often makes an accumulation of methane an unexpected event, and an unexpected event by definition is difficult to anticipate.*” This unpredictability of methane flowrate has also been experienced in the Beatrix Methane registered CDM project.
- The internal combustion engines require specialist labour and infrastructure.

**Barriers due to prevailing practice, *inter alia*:**

- Although a similar project has been implemented by Gold Fields under the CDM at the Beatrix mine, this is still the first and only mine in South Africa to implement a project like this, and is not common practice in the industry. This is demonstrated by the letter from the Chamber of Mines that is in Section B.4.
- Generating electricity is not part of the normal skill set of a mining activity.
- Largely because of the low cost of electricity and technological barriers, most mine operators in South Africa have not really considered the possibility of generating electricity from mine methane. Due to the delocalization of the methane sources and the unpredictability of the methane supply, it is not ideal for use as a fuel source.
- There is no legislative pressure to use the energy content from the methane. South African laws only make provision for safety issues regarding methane venting. Even where utilization has been identified as a priority, current legal policies offer little or no incentive for using mine methane to generate electricity.



- There is no policy or regulations preventing the release of methane in South Africa. In terms of the Mines Health and Safety Act employers and employees are obliged to identify hazards and eliminate, control or minimise the risk to health and safety. Operational experience on Beatrix has led the management to believe that the sealing off of surface holes forces methane that would have escaped on surface to escape into working areas. This increases the risk of workers in these working areas. The sealing of surface holes is therefore not allowed by management.

Registering the proposed project activity as a CDM project will alleviate the identified barriers in the following ways:

**Alleviating the Investment barriers *inter alia*:**

The carbon credit revenue will lower the financial risks associated with the project and, therefore, aid in overcoming the identified investment barriers. Phase 1 not viable without carbon credits, and subsequent phases not possible without Phase 1. Carbon credits will also alleviate the high risk associated with this project and the variable mine methane flowrate.

The project cannot be justified on the basis of a mineral extraction project in which methane is extracted and used to generate power as no resource statement can be prepared in terms of international mineral codes such as SAMREC or JORC. The presentation of the project as a CDM project removes the requirement to classify the project as a mineral resource project and the investment can therefore be approved.

**Alleviating the Technological barriers, *inter alia*:**

The technological barriers are linked to the operators of the technology. The additional revenue can also be used to cover the costs associated with the training of staff required to operate the specialised equipment.

**Alleviating the Barriers due to prevailing practice, *inter alia*:**

As was stated, the Beatrix mine is the “first of its kind” in South Africa to implement power generation projects from gold mine methane. The additional carbon credit revenue will make the project attractive to investors despite this risk.

**Additionality of project activity**

The proposed project activity is additional. This is demonstrated by the barrier analysis. Investment, technological and common practice barriers were identified. These barriers are overcome by the registration of the project as a CDM project. Therefore, the proposed capture and use of the Beatrix West mine methane satisfies the CDM additionality criteria.

**B.6. Emission reductions:**

**B.6.1. Explanation of methodological choices:**

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The emission reduction (ER), baseline emission (BE), project emission (PE) and leakage emissions (LE) are calculated as set out below:

**Baseline emissions for mine methane capture and utilization or destruction**

$$BE_y = BE_{MD,y} + BE_{MR,y} + BE_{Use,y} \quad (1)$$



Where:

$BE_y$	Baseline emissions in year y (tCO <sub>2</sub> e/yr)
$BE_{MD,y}$	Baseline emissions from the destruction of methane in the baseline scenario in year y (tCO <sub>2</sub> e/yr)
$BE_{MR,y}$	Baseline emissions from the release of methane into the atmosphere in year y that is avoided by the project activity (tCO <sub>2</sub> e/yr)
$BE_{Use,y}$	Baseline emissions from the production of power and/or heat displaced by the project activity in year y (tCO <sub>2</sub> e/yr)

In the baseline, no methane is used for any heat or electricity generation. Methane destruction in the baseline only occurs if the gas is ignited by accident. This accidental methane destruction is not desirable and is stopped as soon as possible for safety reasons. (This leads to  $BE_{MD,y} = 0$ .)

In the baseline, all methane was simply vented to atmosphere as ventilation air methane. The baseline emissions due to the ventilation of the methane will be captured in the  $BE_{MR,y}$ .

In the proposed project activity, the methane will be used to generate electricity. Excess methane will be flared. The generation of electricity will displace grid electricity used in the baseline. This will be captured in the  $BE_{Use,y}$  term.

Equation 1 becomes:

$$BE_y = BE_{MR,y} + BE_{Use,y} \quad (1.1)$$

Baseline emissions from the release of methane into the atmosphere:

Baseline emissions from the venting of methane were calculated as follows:

$$BE_{MR,y} = GWP_{CH_4} \times \sum_i \left[ (MM_{PR,i,y} - MM_{BL,i,y}) + (VAM_{PR,i,y} - VAM_{BL,i,y}) \right] \quad (6)$$

Where:

$BE_{MR,y}$	Baseline emissions from the release of methane into the atmosphere in year y that is avoided by the project activity (tCO <sub>2</sub> e/yr)
$GWP_{CH_4}$	Global Warming Potential of methane
$MM_{PR,i,y}$	Mine methane captured, sent to and destroyed by use i in the project activity in year y (tCH <sub>4</sub> /yr)
$MM_{BL,i,y}$	Mine methane that would have been captured, sent to and destroyed by use i in the baseline scenario in year y (tCH <sub>4</sub> /yr)
$VAM_{PR,i,y}$	VAM captured, sent to and destroyed by use i in the project activity in year y (tCH <sub>4</sub> )
$VAM_{BL,i,y}$	VAM that would have been captured, sent to and destroyed by use i in the baseline scenario in year y (tCH <sub>4</sub> )

No ventilation air methane (VAM) is used in the baseline (BL) or in the project case (PR). The result is that:

$$VAM_{PR,i,y} = 0$$

$$VAM_{BL,i,y} = 0$$



No mine methane (MM) is captured and used in the baseline (BL). The result is:

$$MM_{BL,i,y} = 0$$

Combustion engines, absorption chillers, and flaring of excess methane will take place in the project case (PR). Therefore, including the uses of methane, Equation 6 simplifies to equation 6.1:

$$BE_{MR,y} = GWP_{CH_4} \times (MM_{PR,engine,y} + MM_{PR,flare,y}) \quad (6.1)$$

Where:

$MM_{PR,engine,y}$  Mine methane captured, sent to and destroyed by internal combustion engines in the project activity in year y (tCH<sub>4</sub>/yr)

$MM_{PR,flare,y}$  Mine methane captured, sent to and destroyed by flare in the project activity in year y (tCO<sub>2</sub>e/yr)

Baseline emissions from power generation by project activity:

The proposed project activity will generate electricity and chilled water. The electricity generated will displace electricity that was sourced from the national grid in the baseline. The chilled water will be generated in absorption chillers and will displace chilled water generated in electric chillers. Hence, the chilled water generated in absorption chillers will displace electricity from the national grid. No captive power generation occurred in the baseline. Equation 7 originally stated:

$$BE_{Use,y} = GEN_y \times EF_{ELEC,y} + HEAT_y \times EF_{HEAT,y} + VFUEL_y \times EF_{V,y} + ABS_y \times \frac{COP_{ABS}}{COP_{ELEC}} \times EF_{ELEC,y} \quad (7)$$

Where:

$BE_{Use,y}$  Baseline emissions from the production of power or heat replaced by the project activity in year y (tCO<sub>2</sub>e/yr)

$GEN_y$  Electricity generated by the project activity in year y (MWh)

$EF_{ELEC,y}$  Emission factor for electricity generation (grid, captive or a combination) replaced by the project activity (tCO<sub>2</sub>/MWh)

$HEAT_y$  Heat generation by project activity in year y (GJ)

$EF_{HEAT,y}$  Emission factor for heat generation replaced by the project activity (tCO<sub>2</sub>/GJ)

$VFUEL_y$  Vehicle fuel provided by the project activity in year y (GJ)

$EF_{V,y}$  Emission factor for vehicle operation replaced by the project activity (tCO<sub>2</sub>/GJ)

$ABS_y$  Chilling produced in project activity by absorption chillers in year y (MWh)

$COP_{ABS}$  Coefficient of performance of the absorption chiller (MW thermal input / MW thermal output)

$COP_{ELEC}$  Coefficient of performance of the electrical chillers used in the baseline Chillers (MW electrical input / MW thermal output)

No heat will be generated during the project activity. The thermal energy generated will be chilling in the form of chilled water. This chilling is captured in the  $ABS_y$  term. This implies that:



$$HEAT_y = 0$$

No mine methane is used in the baseline or during the project activity as a vehicle fuel. This implies that:

$$VFUEL_y = 0$$

The emission factor for heat generation ( $EF_{HEAT,y}$ ) and the emission factor for the vehicle operation ( $EF_{v,y}$ ) are not applicable.

Equation 7 then simplifies to equation 7.1:

$$BE_{Use,y} = GEN_y \times EF_{ELEC,y} + ABS_y \times \frac{COP_{ABS}}{COP_{ELEC}} \times EF_{ELEC,y} \quad (7.1)$$

The project activity will displace grid electricity.

The emission factor for the grid electricity was calculated in accordance with the latest approved version of the “Tool for calculation of emission factor for electricity systems,” Version 02.2.1. The calculations are presented in Annex 4.

Equation 9 is presented below:

$$EF_{ELEC,y} = S_{grid,y} \times EF_{grid,y} + S_{captive} \times EF_{captive,y} \quad (9)$$

Where:

$EF_{ELEC,y}$	CO <sub>2</sub> baseline emission factor for the electricity displaced due to the project activity during the year y (tCO <sub>2</sub> /MWh)
$EF_{grid,y}$	CO <sub>2</sub> baseline emission factor for the grid electricity displaced due to the project activity during the year y (tCO <sub>2</sub> /MWh)
$EF_{captive,y}$	CO <sub>2</sub> baseline emission factor for the captive electricity displaced due to the project activity during the year y (tCO <sub>2</sub> /MWh)
$S_{grid}$	Share of the electricity demand supplied by the grid imports over the last 3 years (%)
$S_{captive}$	Share of facility electricity demand supplied by captive power over the last 3 years (%)

Taking in consideration that all electricity in the baseline is sourced from the grid:

$$S_{grid} = 100\%$$

$$S_{captive} = 0\%$$

The project activity will not replace any new or existing captive generation electricity generation. The result is that:

$$EF_{captive,y} = 0$$

This implies that Equation 9 can be simplified to Equation 7.2:



$$EF_{ELEC,y} = EF_{grid,y} \quad (7.2)$$

Where:

- $EF_{ELEC,y}$  Emission factor for electricity generation (grid, captive or a combination) replaced by the project activity (tCO<sub>2</sub>/MWh)  
 $EF_{grid,y}$  CO<sub>2</sub> baseline emission factor for the grid electricity displaced due to the project activity during the year y (tCO<sub>2</sub>/MWh)

### **Project emissions due to project activities recovering mine methane**

Project emissions are defined by the following equation:

$$PE_y = PE_{ME,y} + PE_{MD,y} + PE_{UM,y} \quad (13)$$

Where:

- $PE_y$  Project emissions in year y (tCO<sub>2</sub>e/yr)  
 $PE_{ME,y}$  Project emissions from energy use to capture and use methane in year y (tCO<sub>2</sub>e/yr)  
 $PE_{MD,y}$  Project emissions from methane destroyed in year y (tCO<sub>2</sub>e/yr)  
 $PE_{UM,y}$  Project emissions from un-combusted methane in year y (tCO<sub>2</sub>e/yr)

### **Project emissions from the use of additional energy required for MM/VAM capture and utilisation**

Additional energy was required to capture, transport and compress, use or destruct the mine methane. Project emissions from the use of this energy were calculated as follows:

$$PE_{ME,y} = PE_{ELEC,y} + PE_{FF,y} \quad (14)$$

Where:

- $PE_{ELEC,y}$  Project emissions from the use of electricity for capture, transportation, compression and utilisation or destruction of MM/VAM in year y (tCO<sub>2</sub>e/yr). Calculated in accordance with the latest approved version of the "Tool to calculate baseline, project and/or leakage emissions from electricity consumption"  
 $PE_{FF,y}$  Project emissions from the combustion of fossil fuels for capture, transportation, compression and utilisation or destruction of MM/VAM in year y (tCO<sub>2</sub>e/yr). Calculated in accordance with the latest approved version of the "Tool to calculate project or leakage CO<sub>2</sub> emissions from fossil fuel combustion"

No fossil fuel will be used for the capture, transportation, compression, utilisation or destruction of MM/VAM in the project activity. Hence,  $PE_{FF,y} = 0$ .

The mine methane captured will be pumped to surface. The pumping will be done by using an electrical blower. To calculate  $PE_{ELEC,y}$ , AM0064 states that the "Tool to calculate baseline, project and/or leakage emissions from electricity consumption" (Version 01) must be used. The application of this tool can be seen in Annex 4.

### **Project emissions from the combustion of MM/VAM**



AM0064 states that when the captured mine methane is burned in a flare, heat or power plant, or oxidized in a catalytic oxidation unit, emissions from combustion are released. (In addition, if non methane hydrocarbons (NMHC) account for more than 1% by volume of the extracted MM or more than 0.1% by volume of the extracted VAM, combustion emissions from these gases should also be included.) The project emissions (PE) from mine methane destruction (MD) are then accounted for as follows:

$$PE_{MD,y} = (MD_{FL,y} + MD_{OX,y} + MD_{ELEC,y} + MD_{HEAT,y} + MD_{GAS,y}) \times (CEF_{CH_4} + r \times CEF_{NMHC}) \quad (15)$$

Where:

PE <sub>MD,y</sub>	Project emissions from MM/VAM destroyed in year y (tCO <sub>2</sub> e/yr)
MD <sub>FL,y</sub>	Amount of methane destroyed through flaring in year y (tCH <sub>4</sub> /yr)
MD <sub>OX,y</sub>	Amount of methane destroyed through catalytic oxidation in year y (tCH <sub>4</sub> /yr)
MD <sub>ELEC,y</sub>	Amount of methane destroyed through power generation in year y (tCO <sub>2</sub> e/yr)
MD <sub>HEAT,y</sub>	Amount of methane destroyed through heat generation in year y (tCO <sub>2</sub> e/yr)
MD <sub>GAS,y</sub>	Amount of methane destroyed after being supplied to gas grid or for vehicle use in year y (tCH <sub>4</sub> )
CEF <sub>CH<sub>4</sub></sub>	Carbon emission factor for combusted methane (2.75 tCO <sub>2</sub> /tCH <sub>4</sub> )
CEF <sub>NMHC</sub>	Carbon emission factor for combusted non methane hydrocarbons (the concentration varies and, therefore, to be obtained through periodical analysis of captured methane) (tCO <sub>2</sub> /tNMHC)
r	Relative proportion of NMHC compared to methane $r = PC_{NMHC} / PC_{CH_4}$
PC <sub>CH<sub>4</sub></sub>	Concentration (in mass) of methane in extracted gas (%), measured on wet basis
PC <sub>NMHC</sub>	NMHC concentration (in mass) in extracted gas (%)

No mine methane will be:

- Destroyed through catalytic oxidation (MD<sub>OX,y</sub> = 0)
- Supplied to a gas grid or used as vehicle fuel (MD<sub>GAS,y</sub> = 0)
- Destroyed through heat generation (MD<sub>HEAT,y</sub> = 0)

Equation 15 then simplifies to Equation 15.1:

$$PE_{MD,y} = (MD_{FL,y} + MD_{ELEC,y}) \times (CEF_{CH_4} + r \times CEF_{NMHC}) \quad (15.1)$$

Furthermore, gas analysis indicated that non-methane hydrocarbons (NMHCs) accounts for 0.00% of the composition. Therefore, the NMHCs are below the 1% threshold for the ex-ante calculation of the emission reductions and are assumed negligible. Therefore, they are excluded. However, they will be monitored in the project activity. Equation 14.1 is simplified further to Equation 14.2:

$$PE_{MD,y} = (MD_{FL,y} + MD_{ELEC,y}) \times (CEF_{CH_4}) \quad (15.2)$$

AM0064 states that the amount of methane destroyed by each application depends on the efficiency of combustion in that application.

Firstly, the mine methane destroyed by the flare is determined:



$$MD_{FL,y} = MMES_{FL,y} - \frac{PE_{flare,y}}{GWP_{CH_4}} \quad (16)$$

Where:

$MD_{FL,y}$	Amount of methane destroyed through flaring in year y (tCH <sub>4</sub> )
$MMES_{FL,y}$	Amount of methane measured sent to flare in year y (tCH <sub>4</sub> )
$PE_{flare,y}$	Project emissions of non-combusted CH <sub>4</sub> , expressed in terms of tCO <sub>2</sub> e, from flaring of the residual gas stream in year y (tCO <sub>2</sub> e)
$GWP_{CH_4}$	Global warming potential of methane (21 tCO <sub>2</sub> /tCH <sub>4</sub> )

The project emissions of non-combusted CH<sub>4</sub> expressed in terms of CO<sub>2</sub>e from flaring of the residual gas stream ( $PE_{flare,y}$ ) was calculated following the procedures described in the “*Tool to determine project emissions from flaring gases containing methane*” (Version: not stated. Origin: EB 28, Annex 13). The calculations of the project emissions of non-combusted CH<sub>4</sub> can be found in Annex 4.

Secondly, the mine methane destroyed through electricity generation is determined:

$$MD_{ELEC,y} = MMES_{ELEC,y} \times Eff_{ELEC} \quad (20)$$

Where:

$MMES_{ELEC,y}$	Amount of methane measured sent to power plant in year y (tCH <sub>4</sub> )
$Eff_{ELEC}$	Efficiency of methane destruction/oxidation in power plant

#### Project emissions from un-combusted methane

$$PE_{UM,y} = \left[ GWP_{CH_4} \times \sum_i MMES_{i,y} \times (1 - Eff_i) \right] + PE_{flare,y} + PE_{OX,y} \times GWP_{CH_4} \quad (23)$$

Where:

$PE_{UM,y}$	Project emissions from un-combusted methane in year y (tCO <sub>2</sub> e)
$GWP_{CH_4}$	Global warming potential of methane (21 tCO <sub>2</sub> e/tCH <sub>4</sub> )
$MMES_{i,y}$	Methane measured sent to use i in year y (tCH <sub>4</sub> )
$Eff_i$	Efficiency of methane destruction in use i (%)
$PE_{flare,y}$	Project emissions of non-combusted CH <sub>4</sub> , expressed in terms of tCO <sub>2</sub> e, from the residual gas stream (tCO <sub>2</sub> e)
$PE_{OX,y}$	Project emissions of non oxidized CH <sub>4</sub> from catalytic oxidation of the VAM stream in year y (tCH <sub>4</sub> )

As applied to this project, Equation 23 becomes:

$$PE_{UM,y} = \left[ GWP_{CH_4} \times MMES_{ELEC} \times (1 - Eff_{ELEC}) \right] + PE_{flare,y} \quad (23.1)$$

Where:



MMES<sub>ELEC,y</sub> Amount of methane measured sent to power plant in year y (tCH<sub>4</sub>)  
 Eff<sub>ELEC</sub> Efficiency of methane destruction/oxidation in power plant

### Leakage due to project activities recovering mine methane

AM0064 states that “Leakage may occur if the project activity prevents MM/VAM from being used to meet the baseline thermal energy demand, whether as a result of physical constraints on delivery, or price changes.” No mine methane (MM) was used in the baseline.

Such displacement resulting in leakage does not occur and the project activity does not “cause increased emissions outside the project boundary associated with meeting thermal energy demand with other fuels.”

AM0064 states that “because of likely day-to-day fluctuations in MM/VAM extraction rates, to ensure a conservative result, CERs should not be calculated solely from annual data. Any CERs generated from methane destruction should be calculated using daily logs, or monthly logs if daily data are not available, of project-case demand for MM/VAM for non-thermal uses compared against estimates of the baseline MM/VAM demand for thermal uses. For each day (or month) of the crediting period, this form of leakage must be calculated if:”

$$ME_k - (MMES_{ELEC,k} + MMES_{HEAT,k}) < TH_k \quad (28)$$

Where:

ME<sub>k</sub> Methane extracted on day k (tCH<sub>4</sub>)  
 MMES<sub>HEAT,k</sub> Methane measured sent to new heat generation uses on day k in the project scenario that would not have been sent in the baseline scenario on day k (tCH<sub>4</sub>)  
 MMES<sub>ELEC,k</sub> Methane measured sent to power plant on day k (tCH<sub>4</sub>)  
 TH<sub>k</sub> Methane used to serve thermal energy demand in the baseline for day k (tCH<sub>4</sub>)

No mine methane is used in the baseline (TH<sub>k</sub> = 0) and

It is furthermore not possible for the sum of methane sent to heat generation equipment (MMES<sub>HEAT,k</sub>) and the methane sent to electricity generation equipment (MMES<sub>ELEC,k</sub>) to be more than the methane extracted (ME<sub>k</sub>). The result is that:

$$ME_k - (MMES_{ELEC,k} + MMES_{HEAT,k}) \geq 0 \quad (28.1)$$

Taking into consideration that TH<sub>k</sub> = 0, the implication is that no leakage occurs in this project activity.

$$LE_y = Q_{AF} \times NCV_{AF} \times EF_{AF} \times OXID \quad (32)$$

Where:

LE<sub>y</sub> Leakage emissions in year y (tCO<sub>2</sub>e/yr)  
 Q<sub>AF,y</sub> Quantity of alternative fuels displaced by the project activity in year y (tonnes or m<sup>3</sup>)  
 NCV<sub>AF</sub> Net calorific value for alternative fuels (GJ/tonne or m<sup>3</sup>)



EFAF Emissions factor for alternative fuel (tCO<sub>2</sub>/GJ) sourced from IPCC  
 OXID Oxidation efficiency of combustion (%), sourced from IPCC

Since  $Q_{AF,y}$  is zero. The result is that:

$$LE_y = 0 \quad (32.1)$$

### Emission reductions

The emission reduction  $ER_y$  by the project activity during a given year  $y$  is the difference between the baseline emissions ( $BE_y$ ) and project emissions ( $PE_y$ ). The leakage emissions ( $LE_y$ ) in this project activity are zero as no activity which uses methane occurred in the baseline. No baseline methane application was thus displaced. The emission reduction is calculated as below:

$$ER_y = BE_y - PE_y - LE_y \quad (33)$$

Where:

$ER_y$  Emission reductions in year  $y$  (tCO<sub>2</sub>e/yr)  
 $BE_y$  Baseline emissions in year  $y$  (tCO<sub>2</sub>e/yr)  
 $PE_y$  Project emissions in year  $y$  (tCO<sub>2</sub>e/yr)  
 $LE_y$  Leakage emissions in year  $y$  (tCO<sub>2</sub>e/yr)

### **B.6.2. Data and parameters that are available at validation:**

The following table with values is reproduced from the flaring tool:

Parameter	SI Unit	Description	Value
$MM_{CH_4}$	kg/kmol	Molecular mass of methane	16.04
$MM_{CO}$	kg/kmol	Molecular mass of carbon monoxide	28.01
$MM_{CO_2}$	kg/kmol	Molecular mass of carbon dioxide	44.01
$MM_{O_2}$	kg/kmol	Molecular mass of oxygen	32
$MM_{H_2}$	kg/kmol	Molecular mass of hydrogen	2.02
$MM_{N_2}$	kg/kmol	Molecular mass of nitrogen	28.02
$AM_c$	kg/kmol (g/mol)	Atomic mass of carbon	12
$AM_h$	kg/kmol (g/mol)	Atomic mass of hydrogen	1.01
$AM_o$	kg/kmol (g/mol)	Atomic mass of oxygen	16
$AM_n$	kg/kmol (g/mol)	Atomic mass of nitrogen	14.01
$P_n$	Pa	Atmospheric pressure at normal conditions	101 325
$R_u$	Pa.m <sup>3</sup> /kmol.K	Universal ideal gas constant	8 314.472
$T_n$	K	Temperature at normal conditions	273.15
$MF_{O_2}$	Dimensionless	O <sub>2</sub> volumetric fraction of air	0.21
$GWP_{CH_4}$	tCO <sub>2</sub> /tCH <sub>4</sub>	Global warming potential of methane	21



$MV_n$	$m^3/Kmol$	Volume of one mole of any ideal gas at normal	22.414
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<b>Data / Parameter:</b>	$COP_{ABS}$
Data unit:	Dimensionless
Description:	Coefficient of performance of the absorption chillers (MW thermal input / MW thermal output) used in the project activity
Source of data used:	Manufacturer
Value applied:	1
Justification of the choice of data or description of measurement methods and procedures actually applied :	The manufacturer's data for the performance of the absorption chillers was used.
Any comment:	

<b>Data / Parameter:</b>	$COP_{ELEC}$
Data unit:	Dimensionless
Description:	Coefficient of performance of the Electric Chillers (MW thermal input / MW thermal output)
Source of data used:	Manufacturer
Value applied:	3.5
Justification of the choice of data or description of measurement methods and procedures actually applied :	Manufacturer's data was used.
Any comment:	

<b>Data / Parameter:</b>	$S_{grid}$
Data unit:	percentage
Description:	Percentage of the electricity demand supplied by the grid imports for the 3 years preceding the implementation of the project.
Source of data used:	Current and historical mining operations at Beatrix mine.
Value applied:	100%
Justification of the choice of data or description of measurement methods and procedures actually applied :	No captive electricity generation occurs in the baseline. Historically, all electricity is sourced from the national grid.
Any comment:	

<b>Data / Parameter:</b>	$S_{captive}$
Data unit:	percentage
Description:	Percentage of the electricity demand supplied by captive electricity generation



	for the 3 years preceding the implementation of the project.
Source of data used:	Current and historical mining operations at Beatrix mine.
Value applied:	0%
Justification of the choice of data or description of measurement methods and procedures actually applied :	No captive electricity generation occurs in the baseline. Historically, all electricity is sourced from the national grid.
Any comment:	

<b>Data / Parameter:</b>	CEFC <sub>CH4</sub>
Data unit:	tCO <sub>2</sub> /tCH <sub>4</sub>
Description:	Carbon emission factor for combusted methane
Source of data used:	As stated in AM0064
Value applied:	2.75
Justification of the choice of data or description of measurement methods and procedures actually applied :	Ex ante value stated in AM0064
Any comment:	44/16 = 2.75 tCO <sub>2</sub> e/tCH <sub>4</sub>

<b>Data / Parameter:</b>	Eff <sub>ELEC</sub>
Data unit:	Percentage
Description:	Efficiency of methane destruction/oxidation in power plant
Source of data used:	IPCC default value as stated in AM0064
Value applied:	99.5%
Justification of the choice of data or description of measurement methods and procedures actually applied :	IPCC default value as stated in AM0064
Any comment:	

<b>Data / Parameter:</b>	TH <sub>BL</sub>
Data unit:	tCH <sub>4</sub>
Description:	Average annual thermal demand over the past 5 years (tCH <sub>4</sub> )
Source of data used:	Current and historical mining operations at Beatrix mine
Value applied:	0
Justification of the choice of data or description of measurement methods and procedures actually applied :	Historically the baseline scenario had no thermal demand.



applied :	
Any comment:	

<b>Data / Parameter:</b>	EF <sub>grid</sub>
Data unit:	tCO <sub>2</sub> /MWh
Description:	Grid emission factor
Source of data used:	Eskom data
Value applied:	1.021
Justification of the choice of data or description of measurement methods and procedures actually applied :	“Tool to calculate the emission factor for an electricity system”
Any comment:	

### B.6.3. Ex-ante calculation of emission reductions:

&gt;&gt;

The calculations presented in this section were based on:

- A starting date of the project is 23 December 2011 (See “AFE” (authorisation for expenditure) supporting documentation). This is the date that the first approval towards a significant expenditure for this project was made;
- Crediting period starting 01 Jan 2013
- Flaring occurs in the first phase of the project, which runs from 01 Jan to 31 Dec 2013;
- Electricity generation, chilling with absorption chillers, and flaring occur in the second phase of the project, which runs from 01 Jan 2014 to the end of the crediting period.
- The main flare will have all the monitoring equipment necessary to calculate the actual combustion efficiency as per the “Tool to determine project emissions from flaring gases containing methane.” This per the quote obtained for the flare.

### Baseline emissions for mine methane capture and utilization or destruction

#### Equation 1:

$$BE_y = BE_{MD,y} + BE_{MR,y} + BE_{Use,y}$$

Year	BE <sub>y</sub>	BE <sub>MD,y</sub>	BE <sub>MR,y</sub>	BE <sub>Use,y</sub>
1	141 628.52	0	141 628.52	-
2	194 925.07	0	141 628.52	53 296.55
3	194 925.07	0	141 628.52	53 296.55
4	194 925.07	0	141 628.52	53 296.55
5	194 925.07	0	141 628.52	53 296.55
6	194 925.07	0	141 628.52	53 296.55
7	194 925.07	0	141 628.52	53 296.55
8	194 925.07	0	141 628.52	53 296.55



9	194 925.07	0	141 628.52	53 296.55
10	194 925.07	0	141 628.52	53 296.55

**Equation 3:**

$$r = \frac{PC_{NMHC}}{PC_{CH4}}$$

Year	r	PC <sub>NMHC</sub>	PC <sub>CH4</sub>
1	0.00001	0.00%	56%
2	0.00001	0.00%	56%
3	0.00001	0.00%	56%
4	0.00001	0.00%	56%
5	0.00001	0.00%	56%
6	0.00001	0.00%	56%
7	0.00001	0.00%	56%
8	0.00001	0.00%	56%
9	0.00001	0.00%	56%
10	0.00001	0.00%	56%

**Equation 6:**

$$BE_{MR,y} = GWP_{CH4} \times (MM_{PR,engine,y} + MM_{PR,flare,y})$$

Year	BE <sub>MR,y</sub>	GWP <sub>CH4</sub>	MM <sub>PR,engine,y</sub>	MM <sub>PR,flare,y</sub>
1	141 628.52	21	-	6 744.22
2	141 628.52	21	5 953.17	791.04
3	141 628.52	21	5 953.17	791.04
4	141 628.52	21	5 953.17	791.04
5	141 628.52	21	5 953.17	791.04
6	141 628.52	21	5 953.17	791.04
7	141 628.52	21	5 953.17	791.04
8	141 628.52	21	5 953.17	791.04
9	141 628.52	21	5 953.17	791.04
10	141 628.52	21	5 953.17	791.04

**Equation 7:**

$$BE_{Use,y} = GEN_y \times EF_{ELEC,y} + ABS_y \times \frac{COP_{ABS}}{COP_{ELEC}} \times EF_{ELEC,y}$$

Year	BE <sub>Use,y</sub>	GEN <sub>y</sub>	EF <sub>ELEC,y</sub>	ABS <sub>y</sub>	COP <sub>ABS</sub>	COPELEC
1	-	-	1.021	-	1.00	3.5
2	53 297	44 772	1.021	25 998	1.00	3.5
3	53 297	44 772	1.021	25 998	1.00	3.5



4	53 297	44 772	1.021	25 998	1.00	3.5
5	53 297	44 772	1.021	25 998	1.00	3.5
6	53 297	44 772	1.021	25 998	1.00	3.5
7	53 297	44 772	1.021	25 998	1.00	3.5
8	53 297	44 772	1.021	25 998	1.00	3.5
9	53 297	44 772	1.021	25 998	1.00	3.5
10	53 297	44 772	1.021	25 998	1.00	3.5

**Equation 9:**

$$EF_{ELEC,y} = S_{grid} \times EF_{grid,y} + S_{captive} \times EF_{captive,y}$$

Year	EF <sub>ELEC,y</sub>	S <sub>grid</sub>	EF <sub>grid,y</sub>	S <sub>captive</sub>	EF <sub>captive,y</sub>
1	1.021	1	1.021	0	0
2	1.021	1	1.021	0	0
3	1.021	1	1.021	0	0
4	1.021	1	1.021	0	0
5	1.021	1	1.021	0	0
6	1.021	1	1.021	0	0
7	1.021	1	1.021	0	0
8	1.021	1	1.021	0	0
9	1.021	1	1.021	0	0
10	1.021	1	1.021	0	0

**Project emissions due to project activities recovering mine methane****Equation 13:**

$$PE_y = PE_{ME,y} + PE_{MD,y} + PE_{UM,y}$$

Year	PE <sub>y</sub>	PE <sub>ME,y</sub>	PE <sub>MD,y</sub>	PE <sub>UM,y</sub>
1	65 364.28	1 792.25	11 761.94	51 810.10
2	23 797.49	1 792.25	18 025.43	3 979.81
3	23 797.49	1 792.25	18 025.43	3 979.81
4	23 797.49	1 792.25	18 025.43	3 979.81
5	23 797.49	1 792.25	18 025.43	3 979.81
6	23 797.49	1 792.25	18 025.43	3 979.81
7	23 797.49	1 792.25	18 025.43	3 979.81
8	23 797.49	1 792.25	18 025.43	3 979.81
9	23 797.49	1 792.25	18 025.43	3 979.81
10	23 797.49	1 792.25	18 025.43	3 979.81

**Equation 14:**



$$PE_{ME,y} = PE_{ELEC,y} + PE_{FF,y}$$

Year	PE <sub>ME,y</sub>	PE <sub>ELEC,y</sub>	PE <sub>FF,y</sub>
1	1 792.25	1 792.25	0
2	1 792.25	1 792.25	0
3	1 792.25	1 792.25	0
4	1 792.25	1 792.25	0
5	1 792.25	1 792.25	0
6	1 792.25	1 792.25	0
7	1 792.25	1 792.25	0
8	1 792.25	1 792.25	0
9	1 792.25	1 792.25	0
10	1 792.25	1 792.25	0

**Equation 15:**

$$PE_{MD,y} = (MD_{FL,y} + MD_{ELEC,y}) \times (CEF_{CH4} + r \times CEF_{NMHC})$$

Year	PE <sub>MD,y</sub>	MD <sub>FL,y</sub>	MD <sub>ELEC,y</sub>	CEF <sub>CH4</sub>
1	11 761.94	4 277.07	-	2.75
2	18 025.43	631.30	5 923.41	2.75
3	18 025.43	631.30	5 923.41	2.75
4	18 025.43	631.30	5 923.41	2.75
5	18 025.43	631.30	5 923.41	2.75
6	18 025.43	631.30	5 923.41	2.75
7	18 025.43	631.30	5 923.41	2.75
8	18 025.43	631.30	5 923.41	2.75
9	18 025.43	631.30	5 923.41	2.75
10	18 025.43	631.30	5 923.41	2.75

**Equation 16:**

$$MD_{FL,y} = MMES_{FL,y} - \frac{PE_{flare,y}}{GWP_{CH4}}$$

Year	MD <sub>FL,y</sub>	MMES <sub>FL,y</sub>	PE <sub>flare,y</sub>	GWP <sub>CH4</sub>
1	4 277.07	6 744.22	51 810.10	21
2	631.30	791.04	3 354.73	21
3	631.30	791.04	3 354.73	21
4	631.30	791.04	3 354.73	21
5	631.30	791.04	3 354.73	21
6	631.30	791.04	3 354.73	21
7	631.30	791.04	3 354.73	21



8	631.30	791.04	3 354.73	21
9	631.30	791.04	3 354.73	21
10	631.30	791.04	3 354.73	21

**Equation 20:**

$$MD_{ELEC,y} = MMES_{ELEC,y} \times Eff_{ELEC}$$

Year	MD <sub>ELEC,y</sub>	MMES <sub>ELEC,y</sub>	Eff <sub>ELEC</sub>
1	-	-	99.5%
2	5 923.41	5 953.17	99.5%
3	5 923.41	5 953.17	99.5%
4	5 923.41	5 953.17	99.5%
5	5 923.41	5 953.17	99.5%
6	5 923.41	5 953.17	99.5%
7	5 923.41	5 953.17	99.5%
8	5 923.41	5 953.17	99.5%
9	5 923.41	5 953.17	99.5%
10	5 923.41	5 953.17	99.5%

**Equation 23:**

$$PE_{UM,y} = [GWP_{CH4} \times MMES_{ELEC} \times (1 - Eff_{ELEC})] + PE_{flare,y}$$

Year	PE <sub>UM,y</sub>	MMES <sub>ELEC,y</sub>	Eff <sub>ELEC</sub>	PE <sub>flare,y</sub>	PE <sub>OX,y</sub>	GWP <sub>CH4</sub>
1	51 810.10	-	99.5%	51 810.10	0	21
2	3 979.81	5 953.17	99.5%	3 354.73	0	21
3	3 979.81	5 953.17	99.5%	3 354.73	0	21
4	3 979.81	5 953.17	99.5%	3 354.73	0	21
5	3 979.81	5 953.17	99.5%	3 354.73	0	21
6	3 979.81	5 953.17	99.5%	3 354.73	0	21
7	3 979.81	5 953.17	99.5%	3 354.73	0	21
8	3 979.81	5 953.17	99.5%	3 354.73	0	21
9	3 979.81	5 953.17	99.5%	3 354.73	0	21
10	3 979.81	5 953.17	99.5%	3 354.73	0	21

**Leakage due to project activities recovering mine methane****Equation 28:**

$$ME_k - (MMES_{ELEC,k} + MMES_{HEAT,k}) < TH_k$$

Year	ME <sub>k</sub>	MMES <sub>ELEC,k</sub>	MMES <sub>HEAT,k</sub>	LHS	TH <sub>k</sub>
1	18.48	-	0	18.48	0



2	18.48	17.17	0	1.31	0
3	18.48	17.17	0	1.31	0
4	18.48	17.17	0	1.31	0
5	18.48	17.17	0	1.31	0
6	18.48	17.17	0	1.31	0
7	18.48	17.17	0	1.31	0
8	18.48	17.17	0	1.31	0
9	18.48	17.17	0	1.31	0
10	18.48	17.17	0	1.31	0

**Emission reductions****Equation 33:**

$$ER_y = BE_y - PE_y - LE_y$$

Year	ER <sub>y</sub>	BE <sub>y</sub>	PE <sub>y</sub>	LE <sub>y</sub>
1	76 264	141 629	65 364	0
2	171 128	194 925	23 797	0
3	171 128	194 925	23 797	0
4	171 128	194 925	23 797	0
5	171 128	194 925	23 797	0
6	171 128	194 925	23 797	0
7	171 128	194 925	23 797	0
8	171 128	194 925	23 797	0
9	171 128	194 925	23 797	0
10	171 128	194 925	23 797	0

**B.6.4 Summary of the ex-ante estimation of emission reductions:**

&gt;&gt;

Year	Estimation of project activity emissions (tonnes of CO <sub>2</sub> e)	Estimation of baseline emissions (tonnes of CO <sub>2</sub> e)	Estimation of leakage (tonnes of CO <sub>2</sub> e)	Estimation of overall emission reductions (tonnes of CO <sub>2</sub> e)
1	65 364	141 629	0	76 264
2	23 797	194 925	0	171 128
3	23 797	194 925	0	171 128
4	23 797	194 925	0	171 128
5	23 797	194 925	0	171 128
6	23 797	194 925	0	171 128
7	23 797	194 925	0	171 128
8	23 797	194 925	0	171 128



9	23 797	194 925	0	171 128
10	23 797	194 925	0	171 128
<b>Total</b> (tonnes of CO <sub>2</sub> e)	<b>279 542</b>	<b>1 895 954</b>	<b>0</b>	<b>1 616 416</b>

<b>B.7. Application of the monitoring methodology and description of the monitoring plan:</b>
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<b>B.7.1 Data and parameters monitored:</b>
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<b>Data / Parameter:</b>	MM <sub>PR,engine,y</sub> or MMES <sub>ELEC,y</sub>
Data unit:	tCH <sub>4</sub> /yr
Description:	Mine methane captured, sent to and destroyed by internal combustion engines in the project activity in year y.
Source of data to be used:	Engine specifications were used for the purpose of the ex-ante calculations. The flowrate will be measured in the project activity. The methane concentration of the gas will be metered at the flare. Since the methane concentration of the gas sent to the flare and the gas sent to the engines does not differ, the concentration of the gas at the flare can be used to give the concentration of the gas sent to the engines.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	6 266.50 tCH <sub>4</sub> /year
Description of measurement methods and procedures to be applied:	The flowrate of the gas will be monitored continuously, integrated hourly and logged electronically. The monitoring report will consolidate these values monthly for the purpose of the verification. The methane concentration will be measured continuously at the flare and consolidated to a monthly figure for the monitoring report.
QA/QC procedures to be applied:	The flowmeter and concentration meter will be calibrated according to manufacturer's specifications.
Any comment:	

<b>Data / Parameter:</b>	MM <sub>PR,flare,y</sub> or MMES <sub>FL,y</sub>
Data unit:	tCH <sub>4</sub> /yr
Description:	Mine methane captured, sent to and destroyed by flare in the project activity in year y
Source of data to be used:	A flow meter and concentration meter will be installed to measure the flowrate of methane sent to the flare.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	477.72 tCH <sub>4</sub> /year
Description of measurement methods	The flow meter will measure the flowrate of gas. The flow meter has temperature and pressure compensation. The methane value of that gas will be monitored and



and procedures to be applied:	used to calculate the flowrate of methane. These values will be consolidated to a monthly value for the purpose of the report.
QA/QC procedures to be applied:	The flowmeter and methane concentration meter will be calibrated in accordance with manufacturer's specifications.
Any comment:	

<b>Data / Parameter:</b>	GEN <sub>y</sub>
Data unit:	MWh
Description:	Electricity generated by the project activity in year y
Source of data to be used:	The electrical output will be measured by an electricity meter installed at the engines.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	44 772 MWh
Description of measurement methods and procedures to be applied:	The electricity output will be measured at the engines. This meter will be installed in phase 2. The electricity generated will be monitored continuously, integrated hourly and logged electronically. For the monitoring report the values will be consolidated on a monthly basis for verification.
QA/QC procedures to be applied:	The meter will be calibrated according to manufacturer's specifications.
Any comment:	

<b>Data / Parameter:</b>	PC <sub>CH4</sub>
Data unit:	%
Description:	Concentration (in mass) of methane in extracted gas (%), measured on wet basis
Source of data to be used:	The concentration of methane will be monitored continuously at the underground monitoring stations. The methane concentration of the gas is then monitored again at the flare.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	56.18 %
Description of measurement methods and procedures to be applied:	<p>The concentration will be monitored continuously, integrated hourly and logged electronically.</p> <p>The methane concentration will be measured in volume percent. Using the flowrate of the gas, the volumetric concentrations of the components in the gas and molar masses; the volume percent will be converted into a mass percent.</p> <p>The concentration will be monitored on a wet basis and this value will be reported on a wet basis. The concentration is metered by a gas analysis device. This device will first, cool the gas to a temperature of roughly 5 degrees Celsius</p>



	(condensate will be evacuated), logically the gas is now 100% wet since it is very close to the dew point. Afterwards, the gas will move to the measuring cells in this status. So the gas is wet.  For the monitoring report these values will be consolidated and reported on as monthly values for the verification
QA/QC procedures to be applied:	Maintenance of concentration meters will be done according to manufacturer's specification; which comply with manufacturer's specifications.
Any comment:	

<b>Data / Parameter:</b>	$PC_{NMHC}$
Data unit:	%
Description:	NMHC concentration (in mass) in extracted gas
Source of data to be used:	The gas will be sampled every 3 months initially and tested for the NMHC concentration. The frequency of this will be reduced to twice a year after the first year of operation of the plant. The methane concentration will be monitored continuously. If the methane concentration falls below the 75% indicated by the analysis taken prior to the project activity or the average concentration in that year then the gas will be sampled again and the new NMHC concentration will be used.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	0.00 %
Description of measurement methods and procedures to be applied:	The gas is sampled and the samples are sent to a laboratory for testing.
QA/QC procedures to be applied:	
Any comment:	

<b>Data / Parameter:</b>	$EC_{PL,y}$
Data unit:	MWh/y
Description:	Quantity of electricity consumed by the project electricity consumption source in year $y$
Source of data to be used:	The electricity consumed by the plant will be measured.
Value of data applied for the purpose of calculating expected emission reductions in section B.5	1 704 MWh/year
Description of measurement methods and procedures to be applied:	The electricity consumption of the electricity generating equipment and auxiliaries will be measured. The continuous monitored data will be logged electronically. These values will be consolidated and reported on a monthly basis



applied:	for the verification.
QA/QC procedures to be applied:	The measuring equipment will be calibrated according to manufacturer's specifications.
Any comment:	

<b>Data / Parameter:</b>	TDL <sub>y</sub>
Data unit:	-
Description:	Average technical transmission and distribution losses for providing electricity to source in year <i>y</i>
Source of data to be used:	A default value of 3% was used because the scenario presented below was found to be applicable to the project (verbatim text in italics):  <i>(b) project and leakage electricity consumption sources if the electricity consumption by all project and leakage electricity consumption sources to which scenario A or scenario C (cases C.I or C.III) applies is smaller than the electricity consumption of all baseline electricity consumption sources to which scenario A or scenario C (cases C.I or C.III) applies.</i>
Value of data applied for the purpose of calculating expected emission reductions in section B.5	Default 3% as stated in "Tool to calculate baseline, project and/or leakage emissions from electricity consumption"
Description of measurement methods and procedures to be applied:	The tool will be checked annually for updates and new default values.
QA/QC procedures to be applied:	Default values, as stated in the tool, will be used.
Any comment:	

<b>Data / Parameter:</b>	FV <sub>RG,h</sub>
Data unit:	m <sup>3</sup> /h
Description:	Volumetric flow rate of the residual gas in dry basis at normal conditions in the hour <i>h</i>
Source of data to be used:	Measurements will be taken using a flow meter
Value of data applied for the purpose of calculating expected emission reductions in section B.5	105.09 m <sup>3</sup> /h
Description of measurement methods and procedures to be applied:	A flowmeter will be installed to measure the flowrate of gas sent to the flare. The volumetric flowrate will be measured on a dry basis; ensuring that all the moisture is removed prior to the analysis. This will be the same for the density of methane and the fraction of methane in the residual gas.  The flowrate will be measured after the dewatering unit and after the pressure



	<p>increase of the blowers (here, there is also a significant gas temperature increase). At this time, there is no condensate and the relative humidity is not zero but approximately 20-30%. So, the gas is dry.</p> <p>These flowrates will be consolidated into monthly values in the monitoring report for verification.</p>
QA/QC procedures to be applied:	Flow meters are to be calibrated annually according to the manufacturer's specification.
Any comment:	

<b>Data / Parameter:</b>	$f_{V_{i,h}}$
Data unit:	-
Description:	Volumetric fraction of component $i$ in the residual gas in the hour $h$ Where $i$ is $CH_4$ , $N_2$
Source of data to be used:	Initial gas analyses before project start was used for the ex-ante calculations. Thereafter, the volumetric fraction of $CH_4$ will be measured and remainder will be considered to be $N_2$ .
Value of data applied for the purpose of calculating expected emission reductions in section B.5	$f_{V_{CH_4,h}} = 0.708$ (value from initial measurement) $f_{V_{N_2,h}} = 0.292$ (value from initial measurement)
Description of measurement methods and procedures to be applied:	The volumetric fraction of $CH_4$ will be measured continuously. The remainder will be considered as $N_2$ . The volumetric fraction of methane will be measured on a dry basis; ensuring that all the moisture is removed prior to the analysis. This will be in line with the measurement of the gas flowrate and the density of methane. These fractions will be consolidated into a monthly value for the purpose of the monitoring report and verification.
QA/QC procedures to be applied:	The instrument measuring the volumetric fraction of $CH_4$ will be calibrated according to the manufacturer's specifications; which correspond with international standards. Only the $CH_4$ measurement will be used in the calculations as the remainder will be assumed to be $N_2$ .
Any comment:	

<b>Data / Parameter:</b>	$f_{V_{CH_4,FG,h}}$
Data unit:	$mg/m^3$
Description:	Concentration of methane in the exhaust gas of the flare in dry basis at normal conditions in the hour $h$
Source of data to be used:	Measurements at the flare as part of the flare package
Value of data applied for the purpose of calculating expected emission reductions in section B.5	10 721.15 $mg/m^3$
Description of	The volumetric fraction of the methane in the exhaust gas will be measured. This



measurement methods and procedures to be applied:	measurement will be converted to $\text{mg}/\text{m}^3$ . These values will be consolidated into monthly values in the monitoring report for verification.  The concentration of methane will be measured on a dry basis; ensuring that all the moisture is removed prior to the analysis. This will be in line with the measurement of the gas flowrate and the density of methane.
QA/QC procedures to be applied:	The instrument will be calibrated in accordance with manufacturer's specifications.
Any comment:	

<b>Data / Parameter:</b>	$t_{\text{O}_2, \text{h}}$
Data unit:	-
Description:	Volumetric fraction of $\text{O}_2$ in the exhaust gas of the flare in the hour h
Source of data to be used:	Measured using a continuous gas analyser (electrochemical)
Value of data applied for the purpose of calculating expected emission reductions in section B.5	0.04
Description of measurement methods and procedures to be applied:	The concentration of oxygen will be monitored using a flue gas analyser. The concentration of oxygen will be measured on a dry basis; ensuring that all the moisture is removed prior to the analysis. These values will be consolidated into monthly values in the monitoring report for verification.
QA/QC procedures to be applied:	The analyser will be periodically calibrated according to the manufacturer's recommendation. The accuracy of the instrument is +/- 1%.
Any comment:	

<b>Data / Parameter:</b>	$T_{\text{flare}}$
Data unit:	$^{\circ}\text{C}$
Description:	Temperature in the exhaust gas of the flare
Source of data to be used:	Measurement
Value of data applied for the purpose of calculating expected emission reductions in section B.5	$600^{\circ}\text{C}$
Description of measurement methods and procedures to be applied:	Measure the temperature of the exhaust gas stream in the flare by a Type N thermocouple. A temperature above $500^{\circ}\text{C}$ indicates that a significant amount of gases are still being burnt and that the flare is operating. The temperature should be measured continuously. These values will be consolidated into monthly values in the monitoring report for verification.
QA/QC procedures to be applied:	Thermocouples should be replaced or calibrated every year.
Any comment:	An excessively high temperature at the sampling point (above $700^{\circ}\text{C}$ ) may be an



	indication that the flare is not being adequately operated or that its capacity is not adequate to the actual flow.
<b>Data / Parameter:</b>	ABS <sub>y</sub>
Data unit:	MWh <sub>th</sub>
Description:	Chilling produced in project case by absorption chillers in year y (MWh <sub>th</sub> ).
Source of data to be used:	Measurements
Value of data applied for the purpose of calculating expected emission reductions in section B.5	25 998
Description of measurement methods and procedures to be applied:	This variable is reported continuously with an online meter as part of the chiller equipment, which measures the flow and temperature.
QA/QC procedures to be applied:	Calibrated to manufacturers specification
Any comment:	

#### **B.7.2. Description of the monitoring plan:**

>>

The monitoring plan will ensure that project emission reductions are accurately monitored, recorded and reported. The onsite monitoring as well as calibration/verification of measurement equipment will be the responsibility of the operations manager. The data will be collected on site and archived both on site and off site. Promethium Carbon, the CDM project developer, will be responsible for calculating the emission reductions and drafting of the monitoring report.

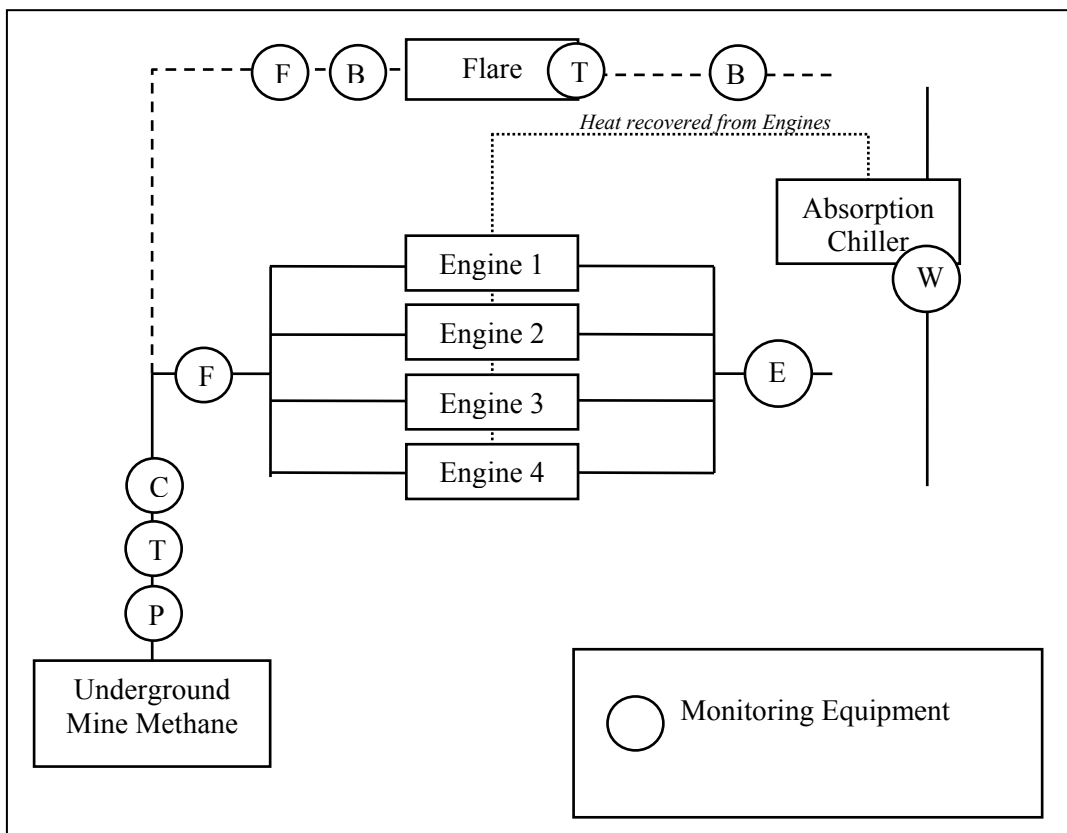
#### **Mine Methane Monitoring Plan**

##### **1. Data to be monitored.**

The monitoring equipment and the placing of the equipment in the project are shown in the diagram below. The following parameters will be monitored as per the applied monitoring methodology:

- The flowrate of the gas sent to the engines and the flare
- The methane concentration in the extracted gas
- The NMHC concentration in the extracted gas
- The composition of the gas going to the flare
- The oxygen and methane concentration of the exhaust gas from the flare
- The temperature of the flare
- The electricity produced by the engines
- Cooling provided by the absorption chiller
- The electricity consumption of the plant

The monitoring equipment is depicted in the diagram below:



**Figure 5: Mine Methane Monitoring System**

In addition, the electricity consumption of the plant will be monitored continuously.

A description of the symbols appears below:

Symbol	Description	Function
B	Methane and Oxygen Concentration Meter	Measure CH <sub>4</sub> and O <sub>2</sub> concentration of gas
F	Flow Meter	Measure gas or liquid flowrate
T	Thermocouple	Measures the temperature
P	Pressure Meter	Measures the pressure
E	Electricity Meter	Measure electricity generated by the engines.
C	Gas composition	Measuring the composition of the gas (CH <sub>4</sub> , NMHC). The gas will be sampled every 3 months and tested for the NMHC concentration.
W	Cooling provided	Measures the amount of cooling provided by the absorption chillers.

The below ground monitoring stations for the collection of the underground mine methane are shown in figure 19 below. These stations are to ensure the safety of the underground workers.

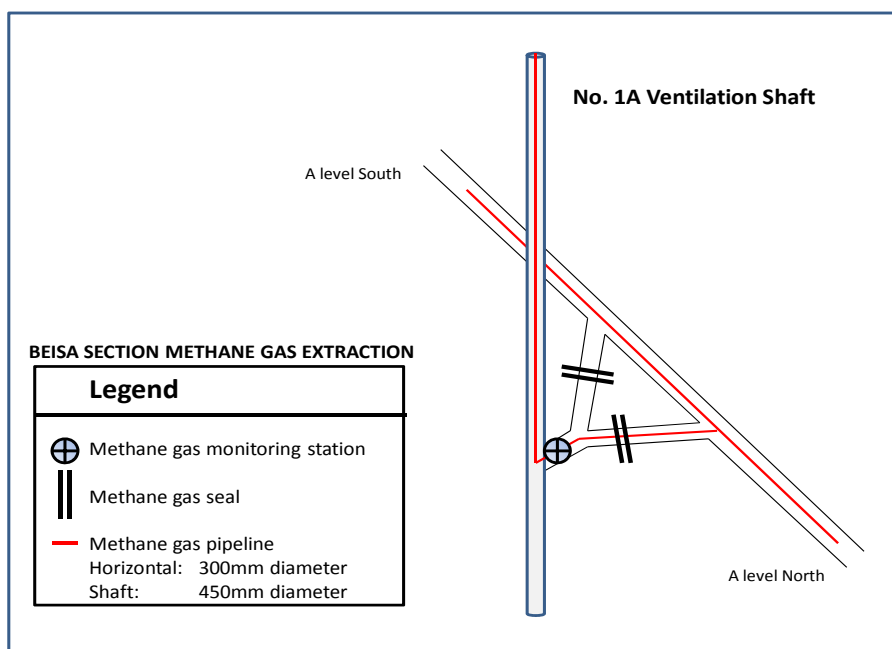


Figure 6: The underground piping and monitoring system for methane extraction.

The monitoring stations underground measure both gas flowrate and methane concentration.

## 2. Responsibility for data monitoring, recording and management.

The operations manager will be responsible for ensuring that the data is monitored and recorded and that the instruments are all in working order.

## 3. Calibration of meters and metering

The following procedures will be implemented by the project to ensure accurate measurement and therefore accurate knowledge of GHG emission reductions.

- The metering equipment will be calibrated in accordance with manufacturer's specifications.
- The metering equipment will be calibrated and checked for accuracy in accordance with manufacturer's specifications.
- The instrumentation has not been finally selected yet. However, the instrumentation must have an accuracy of at least 95%. This can be checked at the first verification.

## 4. Verification Procedure

Verification will be done annually.

- The project participants will provide the data and calculated emission reductions to the DOE during verification.



The operations personnel and the project participants will cooperate with the DOE during the verification process. The personnel working on this project will be available for consultation during the entire verification and will provide correct data to substantiate all queries.

**B.8. Date of completion of the application of the baseline study and monitoring methodology and the name of the responsible person(s)/entity(ies):**

>>

Both the baseline study and the monitoring methodology were developed by Promethium Carbon (Pty) Ltd and completed in September 2011.

**SECTION C. Duration of the project activity / crediting period**

**C.1. Duration of the project activity:**

**C.1.1. Starting date of the project activity:**

>>

The starting date of the project activity is 23 December 2011. This is the date that the flares are ordered in accordance with the project plan. This is in accordance with EB 41 where the starting date can be the date on which contracts have been signed for equipment or construction/operation services required for the project activity.

**C.1.2. Expected operational lifetime of the project activity:**

>>

The life time of the mine exceeds the 10 year period of this project activity (see “Beatrix LOM” supporting documentation for the life of mine).

**C.2. Choice of the crediting period and related information:**

**C.2.1. Renewable crediting period:**

**C.2.1.1. Starting date of the first crediting period:**

>>

Not applicable

**C.2.1.2. Length of the first crediting period:**

>>

Not applicable

**C.2.2. Fixed crediting period:**

**C.2.2.1. Starting date:**

>>

01/01/2013 or the date of registration, whatever occurs later.

**C.2.2.2. Length:**

&gt;&gt;

10 years

**SECTION D. Environmental impacts**

&gt;&gt;

**D.1. Documentation on the analysis of the environmental impacts, including transboundary impacts:**

&gt;&gt;

The project does not involve any activity that is listed in terms of the National Environmental Management Act and, as such, does not require an environmental impact assessment or a basic assessment.

**D.2. If environmental impacts are considered significant by the project participants or the host Party, please provide conclusions and all references to support documentation of an environmental impact assessment undertaken in accordance with the procedures as required by the host Party:**

&gt;&gt;

The impacts of the project is summarised below:

- An environmental analysis concluded that there do not appear to be any environmental fatal-flaws associated with the establishment of the proposed cogeneration plant on the existing ‘brown-fields’ site;
- The proposed cogeneration plant will be installed at an existing “brown-fields” site. It will not be necessary to apply for a Water Use License in terms of Section 21, 37(1) or 38(1) of the National Water Act, 1998, as no listed water uses are contemplated for the proposed project. This is given that municipal water (Sedibeng) will be used as top-up water for the cogeneration plant; and

**SECTION E. Stakeholders’ comments**

&gt;&gt;

**E.1. Brief description how comments by local stakeholders have been invited and compiled:**

&gt;&gt;

An advertisement was placed in a local newspaper to inform all the local stakeholders of the CDM project. The advertisement was placed in the Vista newspaper on 29 September 2011. Comments were invited on the project and the closing date for comments was the 17<sup>th</sup> of October 2011.

**E.2. Summary of the comments received:**

&gt;&gt;



There was one response to the advertisement, but this was only from a person looking to apply for a job on the project.

**E.3. Report on how due account was taken of any comments received:**

>>

The person was answered stating that unfortunately there are no job vacancies.

**Annex 1****CONTACT INFORMATION ON PARTICIPANTS IN THE PROJECT ACTIVITY**

Organization:	GFI Mining South Africa (Pty) Ltd
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Postcode/ZIP:	
Country:	South Africa
Telephone:	057 733 8526
FAX:	057 733 8545
E-Mail:	<a href="mailto:dirk.vangreuning@goldfields.co.za">dirk.vangreuning@goldfields.co.za</a>
URL:	<a href="http://www.goldfields.co.za">www.goldfields.co.za</a>
Represented by:	
Title:	Mr.
Salutation:	
Last name:	Van Greuning
Middle name:	
First name:	Dirk
Department:	
Mobile:	
Direct FAX:	
Direct tel:	
Personal e-mail:	



**Annex 2**

**INFORMATION REGARDING PUBLIC FUNDING**



### Annex 3

#### BASELINE INFORMATION

##### Information about the Occurrence of Methane at a Gold Mine

#### 1. Methane Capturing:

##### 1.1 Methane Occurrence:

The methane in the Beatrix mining area is not liberated homogeneously as is the case in coal beds. Methane is carried in geological faults from unknown reservoir(s) or source(s). Scientific research into the occurrence of the methane indicates that the methane:

- (a) seems to come from a deep-seated source, and
- (b) may be of biological origin.

Some of the literature sources are listed below:

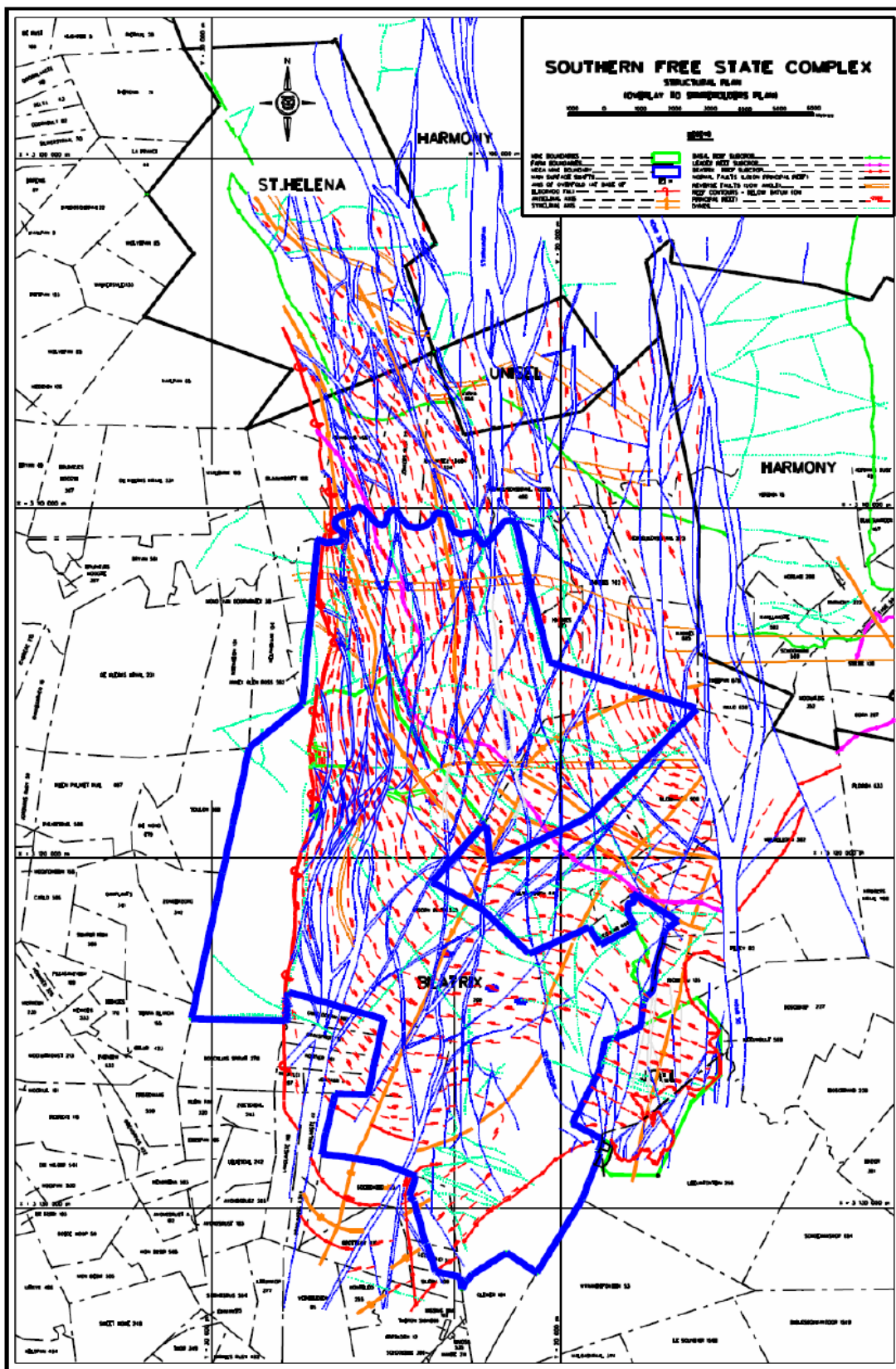
- Hugo P. J., Helium in the Orange Free State Gold Field, Geological Survey, Republic of South Africa, 1963.
- Takai et al., Archaeal Diversity in Waters from Deep South African Gold Mines, Applied and Environmental Microbiology, December 2001, Vol 67, No 12, pp 5750 – 5760
- England, G L, Rasmussen, B, Krapez, B, Groves, D I, Archaean oil migration in the Witwatersrand Basin of South Africa, Journal of the Geological Society, Mar 2002
- Spangenberg J., Frimmel H. E., Basin-internal derivation of hydrocarbons in the Witwatersrand Basin, South Africa: evidence from bulk and molecular <sup>13</sup>C data, Chemical Geology, 2001, 173, 339-355.
- Ward J.A. et al, Microbial hydrocarbon gases in the Witwatersrand Basin, South Africa: Implications for the deep biosphere, Geochimica et Cosmochimica Acta, Vol. 68, No. 15, pp. 3239–3250, 2004.

The conclusion reached by Ward states that: “... *these microbial hydrocarbon gases are the product of in situ methanogenic communities in the deep subsurface of the Witwatersrand basin.*”

Attempts to reduce the methane hazard in the underground mines, by borehole drainage, were made in the 1960s. These attempts were unsuccessful due to the failure to predict the location of the methane gas in the underground mines. This was documented and made public by the Department of Mines in a geological survey on Helium in the Orange Free State Gold-Field. *The South African Government Printer, Bulletin 39, G.P.-s 3479551-1962-63-1200*

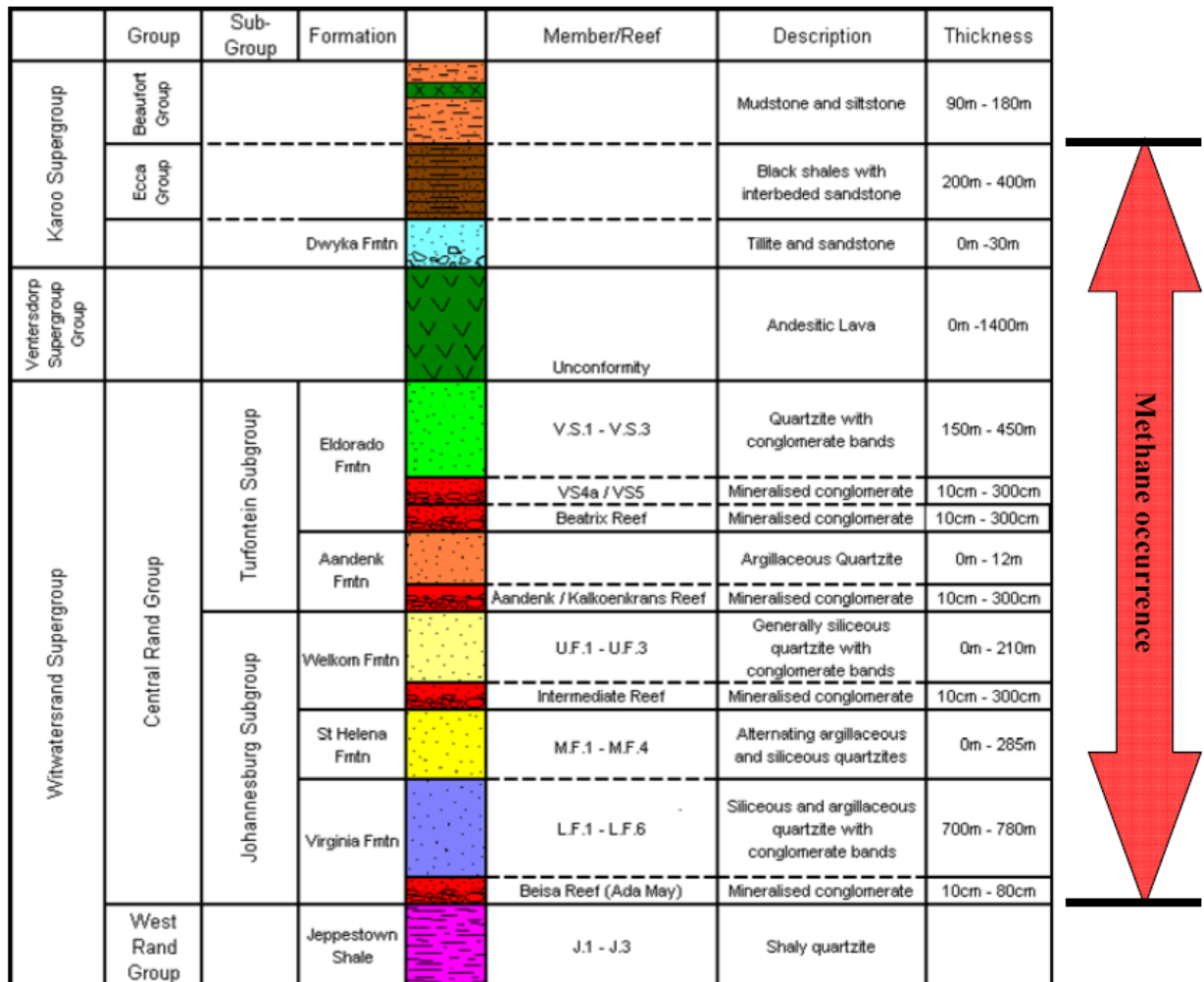


The difficulties in predicting the location of the methane in the Beatrix mine are exacerbated by the lack of detailed major and minor geological fault charts. The major geological fault zones, running through the Beatrix mining area, are depicted in Figure 3. The minor faults are largely uncharted. As the country rock in the area is impermeable, methane is carried exclusively in these discrete faults. The exact location of the methane in these discrete faults is difficult to determine. Hence, the management of methane in the mine can only be done on an *ex post* basis; when the area is mined and the methane is released.



**Figure 7: Geological faults in the Beatrix mining area**

Historically, methane emissions from mining operations has occurred from the Karoo Supergroup through to the Virginia Formation (refer Figure 8 below) at depths ranging from 300 meters to 3 kilometres.



**Figure 8: Free State goldfields stratigraphic column**

Methane from these geological structures is vented from two main sources: surface boreholes and underground mining areas.

Currently, all of the methane from the underground workings is diluted into the ventilation air and vented to surface through the vent shafts. Examples of these vent shafts can be seen in Figure 9.

**Annex 4****MONITORING INFORMATION****From the “Tool to determine project emissions from flaring gases containing methane” (EB 28, Annex 13):**

The steps in this tool were carried out to determine the project emissions from flaring the mine methane. A single flare will be installed at the Beisa Shaft to combust the mine methane.

The steps in the tool are as follows:

***STEP 1: Determination of the mass flow rate of the residual gas that is flared***

*This step calculates the residual gas mass flow rate in each hour h, based on the volumetric flow rate and the density of the residual gas. The density of the residual gas is determined based on the volumetric fraction of all components in the gas.*

$$FM_{RG,h} = \rho_{RG,n,h} \times FV_{RG,h} \quad (\text{Flaring Tool}^1 1)$$

Where:

$FM_{RG,h}$	Mass flow rate of residual gas in hour h (kg/h)
$\rho_{RG,n,h}$	Density of residual gas at normal conditions in hour h
$FV_{RG,h}$	Volumetric flow rate of the residual gas in dry basis at normal conditions in hour h ( $m^3/h$ )

And:

$$\rho_{RG,n,h} = \frac{P_n}{\frac{R_u}{MM_{RG,h}} \times T_n} \quad (\text{Flaring Tool 2})$$

Where:

$\rho_{RG,n,h}$	Density of residual gas at normal conditions in hour h
$P_n$	Atmospheric pressure at normal conditions (101,325 Pa)
$R_u$	Universal ideal gas constant (8,314 Pa.m <sup>3</sup> /kmol.K)
$MM_{RG,h}$	Molecular mass of the residual gas in hour h (kg/kmol)
$T_n$	Temperature at normal conditions (273.15K)

And:

$$MM_{RG,h} = \sum_i (fv_{i,h} \times MM_i) \quad (\text{Flaring Tool 3})$$

<sup>1</sup> UNFCCC methodological tool, “Tool to determine project emissions from flaring gases containing methane”.



Where:

$MM_{RG,h}$	Molecular mass of the residual gas in hour $h$ (kg/kmol)
$fv_{i,h}$	Volumetric fraction of component $i$ in the residual gas in the hour $h$
$MM_i$	Molecular mass of residual gas component $i$
$i$	The components $CH_4$ , $CO$ , $CO_2$ , $O_2$ , $H_2$ , $N_2$

If Flaring Tool 3 is applied to this project activity it becomes:

$$MM_{RG,h} = (fv_{CH_4,h} \times MM_{CH_4} + fv_{CO} \times MM_{CO} + fv_{CO_2} \times MM_{CO_2} + fv_{O_2} \times MM_{O_2} + fv_{H_2} \times MM_{H_2} + fv_{N_2} \times MM_{N_2})$$

(Flaring Tool 3.1)

Where:

$fv_{CH_4,h}$	Volumetric fraction of methane in the residual gas in the hour $h$
$fv_{CO,h}$	Volumetric fraction of CO in the residual gas in the hour $h$
$fv_{CO_2,h}$	Volumetric fraction of $CO_2$ in the residual gas in the hour $h$
$fv_{O_2,h}$	Volumetric fraction of $O_2$ in the residual gas in the hour $h$
$fv_{H_2,h}$	Volumetric fraction of $H_2$ in the residual gas in the hour $h$
$fv_{N_2,h}$	Volumetric fraction of $N_2$ in the residual gas in the hour $h$
$MM_{CH_4}$	Molecular mass of methane (kg/kmol)
$MM_{CO}$	Molecular mass of CO (kg/kmol)
$MM_{CO_2}$	Molecular mass of $CO_2$ (kg/kmol)
$MM_{O_2}$	Molecular mass of $O_2$ (kg/kmol)
$MM_{H_2}$	Molecular mass of $H_2$ (kg/kmol)
$MM_{N_2}$	Molecular mass of $N_2$ (kg/kmol)

### **STEP 2: Determination of the mass fraction of carbon, hydrogen, oxygen and nitrogen in the residual gas**

The mass fractions of carbon, hydrogen, oxygen and nitrogen in the residual gas, were calculated from the volumetric fraction of each component  $i$  in the residual gas, as follows:

$$fm_{j,h} = \frac{\sum_i fv_{i,h} \times AM_j \times NA_{j,i}}{MM_{RG,h}} \quad (\text{Flaring Tool 4})$$

Where:

$fm_{j,h}$	Mass fraction of element $j$ in the residual gas in hour $h$
$fv_{i,h}$	Volumetric fraction of component $i$ in the residual gas in the hour $h$
$AM_j$	Atomic mass of element $j$ (kg/kmol)
$NA_{j,i}$	Number of atoms of element $j$ in the component $i$
$MM_{RG,h}$	Molecular mass of the residual gas in hour $h$ (kg/kmol)
$j$	The elements carbon, hydrogen, oxygen and nitrogen
$i$	The components $CH_4$ , $CO$ , $CO_2$ , $O_2$ , $H_2$ , $N_2$



When applied in this project Flaring Tool equation 4 became:

$$fm_{C,h} = \frac{fv_{CH_4,h} \times AM_C \times NA_{C,CH_4} + fv_{CO,h} \times AM_C \times NA_{C,CO} + fv_{CO_2,h} \times AM_C \times NA_{C,CO_2}}{MM_{RG,h}}$$

(Flaring Tool 4.1)

Where:

$fm_{C,h}$	Mass fraction of carbon in the residual gas in hour h
$fv_{CH_4,h}$	Volumetric fraction of methane in the residual gas in the hour h
$fv_{CO,h}$	Volumetric fraction of CO in the residual gas in the hour h
$fv_{CO_2,h}$	Volumetric fraction of CO <sub>2</sub> in the residual gas in the hour h
$AM_C$	Atomic mass of carbon (kg/kmol)
$NA_{C,CH_4}$	Number of atoms of carbon in methane
$NA_{C,CO}$	Number of atoms of carbon in CO
$NA_{C,CO_2}$	Number of atoms of carbon in CO <sub>2</sub>

$$fm_{H,h} = \frac{fv_{CH_4,h} \times AM_H \times NA_{H,CH_4} + fv_{H_2,h} \times AM_H \times NA_{H,H_2}}{MM_{RG,h}}$$

(Flaring Tool 4.2)

Where:

$fm_{H,h}$	Mass fraction of hydrogen in the residual gas in hour h
$fv_{CH_4,h}$	Volumetric fraction of methane in the residual gas in the hour h
$fv_{H_2,h}$	Volumetric fraction of H <sub>2</sub> in the residual gas in the hour h
$AM_H$	Atomic mass of hydrogen (kg/kmol)
$NA_{H,CH_4}$	Number of atoms of hydrogen in methane
$NA_{H,H_2}$	Number of atoms of hydrogen in H <sub>2</sub>
$MM_{RG,h}$	Molecular mass of the residual gas in hour h (kg/kmol)

$$fm_{O,h} = \frac{fv_{CO,h} \times AM_O \times NA_{O,CO} + fv_{CO_2,h} \times AM_O \times NA_{O,CO_2} + fv_{O_2,h} \times AM_O \times NA_{O,O_2}}{MM_{RG,h}}$$

(Flaring Tool 4.3)

Where:

$fm_{O,h}$	Mass fraction of oxygen in the residual gas in hour h
$fv_{CO,h}$	Volumetric fraction of CO in the residual gas in the hour h
$fv_{CO_2,h}$	Volumetric fraction of CO <sub>2</sub> in the residual gas in the hour h
$fv_{O_2,h}$	Volumetric fraction of O <sub>2</sub> in the residual gas in the hour h
$AM_O$	Atomic mass of oxygen (kg/kmol)
$NA_{O,CO}$	Number of atoms of oxygen in CO
$NA_{O,CO_2}$	Number of atoms of oxygen in CO <sub>2</sub>
$NA_{O,O_2}$	Number of atoms of oxygen in O <sub>2</sub>
$MM_{RG,h}$	Molecular mass of the residual gas in hour h (kg/kmol)



$$fm_{N,h} = \frac{fv_{N2,h} \times AM_N \times NA_{N,N2}}{MM_{RG,h}} \quad (\text{Flaring Tool 4.4})$$

Where:

$fm_{N,h}$	Mass fraction of nitrogen in the residual gas in hour h
$fv_{N2,h}$	Volumetric fraction of nitrogen in the residual gas in the hour h
$AM_N$	Atomic mass of hydrogen (kg/kmol)
$NA_{N,N2}$	Number of atoms of hydrogen in nitrogen
$MM_{RG,h}$	Molecular mass of the residual gas in hour h (kg/kmol)

**STEP 3:** Determination of the volumetric flow rate of the exhaust gas on a dry basis

*This step is only applicable if the methane combustion efficiency of the flare is continuously monitored.*

*Determine the average volumetric flow rate of the exhaust gas in each hour h based on a stoichiometric calculation of the combustion process, which depends on the chemical composition of the residual gas, the amount of air supplied to combust it and the composition of the exhaust gas, as follows:*

$$TV_{n,FG,h} = V_{n,FG,h} \times FM_{RG,h} \quad (\text{Flaring Tool 5})$$

Where:

$TV_{n,FG,h}$	Volumetric flow rate of the exhaust gas in basis at normal conditions in hour h ( $m^3/h$ )
$V_{n,FG,h}$	Volume of the exhaust gas of the flare in dry basis at normal conditions per kg of residual gas in hour h ( $m^3/h$ residual gas)
$FM_{RG,h}$	Mass flow rate of the residual gas in hour h (kg residual gas/h)

$$V_{n,FG,h} = V_{n,CO2,h} + V_{n,O2,h} + V_{n,N2,h} \quad (\text{Flaring Tool 6})$$

Where:

$V_{n,FG,h}$	Volume of the exhaust gas of the flare in dry basis at normal conditions per kg of residual gas in the hour h ( $m^3/kg$ residual gas)
$V_{n,CO2,h}$	Quantity of $CO_2$ volume free in the exhaust gas of the flare at normal conditions per kg of residual gas in the hour h ( $m^3/kg$ residual gas)
$V_{n,O2,h}$	Quantity of $O_2$ volume free in the exhaust gas of the flare at normal conditions per kg of residual gas in the hour h ( $m^3/kg$ residual gas)
$V_{n,N2,h}$	Quantity of $N_2$ volume free in the exhaust gas of the flare at normal conditions per kg of residual gas in the hour h ( $m^3/kg$ residual gas)

$$V_{n,O2,h} = n_{O2,h} \times MV_n \quad (\text{Flaring Tool 7})$$

Where:

$V_{n,O2,h}$	Quantity of $O_2$ volume free in the exhaust gas of the flare at normal conditions per kg of residual gas in the hour h ( $m^3/kg$ residual gas)
$n_{O2,h}$	Quantity of moles $O_2$ in the exhaust gas of the flare per kg residual gas flared in hour h (kmol/kg residual gas)



$MV_n$  Volume of one mole of any ideal gas at normal temperature and pressure (22.4 L/mol)

$$V_{n,N_2,h} = MV_n \times \left\{ \frac{fm_{N,h}}{200AM_n} + \left( \frac{1 - MF_{O_2}}{MF_{O_2}} \right) \times [F_h + n_{O_2,h}] \right\} \quad (\text{Flaring Tool 8})$$

Where:

$V_{n,N_2,h}$  Quantity of  $N_2$  volume free in the exhaust gas of the flare at normal conditions per kg of residual gas in the hour  $h$  ( $m^3/kg$  residual gas)  
 $MV_n$  Volume of one mole of any ideal gas at normal temperature and pressure (22.4 L/mol)  
 $fm_{N,h}$  Mass fraction of nitrogen in the residual gas in hour  $h$   
 $AM_n$  Atomic mass of nitrogen (kg/kmol)  
 $MF_{O_2}$   $O_2$  volumetric fraction of air  
 $F_h$  Stoichiometric quantity of moles  $O_2$  required for complete oxidation of one kg residual gas in hour  $h$   
 $n_{O_2,h}$  Quantity of moles of  $O_2$  in the exhaust gas of the flare per kg residual gas flared in hour  $h$

$$V_{n,CO_2,h} = \frac{fm_{C,h}}{AM_c} \times MV_v \quad (\text{Flaring Tool 9})$$

Where:

$V_{n,CO_2,h}$  Quantity of  $CO_2$  volume free in the exhaust gas of the flare at normal conditions per kg of residual gas in the hour  $h$  ( $m^3/kg$  residual gas)  
 $fm_{C,h}$  Mass fraction of carbon in the residual gas in the hour  $h$   
 $AM_c$  Atomic mass of carbon (kg/kmol)  
 $MV_n$  Volume of one mole of any ideal gas at normal temperature and pressure (22.4 L/mol)

$$n_{O_2,h} = \frac{t_{O_2,h}}{\left( 1 - \frac{t_{O_2,h}}{MF_{O_2}} \right)} \times \left[ \frac{fm_{C,h}}{AM_c} + \frac{fm_{N,h}}{2AM_N} + \frac{1 - MF_{O_2}}{MF_{O_2}} \times F_h \right] \quad (\text{Flaring Tool 10})$$

Where:

$n_{O_2,h}$  Quantity of moles  $O_2$  in the exhaust gas of the flare per kg residual flared in hour  $h$  (kmol/kg residual gas)  
 $t_{O_2,h}$  Volumetric fraction of  $O_2$  in the exhaust gas in the hour  $h$   
 $MF_{O_2}$  Volumetric fraction of  $O_2$  in the air (0.21)  
 $fm_{C,h}$  Mass fraction of C in the residual gas in hour  $h$   
 $fm_{N,h}$  Mass fraction of N in the residual gas in hour  $h$   
 $F_h$  Stoichiometric quantity of moles of  $O_2$  required for a complete oxidation of one kg residual gas in hour  $h$  (kmol/kg residual gas)  
 $AM_c$  Atomic mass of C (kg/kmol)  
 $AM_N$  Atomic mass of N (kg/kmol)



$$F_h = \frac{fm_{C,h}}{AM_C} + \frac{fm_{H,h}}{4AM_H} - \frac{fm_{O,h}}{2AM_O} \quad (\text{Flaring Tool 11})$$

Where:

$F_h$	Stoichiometric quantity of moles of O <sub>2</sub> required for a complete oxidation of one kg residual gas in hour h (kmol/kg residual gas)
$fm_{C,h}$	Mass fraction of C in the residual gas in hour h
$fm_{H,h}$	Mass fraction of H in the residual gas in hour h
$fm_{O,h}$	Mass fraction of O in the residual gas in hour h
$AM_C$	Atomic mass of C (kg/kmol)
$AM_H$	Atomic mass of H (kg/kmol)
$AM_O$	Atomic mass of O (kg/kmol)

**STEP 4: Determination of methane mass flow rate in the exhaust gas on a dry basis**

**This step is only applicable if the methane combustion efficiency of the flare is continuously monitored.**

The combustion efficiency will be measured continuously in this project for the flare installed at Beisa Shaft.

The mass flow of methane in the exhaust gas is based on the volumetric flow of the exhaust gas and the measured concentration of methane in the exhaust gas, as follows:

$$TM_{FG,h} = \frac{TV_{n,FG,h} \times fv_{CH_4,FG,h}}{1,000,000} \quad (\text{Flaring Tool 12})$$

Where:

$TM_{FG,h}$	Mass flow rate of methane in the exhaust gas of the flare in dry basis at normal conditions in the hour h (kg/h)
$TV_{n,FG,h}$	Volumetric flow rate of the exhaust gas in dry basis at normal conditions in hour h (m <sup>3</sup> /h exhaust gas)
$fv_{CH_4,FG,h}$	Concentration of methane in the exhaust gas of the flare in dry basis at normal conditions in hour h (mg/m <sup>3</sup> )

**STEP 5: Determination of methane mass flow rate in the residual gas on a dry basis**

The quantity of methane in the residual gas flowing into the flare is the product of the volumetric flow rate of the residual gas ( $FV_{RG,h}$ ), the volumetric fraction of methane in the residual gas ( $fv_{CH_4,RG,h}$ ) and the density of methane ( $\rho_{CH_4,n,h}$ ) in the same reference conditions (normal conditions and dry or wet basis).

It is necessary to refer both measurements (flow rate of the residual gas and volumetric fraction of methane in the residual gas) to the same reference condition that may be dry or wet basis. If the residual gas moisture is significant (temperature greater than 60°C), the measured flow rate of the residual gas that is usually referred to wet basis should be corrected to dry basis due to the fact that the measurement of methane is usually undertaken on a dry basis (i.e. water is removed before sample analysis).



$$TM_{RG,h} = FV_{RG,h} \times fv_{CH4,RG,h} \times \rho_{CH4,n} \quad (\text{Flaring Tool 13})$$

Where:

$TM_{RG,h}$	Mass flow rate of methane in the residual gas in the hour h (kg/h)
$FV_{RG,h}$	Volumetric flow rate of the residual gas in dry basis at normal conditions in hour h ( $m^3/h$ )
$fv_{CH4,RG,h}$	Volumetric fraction of methane in the residual gas on dry basis in hour h
$\rho_{CH4,n}$	Density of methane at normal conditions ( $0.716 \text{ kg/m}^3$ )

#### STEP 6: Determination of the hourly flare efficiency

The determination of the hourly flare efficiency depends on the operation of flare (e.g. temperature), the type of flare used (open or enclosed) and, in case of enclosed flares, the approach selected by project participants to determine the flare efficiency (default value or continuous monitoring)

This project will use an enclosed, continuously monitored flare for the mine methane.

The tool states that in the case of enclosed flares and continuous monitoring of the flare efficiency, the flare efficiency in the hour h ( $\eta_{flare,h}$ ) is:

- 0% if the temperature of the exhaust gas of the flare ( $T_{flare}$ ) is below  $500 \text{ }^\circ\text{C}$  during more than 20 minutes during the hour h.
- determined as follows in cases where the temperature of the exhaust gas of the flare ( $T_{flare}$ ) is above  $500 \text{ }^\circ\text{C}$  for more than 40 minutes during the hour h :

$$\eta_{flare,h} = 1 - \frac{TM_{FG,h}}{TM_{RG,h}} \quad (\text{Flaring Tool 14})$$

Where:

$\eta_{flare,h}$	Flare efficiency in the hour h
$TM_{FG,h}$	Methane mass flow rate in the exhaust gas averaged in a period of time t (kg/h)
$TM_{RG,h}$	Mass flow rate of methane in the residual gas in the hour h (kg/h)

#### STEP 7: Calculation of annual project emissions from flaring

Project emissions from flaring are calculated as the sum of emissions from each hour h, based on the methane flow rate in the residual gas ( $TM_{RG,h}$ ) and the flare efficiency during each hour h ( $\eta_{flare,h}$ ), as follows:

$$PE_{flare,y} = \sum_{h=1}^{8760} TM_{RG,h} \times (1 - \eta_{flare,h}) \times \frac{GWP_{CH4}}{1,000} \quad (\text{Flaring Tool 15})$$

Where:

$PE_{flare,y}$	Project emissions from flaring the residual gas stream in year y ( $t\text{CO}_2\text{e}$ )
$TM_{RG,h}$	Mass flow rate of methane in the residual gas in the hour h (kg/h)



$\eta_{flare,h}$  Flare efficiency in hour  $h$   
 $GWP_{CH_4}$  Global warming potential of methane valid for the commitment period ( $tCO_2e/tCH_4$ )

**Flaring Tool result of Equation 1:**

Year	$FM_{RG,h}$	$\rho_{RG,n,h}$	$FV_{RG,h}$
1	1 414.84	0.87	1 623.00
2	91.61	0.87	105.09
3	91.61	0.87	105.09
4	91.61	0.87	105.09
5	91.61	0.87	105.09
6	91.61	0.87	105.09
7	91.61	0.87	105.09
8	91.61	0.87	105.09
9	91.61	0.87	105.09
10	91.61	0.87	105.09

**Flaring Tool result of Equation 2:**

Year	$\rho_{RG,n,h}$	$P_n$	$R_u$	$MM_{RG,h}$	$T_n$
1	0.8717442	101 325	8 314	19.54	273.15
2	0.8717442	101 325	8 314	19.54	273.15
3	0.8717442	101 325	8 314	19.54	273.15
4	0.8717442	101 325	8 314	19.54	273.15
5	0.8717442	101 325	8 314	19.54	273.15
6	0.8717442	101 325	8 314	19.54	273.15
7	0.8717442	101 325	8 314	19.54	273.15
8	0.8717442	101 325	8 314	19.54	273.15
9	0.8717442	101 325	8 314	19.54	273.15
10	0.8717442	101 325	8 314	19.54	273.15

**Flaring Tool result of Equation 3:**

Year	$MM_{RG,h}$	$fv_{CH_4,h}$	$MM_{CH_4}$	$fv_{CO,h}$	$MM_{CO}$	$fv_{CO_2,h}$
1	19.54	0.71	16.04	0	28.01	0
2	19.54	0.71	16.04	0	28.01	0
3	19.54	0.71	16.04	0	28.01	0
4	19.54	0.71	16.04	0	28.01	0
5	19.54	0.71	16.04	0	28.01	0
6	19.54	0.71	16.04	0	28.01	0
7	19.54	0.71	16.04	0	28.01	0
8	19.54	0.71	16.04	0	28.01	0



9	19.54	0.71	16.04	0	28.01	0
10	19.54	0.71	16.04	0	28.01	0

Year	MM <sub>CO2</sub>	fv <sub>O2,h</sub>	MM <sub>O2</sub>	fv <sub>H2,h</sub>	MM <sub>H2</sub>	fv <sub>N2,h</sub>	MM <sub>N2</sub>
1	44.01	0	32	0	2.02	0.29	28.02
2	44.01	0	32	0	2.02	0.29	28.02
3	44.01	0	32	0	2.02	0.29	28.02
4	44.01	0	32	0	2.02	0.29	28.02
5	44.01	0	32	0	2.02	0.29	28.02
6	44.01	0	32	0	2.02	0.29	28.02
7	44.01	0	32	0	2.02	0.29	28.02
8	44.01	0	32	0	2.02	0.29	28.02
9	44.01	0	32	0	2.02	0.29	28.02
10	44.01	0	32	0	2.02	0.29	28.02

**Flaring Tool result of Equation 4:**

Year	fm <sub>C,h</sub>	fv <sub>CH4,h</sub>	AM <sub>C</sub>	NA <sub>C,CH4</sub>
1	0.43	0.71	12	1
2	0.43	0.71	12	1
3	0.43	0.71	12	1
4	0.43	0.71	12	1
5	0.43	0.71	12	1
6	0.43	0.71	12	1
7	0.43	0.71	12	1
8	0.43	0.71	12	1
9	0.43	0.71	12	1
10	0.43	0.71	12	1

Year	fv <sub>CO,h</sub>	NA <sub>C,CO</sub>	fv <sub>CO2,h</sub>	NA <sub>C,CO2</sub>	MM <sub>RG,h</sub>
1	0	1	0	1	19.54
2	0	1	0	1	19.54
3	0	1	0	1	19.54
4	0	1	0	1	19.54
5	0	1	0	1	19.54
6	0	1	0	1	19.54
7	0	1	0	1	19.54
8	0	1	0	1	19.54
9	0	1	0	1	19.54
10	0	1	0	1	19.54



Year	$fm_{H,h}$	$fv_{CH_4,h}$	$AM_H$	$NA_{H,CH_4}$	$fv_{H_2,h}$	$NA_{H,H_2}$	$MM_{RG,h}$
1	0.15	0.71	1.01	4	0	2	19.54
2	0.15	0.71	1.01	4	0	2	19.54
3	0.15	0.71	1.01	4	0	2	19.54
4	0.15	0.71	1.01	4	0	2	19.54
5	0.15	0.71	1.01	4	0	2	19.54
6	0.15	0.71	1.01	4	0	2	19.54
7	0.15	0.71	1.01	4	0	2	19.54
8	0.15	0.71	1.01	4	0	2	19.54
9	0.15	0.71	1.01	4	0	2	19.54
10	0.15	0.71	1.01	4	0	2	19.54

Year	$fm_{N,h}$	$fv_{N_2,h}$	$AM_N$	$NA_{N,N_2}$	$MM_{RG,h}$
1	0.42	0.29	14.01	2	19.54
2	0.42	0.29	14.01	2	19.54
3	0.42	0.29	14.01	2	19.54
4	0.42	0.29	14.01	2	19.54
5	0.42	0.29	14.01	2	19.54
6	0.42	0.29	14.01	2	19.54
7	0.42	0.29	14.01	2	19.54
8	0.42	0.29	14.01	2	19.54
9	0.42	0.29	14.01	2	19.54
10	0.42	0.29	14.01	2	19.54

Year	$fm_{O,h}$	$fv_{O_2,h}$	$AM_O$	$NA_{O,O_2}$	$fv_{CO,h}$
1	0	0	16	2	0
2	0	0	16	2	0
3	0	0	16	2	0
4	0	0	16	2	0
5	0	0	16	2	0
6	0	0	16	2	0
7	0	0	16	2	0
8	0	0	16	2	0
9	0	0	16	2	0
10	0	0	16	2	0

Year	$NA_{O,CO}$	$fv_{CO_2,h}$	$NA_{O,CO_2}$	$MM_{RG,h}$
1	1	0	2	19.54
2	1	0	2	19.54



3	1	0	2	19.54
4	1	0	2	19.54
5	1	0	2	19.54
6	1	0	2	19.54
7	1	0	2	19.54
8	1	0	2	19.54
9	1	0	2	19.54
10	1	0	2	19.54

**Flaring Tool result of Equation 5:**

Year	$TV_{n,FG,h}$	$V_{n,FG,h}$	$FM_{RG,h}$
1	26 280.16	19.18	1 370.32
2	1 701.65	19.18	88.73
3	1 701.65	19.18	88.73
4	1 701.65	19.18	88.73
5	1 701.65	19.18	88.73
6	1 701.65	19.18	88.73
7	1 701.65	19.18	88.73
8	1 701.65	19.18	88.73
9	1 701.65	19.18	88.73
10	1 701.65	19.18	88.73

**Flaring Tool result of Equation 6:**

Year	$V_{n,FG,h}$	$V_{n,CO2,h}$	$V_{n,O2,h}$	$V_{n,N2,h}$
1	19.18	0.78	0.67	17.72
2	19.18	0.78	0.67	17.72
3	19.18	0.78	0.67	17.72
4	19.18	0.78	0.67	17.72
5	19.18	0.78	0.67	17.72
6	19.18	0.78	0.67	17.72
7	19.18	0.78	0.67	17.72
8	19.18	0.78	0.67	17.72
9	19.18	0.78	0.67	17.72
10	19.18	0.78	0.67	17.72

**Flaring Tool result of Equation 7:**

Year	$V_{n,O2,h}$	$n_{O2,h}$	$MV_n$
1	0.67	0.03	22.4
2	0.67	0.03	22.4
3	0.67	0.03	22.4



4	0.67	0.03	22.4
5	0.67	0.03	22.4
6	0.67	0.03	22.4
7	0.67	0.03	22.4
8	0.67	0.03	22.4
9	0.67	0.03	22.4
10	0.67	0.03	22.4

**Flaring Tool result of Equation 8:**

Year	$V_{n,N_2,h}$	$MV_n$	$fm_{N,h}$	$AM_n$	$MF_{O_2}$	$F_h$	$n_{O_2,h}$
1	17.72	22.4	36%	14.01	0.21	0.18	0.03
2	17.72	22.4	36%	14.01	0.21	0.18	0.03
3	17.72	22.4	36%	14.01	0.21	0.18	0.03
4	17.72	22.4	36%	14.01	0.21	0.18	0.03
5	17.72	22.4	36%	14.01	0.21	0.18	0.03
6	17.72	22.4	36%	14.01	0.21	0.18	0.03
7	17.72	22.4	36%	14.01	0.21	0.18	0.03
8	17.72	22.4	36%	14.01	0.21	0.18	0.03
9	17.72	22.4	36%	14.01	0.21	0.18	0.03
10	17.72	22.4	36%	14.01	0.21	0.18	0.03

**Flaring Tool result of Equation 9:**

Year	$V_{n,CO_2,h}$	$fm_{C,h}$	$AM_C$	$MV_n$
1	0.78	42%	12	22.4
2	0.78	42%	12	22.4
3	0.78	42%	12	22.4
4	0.78	42%	12	22.4
5	0.78	42%	12	22.4
6	0.78	42%	12	22.4
7	0.78	42%	12	22.4
8	0.78	42%	12	22.4
9	0.78	42%	12	22.4
10	0.78	42%	12	22.4

**Flaring Tool result of Equation 10:**

Year	$n_{O_2,h}$	$t_{O_2,h}$	$fm_{C,h}$	$AM_C$	$fm_{N,h}$
1	0.03	4%	42%	12	35.82%
2	0.03	4%	42%	12	35.82%
3	0.03	4%	42%	12	35.82%
4	0.03	4%	42%	12	35.82%



5	0.03	4%	42%	12	35.82%
6	0.03	4%	42%	12	35.82%
7	0.03	4%	42%	12	35.82%
8	0.03	4%	42%	12	35.82%
9	0.03	4%	42%	12	35.82%
10	0.03	4%	42%	12	35.82%

Year	AM <sub>N</sub>	MF <sub>O2</sub>	F <sub>h</sub>
1	14.01	0.21	0.18
2	14.01	0.21	0.18
3	14.01	0.21	0.18
4	14.01	0.21	0.18
5	14.01	0.21	0.18
6	14.01	0.21	0.18
7	14.01	0.21	0.18
8	14.01	0.21	0.18
9	14.01	0.21	0.18
10	14.01	0.21	0.18

**Flaring Tool result of Equation 11:**

Year	F <sub>h</sub>	fm <sub>C,h</sub>	AM <sub>C</sub>	fm <sub>H,h</sub>	AM <sub>H</sub>	fm <sub>O,h</sub>	AM <sub>O</sub>
1	0.18	42%	12	14.15%	1.01	8%	16
2	0.18	42%	12	14.15%	1.01	8%	16
3	0.18	42%	12	14.15%	1.01	8%	16
4	0.18	42%	12	14.15%	1.01	8%	16
5	0.18	42%	12	14.15%	1.01	8%	16
6	0.18	42%	12	14.15%	1.01	8%	16
7	0.18	42%	12	14.15%	1.01	8%	16
8	0.18	42%	12	14.15%	1.01	8%	16
9	0.18	42%	12	14.15%	1.01	8%	16
10	0.18	42%	12	14.15%	1.01	8%	16

**Flaring Tool result of Equation 12:**

Year	TM <sub>FG,h</sub>	TV <sub>n,FG,h</sub>	fv <sub>CH4,FG,h</sub>
1	281.64	26 280.16	10 716.75
2	18.24	1 701.65	10 716.75
3	18.24	1 701.65	10 716.75
4	18.24	1 701.65	10 716.75
5	18.24	1 701.65	10 716.75
6	18.24	1 701.65	10 716.75



7	18.24	1 701.65	10 716.75
8	18.24	1 701.65	10 716.75
9	18.24	1 701.65	10 716.75
10	18.24	1 701.65	10 716.75

**Flaring Tool result of Equation 13:**

Year	$TM_{RG,h}$	$FV_{RG,h}$	$f_{CH_4,RG,h}$	$\rho_{CH_4,n}$
1	822.75	1 623.00	71%	0.716
2	53.27	105.09	71%	0.716
3	53.27	105.09	71%	0.716
4	53.27	105.09	71%	0.716
5	53.27	105.09	71%	0.716
6	53.27	105.09	71%	0.716
7	53.27	105.09	71%	0.716
8	53.27	105.09	71%	0.716
9	53.27	105.09	71%	0.716
10	53.27	105.09	71%	0.716

**Flaring Tool result of Equation 14:**

Year	$\eta_{flare,h}$	$TM_{FG,h}$	$TM_{RG,h}$
1	0.6576854	281.64	822.75
2	0.6576854	18.24	53.27
3	0.6576854	18.24	53.27
4	0.6576854	18.24	53.27
5	0.6576854	18.24	53.27
6	0.6576854	18.24	53.27
7	0.6576854	18.24	53.27
8	0.6576854	18.24	53.27
9	0.6576854	18.24	53.27
10	0.6576854	18.24	53.27

**Flaring Tool result of Equation 15:**

Year	$PE_{flare,y}$	$TM_{RG,h}$	$\eta_{flare,h}$	$GWP_{CH_4}$
1	51 810.10	822.75	0.66	21
2	3 354.73	53.27	0.66	21
3	3 354.73	53.27	0.66	21
4	3 354.73	53.27	0.66	21
5	3 354.73	53.27	0.66	21
6	3 354.73	53.27	0.66	21
7	3 354.73	53.27	0.66	21



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8	3 354.73	53.27	0.66	21
9	3 354.73	53.27	0.66	21
10	3 354.73	53.27	0.66	21

**The “Tool to calculate the emission factor for an electricity system” (EB 63, Annex 19, Version 02.2.1)**

This tool was used to calculate the emission factor for all the grid electricity that the project will be displacing.

**STEP 1: IDENTIFY THE RELEVANT ELECTRICITY SYSTEMS**

This tool will serve project activities that prospect to displace grid electricity in South Africa.

The **project electricity system** is defined by the spatial extent of the power plants that are physically connected through transmission and distribution lines to the project activity and that can be displaced without significant transmission constraints.

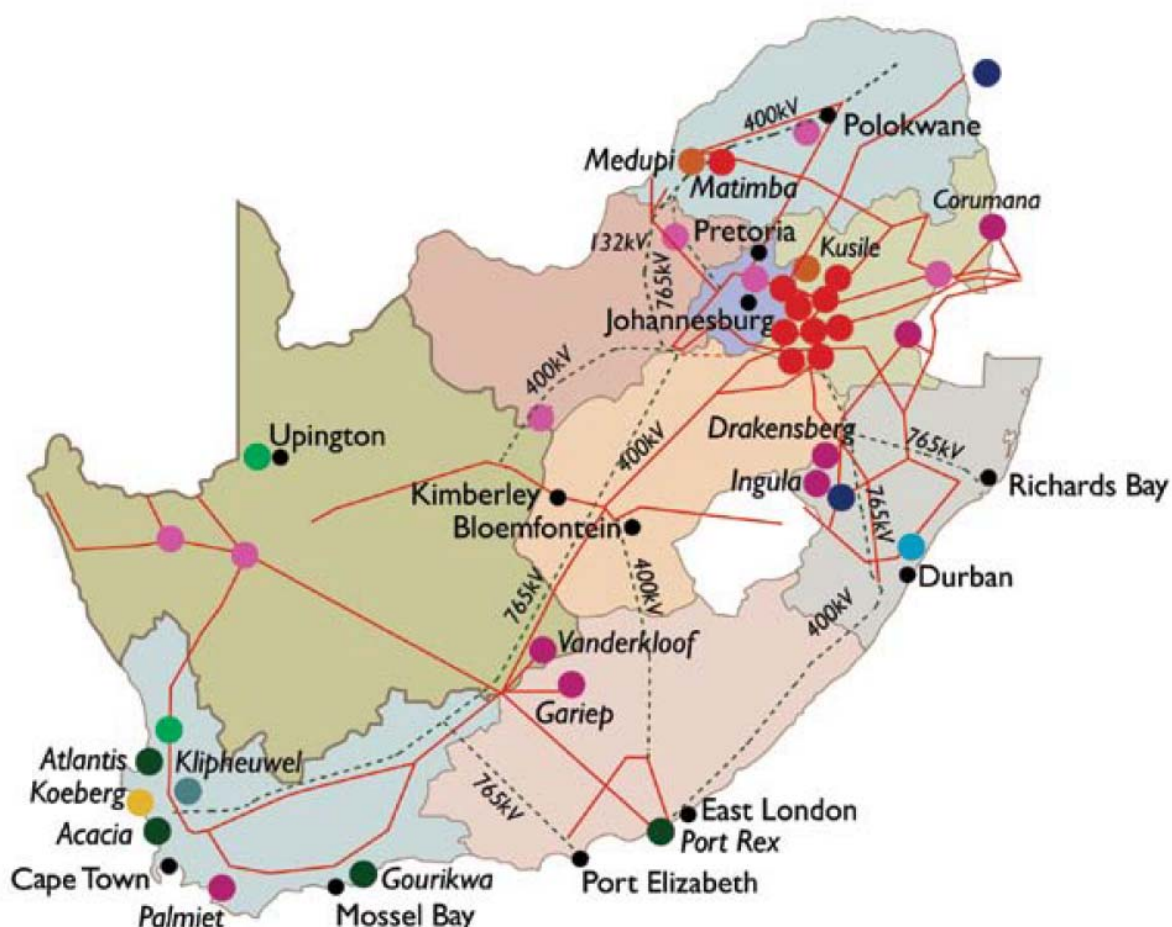
Similarly, a **connected electricity system**, e.g. national or international, is defined as an electricity system that is connected by transmission lines to the project electricity system. Power plants within the connected electricity system can be dispatched without significant transmission constraints, but transmission to the project electricity system has significant transmission constraints.

The DNA of South Africa has not published a delineation of the project electricity system and connected electricity systems. Also, the application of the criteria with regards to determining significant transmission constraints does not result in a clear grid boundary due to a lack of sufficient data. For these reasons the following was chosen for the reference system of this project:

- The **project electricity system** entails all the Eskom power plants in the South African electricity grid.
- Due to a lack of data available in the public domain (in order to evaluate significant transmission constraints), all other power stations (non-Eskom) and countries with power grids connected to South Africa, are treated as **connected electricity systems**, and emission factors for imports from these systems are conservatively assumed to be 0 tCO<sub>2</sub>/MWh.

All electricity generated by the Eskom power stations is taken into consideration when calculating the grid emission factor; exports are not subtracted.

All the data for the Eskom power stations are obtained from the Eskom website, where they have a specific webpage dedicated to CDM grid emission factor related data (Eskom Holdings SOC Limited, 2011). This data includes commissioning dates, electricity generated, and fuel consumed. Data for the imported electricity are obtained from the Eskom annual report, where “*Total purchased for the Eskom system (GWh)*” is shown in the “*Statistical overview*” table on pg. 324 of the report (Eskom Holdings SOC Limited, 2011).



## STEP 2: CHOSE WHETHER TO INCLUDE OFF-GRID POWER PLANTS IN THE PROJECT ELECTRICITY SYSTEM

This step is optional according to the tool. The grid emission factor is calculated from only grid power plants (**Option I**). Off-grid power plants are not included in the calculations.

## STEP 3: SELECT A METHOD TO DETERMINE THE OPERATING MARGIN (OM)

The OM is calculated using the **simple OM method (Option a)**. The simple OM method can be used provided that the low-cost/must-run resources constitute less than 50% of the total grid generation in average of the five most recent years.

The average percentage of low-cost/must-run resources amount to 0.00% of the total grid generation for this project electricity system. Therefore, Option (a) is applicable.

In terms of data vintages, the *ex ante* option were chosen to calculate the simple OM. In this option a 3 year generation-weighted average are used for the grid power plants. Using this option also means that



the emission factor is determined only once at the validation stage, thus no monitoring and recalculation is required during the crediting period.

The data used in OM calculations are for the 3 year period of 1 April 2008 – 31 March 2011 (Eskom financial year runs from 1 April – 31 March). This is the latest available data.

#### STEP 4: CALCULATE THE OPERATING MARGIN EMISSION FACTOR ACCORDING TO THE SELECTED METHOD

The simple OM emission factor ( $EF_{grid,OMsimple,y}$ ) is calculated as the generation-weighted average CO<sub>2</sub> emissions per unit net electricity generation (tCO<sub>2</sub>/MWh) of all generating power plants serving the system, not including low-cost/must-run power plants/units. Hence, the hydro and nuclear power plants are excluded from the calculation of the OM.

**Option A** is used for calculating the simple OM. The calculations in this option are based on the total net electricity generation and a CO<sub>2</sub> emission factor of each power plant.

*Option A – Calculation based on average efficiency and electricity generation of each plant*

Under this option, the simple OM emission factor is calculated based on the net electricity generation of each power plant and an emission factor of each power plant, as follows:

$$EF_{grid,OMsimple,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}}$$

Where:

$EF_{grid,OMsimple,y}$	= Simple operating margin CO <sub>2</sub> emission factor in year y (tCO <sub>2</sub> /MWh)
$EG_{m,y}$	= Net quantity of electricity generated and delivered to the grid by power unit $m$ in the year y (MWh)
$EF_{EL,m,y}$	= CO <sub>2</sub> emission factor of power unit $m$ in year y (tCO <sub>2</sub> /MWh)
$m$	= All power units serving the grid in year y except low-cost/must-run power units
$y$	= The relevant year as per data vintage chosen in Step 3

*Determination of  $EF_{EL,m,y}$*

The emission factor for each power plant  $m$  were determined as follows (**Option A1**):

$$EF_{grid,OMsimple,y} = \frac{\sum_i (FC_{i,y} \times NCV_{i,y} \times EF_{CO_2,i,y})}{EG_y} \quad (6)$$

Where:



$EF_{grid, OMsimple,y}$	=	Simple operating margin CO <sub>2</sub> emission factor in year $y$ (tCO <sub>2</sub> /MWh)
$FC_{i,y}$	=	Amount of fossil fuel type $i$ consumed in the project electricity system in year $y$ (mass or volume unit)
$NCV_{i,y}$	=	Net calorific value (energy content) fossil fuel type $i$ in year $y$ (GJ/mass or volume unit)
$EF_{CO2,i,y}$	=	CO <sub>2</sub> emission factor of fossil fuel type $i$ in year $y$ (tCO <sub>2</sub> /GJ)
$EG_y$	=	Net electricity generated and delivered to the grid by all power sources serving the system, not including low-cost/must-run power plants/units, in year $y$ (MWh)
$i$	=	All fossil fuel types combusted in power sources in the project electricity system in year $y$
$y$	=	The relevant year as per data vintage chosen in Step 3.

Electricity imports are treated as one power plant, as per the tool guidance.  
The constants used in calculations appear in Table 1.

**Table 1: Constants used in calculations**

Constants		
$NCV_{\text{other bituminous coal}}$	19.9	GJ/T
$NCV_{\text{other kerosene}}$	42.9	GJ/T
$EF_{CO2\text{other bituminous coal}}$	0.0895	tCO <sub>2</sub> /GJ
$EF_{CO2,\text{other kerosene}}$	0.0708	tCO <sub>2</sub> /GJ

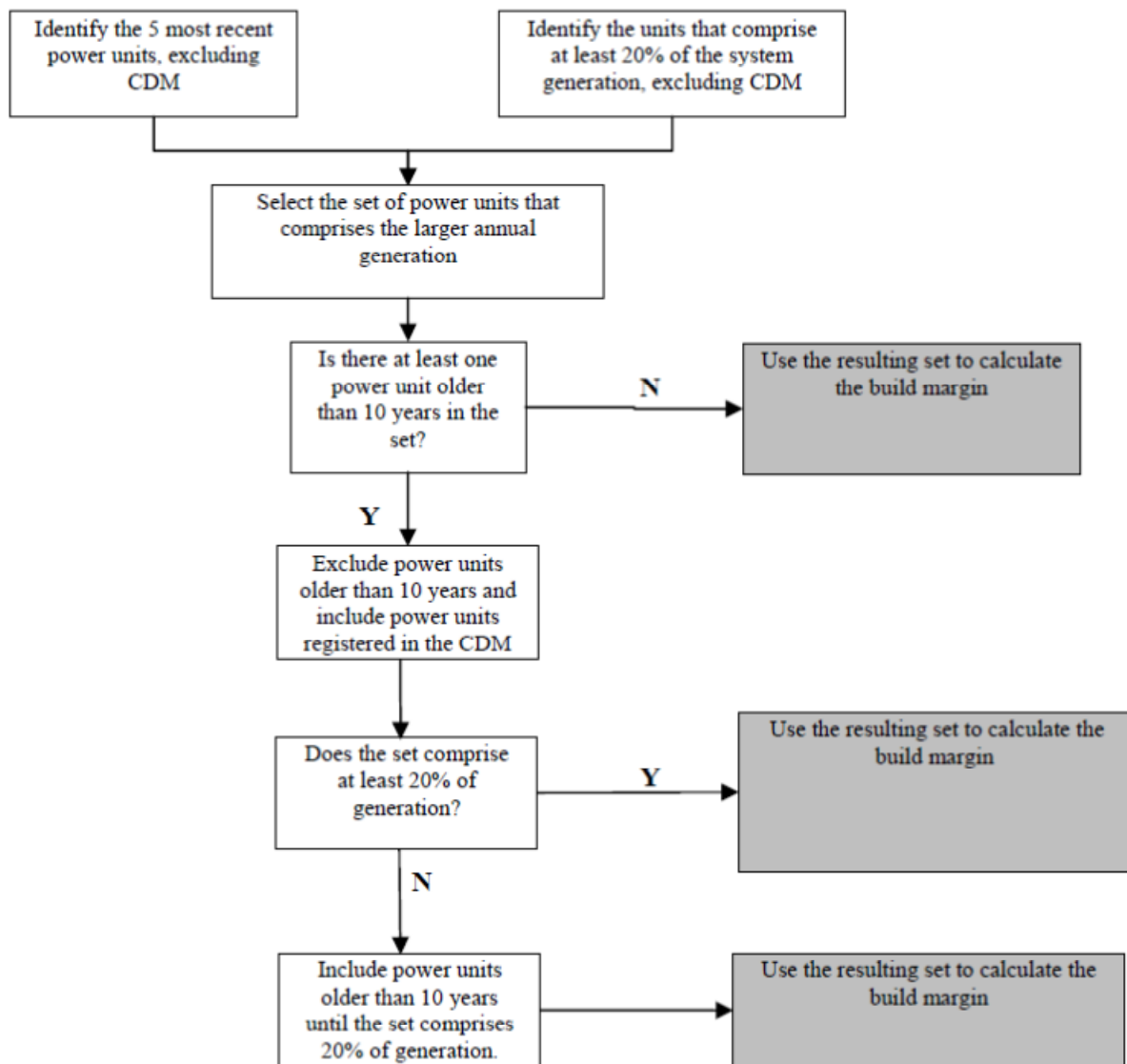
Using equation 6, the OM is calculated as **1.018** tCO<sub>2</sub>e/MWh.

## STEP 5: CALCULATE THE BUILD MARGIN (BM) EMISSION FACTOR

In terms of vintage of data, one **Option 1** was selected: For the first crediting period, calculate the build margin emission factor *ex ante* based on the most recent information available on units already built for sample group  $m$  at the time of CDM-PDD submission to the DOE for validation.

The sample group of power units  $m$  used to calculate the build margin were determined as per the procedure delineated in the tool, consistent with the data vintages selected.

The following diagram summarizes the procedure of identifying the sample group:



The build margin emissions factor is the generation-weighted average emission factor (tCO<sub>2</sub>/MWh) of all power units *m* during the most recent year *y* for which power generation data is available, calculated as follows:

$$EF_{grid,BM,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}} \quad (13)$$

Where:

$EF_{grid,BM,y}$  = Build margin CO<sub>2</sub> emission factor in year *y* (tCO<sub>2</sub>/MWh)



$EG_{m,y}$	= Net quantity of electricity generated and delivered to the grid by power unit $m$ in year $y$ (MWh)
$EF_{EL,m,y}$	= CO <sub>2</sub> emission factor of power unit $m$ in year $y$ (tCO <sub>2</sub> /GJ)
$m$	= Power units included in the build margin
$y$	= Most recent historical year for which power generation data is available.

The CO<sub>2</sub> emission factor of each power unit  $m$  ( $EF_{EL,m,y}$ ) should be determined as per the guidance in Step 4 (a) for the simple OM, using **Option A1** using for  $y$  the most recent historical year for which power generation data is available, and using for  $m$  the power units included in the build margin. If for a power unit  $m$  data on fuel consumption and electricity generation is available the emission factor ( $EF_{EL,m,y}$ ) should be determined as follows:

$$EF_{EL,m,y} = \frac{\sum_i FC_{i,m,y} \times NCV_{i,y} \times EF_{CO_2,i,y}}{\sum_m EG_{m,y}} \quad (2)$$

Where:

$EF_{EL,m,y}$	= CO <sub>2</sub> emission factor of power unit $m$ in year $y$ (tCO <sub>2</sub> /MWh)
$FC_{i,m,y}$	= Amount of fossil fuel type $i$ consumed by power unit $m$ in year $y$ (mass or volume unit)
$NCV_{i,y}$	= Net calorific value (energy content) fossil fuel type $i$ in year $y$ (GJ/mass or volume)
$EF_{CO_2,i,y}$	= CO <sub>2</sub> emission factor of fossil fuel type $i$ in year $y$ (tCO <sub>2</sub> /GJ)
$EG_{m,y}$	= Net electricity generated and delivered to the grid by power unit $m$ in year $y$ (MWh)
$m$	= All power plants/units serving the grid in year $y$ except low-cost/must-run power plants/units
$i$	= All fossil fuel types combusted in power plant/unit $m$ in year $y$
$y$	= The relevant year as per data vintage chosen in Step 3.

Using equation 13, the BM is calculated as **1.024** tCO<sub>2</sub>e/MWh.

## STEP 6: CALCULATE THE COMBINED MARGIN (CM) EMISSION FACTOR

The combined margin factor is calculated as follows:

$$EF_{grid,CM,y} = EF_{grid,OM,y} \times w_{OM} + EF_{grid,BM,y} \times w_{BM} \quad (14)$$

Where:

$EF_{grid,BM,y}$	= Build Margin CO <sub>2</sub> emission factor in year $y$ (tCO <sub>2</sub> /MWh)
$EF_{grid,OM,y}$	= Operating margin CO <sub>2</sub> emission factor in year $y$ (tCO <sub>2</sub> /MWh)
$w_{OM}$	= Weighting of operating margin emissions factor (%)
$w_{BM}$	= Weighting of build margin emissions factor (%)

The emission factors for the the final combined margin appear in Table 8.

**Table 3: CM emission factor**

	W <sub>OM</sub>	W <sub>BM</sub>	<b>Combined Margin Emission Factor</b>
Wind and solar power generation project activities for the first crediting period and for subsequent crediting periods.	0.75	0.25	<b>1.020</b>
All other projects for the first crediting period.	0.5	0.5	<b>1.021</b>
All other projects for the second and third crediting period.	0.25	0.75	<b>1.023</b>

**The “Tool to calculate baseline, project and/or leakage emissions from electricity consumption” (EB 39, Annex 7, Version 01)**

The equipment for the destruction and utilisation of mine methane will use electricity from the South African National Grid.

**Project Emissions from Electricity Consumption for Mine Methane**

During the project case, grid electricity and captive electricity (electricity generated by the project) will be required for the capture, transportation, compression and utilisation or destruction of the mine methane ( $PE_{ELEC,y}$ ). In order to calculate  $PE_{ELEC,y}$ , the “*Tool to calculate baseline, project and/or leakage emissions from electricity consumption*” must be applied. This tool provides the procedure to estimate the project emissions associated with the consumption of electricity.

Applying this tool:

Scenario C applies to the proposed project activity. Scenario C is presented below (verbatim text is in *italics*):

*“Scenario C: Electricity consumption from the grid and (a) fossil fuel fired captive power plant(s).*

*One or more fossil fuel fired captive power plants operate at the site of the electricity consumption source. The captive power plant(s) can provide electricity to the electricity consumption source. The captive power plant(s) is/are also connected to the electricity grid.*

*Hence, the electricity consumption source can be provided with electricity from the captive power plant(s) and the grid”.*

Scenario C was selected as the electricity consumed by the proposed project activity will be sourced either from the grid or from the captive power plant (the project). This captive power plant will be connected to the grid. Hence, it will not be possible to determine how much of the electricity consumed in the project case is sourced from the captive power plant and how much is purchased from the grid.

Furthermore, Case C.I applies (*italic text is verbatim from the tool*):

*“Case C.I: Grid electricity. The implementation of the project activity only affects the quantity of electricity that is supplied from the grid and not the operation of the captive power plant. This applies, for example,*

- If at all times during the monitored period the total electricity demand at the site of the captive power plant(s) is, both with the project activity and in the absence of the project activity, larger than the electricity generation capacity of the captive power plant(s); or*
- If the captive power plant is operated continuously (apart from maintenance) and feeds any excess electricity into the grid, because the revenues for feeding electricity into the grid are above the plant operation costs; or*
- If the captive power plant is centrally dispatched and the dispatch of the captive power plant is thus outside the control of the project participants.”*



Case C.I. applies since the implementation of the project activity will only affect the quantity of electricity that the Beatrix mine imports from the grid and not the operation of the captive power plant. The total electricity demand at the Beatrix mine, which is the site of the captive power plant, is always larger than the electricity generation capacity of the plant.

- The total electricity demand of Beatrix is approximately 864,000MWh/year.
- The total captive generation ability is 9.415 installed MW electrical.

The captive power plant will be operated continuously (apart from maintenance) and the electricity generated by the plant will be dispatched centrally. The dispatch of the electricity will be outside the control of the GFI Mining South Africa' Beatrix mine.

Since, Scenario C.I applies to the project activity; the electricity emission factor can be calculated using either Option A1 or Option A2.

Option A1 was selected in order to calculate the electricity emission factor. Option A1 states (verbatim test in italics):

*“Option A1: Calculate the combined margin emission factor of the applicable electricity system, using the procedures in the latest approved version of the “Tool to calculate the emission factor for an electricity system” ( $EF_{EL,j/k/l,y} = EF_{grid,CM,y}$ ).”*

The identified term,  $EF_{grid,CM,y}$ , refers to Step 6 of the “Tool to calculate the emission factor for an electricity system” (version 02.2.1), which states (verbatim text in italics):

*“Step 6. Calculate the combined margin emissions factor*

*The combined margin emissions factor is calculated as follows:*

$$EF_{grid,CM,y} = EF_{grid,OM,y} \times w_{OM} + EF_{grid,BM,y} \times w_{BM}$$

(Equation 13 in the “Tool to calculate the emission factor for an electricity system”)

$EF_{grid,BM,y}$  = Build margin CO<sub>2</sub> emission factor in year y (tCO<sub>2</sub>/MWh)

$EF_{grid,OM,y}$  = Operating margin CO<sub>2</sub> emission factor in year y (tCO<sub>2</sub>/MWh)

$w_{OM}$  = Weighting of operating margin emissions factor (%)

$w_{BM}$  = Weighting of build margin emissions factor (%)

- *Wind and solar power generation project activities:  $w_{OM} = 0.75$  and  $w_{BM} = 0.25$  (owing to their intermittent and non-dispatchable nature) for the first crediting period and for subsequent crediting periods.*
- *All other projects:  $w_{OM} = 0.5$  and  $w_{BM} = 0.5$  for the first crediting period, and  $w_{OM} = 0.25$  and  $w_{BM} = 0.75$  for the second and third crediting period, unless otherwise specified in the approved methodology which refers to this tool.”*

The default value of  $w_{OM} = 0.5$  and  $w_{BM} = 0.5$  will be used.



The electricity emission factor is then used to determine the project emissions due to electricity consumption by the proposed project activity. These emissions can be determined by applying Equation 1 from the “Tool to calculate baseline, project and/or leakage emissions from electricity consumption,” version 01:

$$PE_{EC,y} = \sum_j EC_{PJ,j,y} \times EF_{EL,j,y} \times (1 + TDL_{j,y})$$

(Equation 1 from the “Tool to calculate, project and/or leakage emissions from electricity consumption)

Where:

$PE_{EC,y}$	Project emissions from electricity consumption in year y (tCO <sub>2</sub> /yr)
$EC_{PJ,j,y}$	Quantity of electricity consumed by the project electricity consumption source j in year y (MWh/year)
$EF_{EL,j,y}$	Emission factor for electricity generation for source j in year y (tCO <sub>2</sub> /MWh)
$TDL_{j,y}$	Average technical transmission and distribution losses for providing electricity to source l in year y
j	Sources of electricity consumption in the project
l	Leakage sources of electricity consumption

This equation could then be applied to this project taking into account that the sources of electricity (j) will only be the national grid.

There will be one source of electricity consumption in the project. Hence, ‘j’ will be one. Applied to this project, Equation 1 becomes:

$$PE_{EC,y} = EC_{PJ,y} \times EF_{EL,y} \times (1 + TDL_y)$$

A default of 3% was used for the average technical transmission and distribution losses for providing electricity ( $TDL_{j,y}$ ). A default was chosen as there is no recent, accurate and reliable data available within South Africa. The 3% was used since the electricity consumption by the proposed project activity is smaller than the electricity consumption of all the baseline electricity consumption sources.



From “Tool to calculate baseline, project and/or leakage emissions from electricity consumption”:

**Equation 1:**

Year	$PE_{EC,y}$	$EC_{PJ,j,y}$	$EF_{EL,j,y}$	$TDL_{j,y}$
1	1,701.74	1,588.63	1.04	3%
2	1,701.74	1,588.63	1.04	3%
3	1,701.74	1,588.63	1.04	3%
4	1,701.74	1,588.63	1.04	3%
5	1,701.74	1,588.63	1.04	3%
6	1,701.74	1,588.63	1.04	3%
7	1,701.74	1,588.63	1.04	3%
8	1,701.74	1,588.63	1.04	3%
9	1,701.74	1,588.63	1.04	3%
10	1,701.74	1,588.63	1.04	3%

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