CDM: Proposed New Methodology
Meth Panel recommendation to the Executive Board

To be completed by UNFCCC Secretariat

Date of Meth Panel meeting:	
Related F-CDM-NM document ID number (electronically available to EB members)	F-CDM-NM0 : “ ”
Related F-CDM-NMex document ID number(s) (electronically available to EB members)	F-CDM-NMex0 :
Related F-CDM-NMpu document ID number(s) (electronically available to EB members)	F-CDM-NMpu0 :

Signature of Meth Panel Chair ……………………………………………..
Date:

Signature of Meth Panel Vice-Chair ……………………………………………..
Date:

Information to be completed by the secretariat

F-CDM-NMmp doc id number	NM
Date when the form was received at UNFCCC secretariat	
Date of transmission to the EB	
Date of posting in the UNFCCC CDM web site	

NM0xxx Version ## (to be completed by UNFCCC)

CLEAN DEVELOPMENT MECHANISM
PROPOSED NEW BASELINE AND MONITORING METHODOLOGIES
(CDM-NM)
(Version 03.1)

CONTENTS

Instructions for using this form

In using this form, please follow the guidance established in the following documents:

- Guidelines for completing the project design document (CDM-PDD) and proposed new baseline and monitoring methodologies (CDM-NM);
- Technical guidelines for the development of new baseline and monitoring methodologies (contained in part III of the above);
- Relevant methodological guidance by the Executive Board.

This guidance can be found at <https://cdm.unfccc.int/Reference/Guidclarif/index.html>

Formatting Instructions:

- The form provides the formatted headings which should be used throughout the document;
- Please note that each paragraph in section C and D should have a paragraph number, as demonstrated through example. When adding further paragraphs, please ensure it is numbered;
- Please use word equation editor to write equations;
- Please format figures, tables and footnotes to update automatically;
- Please note the footnotes have a separate format (Times New Roman - size 10).[1]

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[1] Format for footnotes.

Please complete sections B to E. In section C, the text shaded in grey shall not be changed, whereas other text is used as an example and may be changed or deleted.

Section A. Recommendation by the Methodological Panel (to be completed by the Meth Panel)

1. Recommendation (preliminary or final / approval or rejection / consolidation)

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2. Major changes required

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3. Minor changes required

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Section B. Summary and applicability of the baseline and monitoring methodology

1. Methodology title (for baseline and monitoring), submission date and version number

Capture, transport and long-term storage in Geological Formations of carbon dioxide from natural gas processing operations

Version number of the document: 1.0

Date of the document: 05/08/2009

2. If this methodology is based on a previous submission or an approved methodology, please state the reference numbers (NMXXXX/AMXXXX/ACMXXXX) here. Explain briefly the main differences and their rationale.

This methodology is not based on previous submissions.

3. Summary description of the methodology, including major baseline and monitoring methodological steps

This methodology is applicable to project activities that reduce emissions of greenhouse gases (GHG) to the atmosphere by capturing separated CO_2 from the processing of natural gas, transporting it by pipelines, and its injection and storage in appropriately selected and well-managed Geological Formations for the purpose of its long-term isolation from the atmosphere; carbon dioxide capture and storage (CCS) in Geological Formations.

It applies where a significant quantity of CO_2 is present in the formation from which natural gas is produced, and is produced from wells co-mingled with the natural gas and emitted to atmosphere as a by-product of separation by venting. Separation of CO_2 from the natural gas is carried out to meet sales specification (usually <2% by vol.) or for liquefied natural gas production, which requires an even lower CO_2 content. It typically involves the use of amine solvent-based CO_2 removal plant or membrane separation systems. In the absence of markets for separated CO_2 or other incentives to avoid venting, the baseline scenario for this type of activity is typically venting of CO_2. The methodology requires project participants to identify all plausible and credible potential alternatives to venting of CO_2 – including undertaking the project not as a CDM project activity or exporting the gas without separating the CO_2.

In addition, project participants must provide an overview of other technologies and practices that have been implemented or currently planned in the relevant geographical area or sector in relation to treatment of natural gas containing CO_2. For new build projects, a range of data must be provided to show that no measures have been taken to enhance the amount of CO_2 that might be vented or stored in the project activity. These are designed to avoid the creation of perverse incentives for new build projects. Each option is then subject to assessment of legality, barriers analysis, and an evaluation of economic attractiveness. The most economically attractive of remaining options is considered to be the baseline scenario. Additionality is demonstrated by showing that the project activity is not the baseline scenario.

Baseline emissions are equal to the amount of CO_2 captured from separation in a Natural Gas Processing Plant, and that would be vented to the atmosphere in the absence of the project activity. This methodology does not include methods for calculating baseline emissions in the event of the capture of any other Streams of CO_2 at the plant (e.g. combustion emissions); it is only applicable to capture of Formation CO_2 separated from natural gas during processing. Project emissions from fossil fuel combustion and electricity use during capture, transport and storage are calculated using similar approaches as outlined in the latest "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion" and "Tool to calculate project emissions from electricity consumption". Project emissions as a result of Fugitive Emissions during capture, transport and injection are calculated using a mass balance approach (amount of CO_2 captured minus the amount injected).

In addition, this methodology includes an approach for the calculation of Seepage emissions as a *potential* source of project emissions. This involves a four-step process covering: [a] avoidance of Seepage emissions (through appropriate CO_2 Geological Storage Complex selection, characterisation and management); [b] monitoring of the Geological Storage Complex and CO_2 Plume (for assurance that predicted storage performance is valid, and to detect early signs of *potential* Seepage) [c] quantification of any detected Seepage emissions; and [d] an approach to handling the permanence of emission reductions. It is envisaged that any PDD will include an Annex on Characterisation, Selection and Management of the Geological Storage Complex and an Annex on the Design of the Geological Storage Complex monitoring plan. In this context, Annexes to this document are provided:

A. Appropriate characterisation, selection and management of the Geological Storage Complex

B. Design of the Geological Storage Complex monitoring plan

C. Reporting of monitoring results

D. Guidance on Site Closure and Final Geological Storage Complex Performance Assessment

Data on surface flows and composition of the captured CO_2 Stream must be collected as part of the monitoring plan in order to calculate baseline emissions and Fugitive Emissions. Data on fuel, heat and electricity use (including fuel composition) must be collected to determine project emissions. Subsurface and surface data, which can indicate the performance of the CO_2 Geological Storage Complex, must also be collected, and additional methods may be employed to quantify Seepage emissions if they are detected during routine monitoring of the CO_2 Plume. Emission reductions are calculated as the difference between the baseline emissions (captured CO_2) and project emissions (from fuel and electricity use, Fugitive Emissions and Seepage).

This methodology also sets out a process for handling the long-term permanence of emission reductions. By permitting a CO_2 CCS project in Geological Formations the host country temporarily transfers Stewardship of the Geological Storage Complex to the project participants. The project participants then Develop, Operate and Close the Geological Storage Complex before transferring Stewardship back to the host country, as shown schematically in Figure 3.

Stewardship of a Geological Storage Complex extends beyond the end of the crediting period. Following cessation of injection operations project participants are required to continue monitoring the Geological Storage Complex during the Closure phase. If Seepage is detected, then the project participants must compensate through the surrender of Permanent Emission Certificates to the UNFCCC CDM Registry account, equal to the quantified mass of Seepage.

Monitoring during the Closure phase must also provide information on the stability of the CO_2 Plume When the pre-agreed performance objectives have been achieved then the project participants may transfer Stewardship of the Geological Storage Complex back to the host country (the Post Closure phase). During the Post Closure phase, the host country should monitor the Geological Storage Complex in accordance with applicable IPCC Inventory Guidelines. At this time, monitoring may be ramped down or ceased, and only undertaken if an event which could cause a Significant Irregularity occurs. In order to ensure that sufficient funds are available to the host country to finance Stewardship of the Geological Storage Complex, this methodology requires the use of a financial mechanism by the project participants – involving insurance, royalties or escrow accounts – that can be transferred to the host country.

Section C. Proposed new baseline and monitoring methodology

Draft baseline and monitoring methodology AMXXXX

"Capture, transport and long-term storage in Geological Formations of carbon dioxide from natural gas processing operations"

I. SOURCE, DEFINITIONS AND APPLICABILITY

Sources

This baseline and monitoring methodology is not based on any approved baseline and monitoring methodologies or proposed new methodologies.

This methodology does refer to the latest approved versions of the following tools:

- Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion;
- Tool to calculate baseline, project and/or leakage emissions from electricity consumption;
- Tool to calculate the emission factor for an electricity system;
- Tool for the demonstration and assessment of additionality;

The tools referred to above can be found on the CDM website at the following address: http://cdm.unfccc.int/Reference/tools/index.html

Selected approach from paragraph 48 of the CDM modalities and procedures

1. "Existing actual or historical emissions, as applicable"

   OR

2. "Emissions from a technology that represents an economically attractive course of action, taking into account barriers to investment"

Definitions: Please provide definitions of key terms that are used in this proposed new methodology

3. For the purpose of this methodology, the following definitions apply:

- **'Avoidance'** means avoiding (through maximising separation and/or inclusion of multiple barriers) wherever reasonable and technical feasible (a) known Seepage risk Features and highly stressed areas such as natural transmissive faults and fractures and (b) areas of known environmental, health and safety sensitivities.

- **'Caprock Formation'** means a Geological Formation with very low permeability that acts as an upper seal to prevent fluid flow out of an Injection Formation.

- **'Closure'** of a Geological Storage Complex is the period after the cessation of the Operation period (i.e. permanent cessation of CO_2 injection) and before the Post Closure period (i.e. the transfer of Stewardship from the project participants to the host Country). During the Closure period, the Participants close the site (including de-commissioning of facilities such as wells) and perform Subsurface Monitoring required to assure secure storage.

- **'CO_2 Geological Storage Centre of Expertise (CGSCoE)'** means an independent assurance agency providing technical advice on long-term security of CO_2 Geological Storage. Such an agency must be approved by the CDM Executive Board and be economically independent of the project participants and any other party involved in the CDM activity.

- **'CO_2 Plume'** means the dispersing volume of injected CO_2 in the Geological Storage Complex.

- **'CO_2 Stream'** means a stream that consists overwhelmingly of CO_2 and/or other trace or incidental substances derived from the source, its processing or any substances added to the Stream to enable or improve the injection process, but excluding matter added unlawfully for the sole purpose of disposal, captured and treated for the purpose of geological storage. Levels of other trace substances shall be below levels that could adversely affect the integrity of the Geological Storage Complex, relevant transport infrastructure, or pose a significant risk to the environment or human health or breach the requirements of applicable regulations in the host country.

- **'Compensation'** means the offsetting of Seepage, if required, through surrender by the project participants or host country, depending on the point in time when Seepage has occurred, of an equivalent amount of Permanent Emissions Certificates to the UNFCCC CDM registry.

- **'Containment System'** means an Injection Formation and Caprock Formation pairing, the combination of which is suitable for the long-term secure storage of CO_2.

- **'Corrective Measures'** means the actions reasonably necessary to correct or mitigate a Significant Irregularity in order to avoid, prevent or minimize emissions of CO_2 as a result of Seepage, including Compensation where required.

- **'Development'** of a Geological Storage Complex is the period that begins with the transfer of Stewardship from the host country to the project participants and ends when CO_2 injection commences (the beginning of the Operation period).

- **'Features'** means subsurface characteristics which could have an effect on CO_2 containment and Seepage e.g. through becoming active emission pathways and sources such as wells, faults, fissures, mineshafts, boreholes, spill points, caprock (and localised discontinuities).

- **'Formation CO_2'** means naturally occurring CO_2 present in natural gas produced from the reservoir.

- **'Fugitive Emissions'** for the purposes of this methodology means the intentional or unintentional above ground physical release of CO_2 to the atmosphere from the capture, treatment, transport, reception and injection system. It excludes Seepage emissions from the Geological Storage Complex[2].

- **'Geological Formation'** means a lithostratigraphical subdivision within which distinct rock layers can be found and mapped.

- **'Geological Storage Complex'** means one or more Containment Systems into which CO_2 could be injected and securely stored.

- **'Geological Storage Complex Report'** means a report characterising the geological features in the Injection Formation and surrounding domains of the storage complex for the purpose of identifying Seepage risk features and secure Modes of Operation for CO_2 storage in the subsurface. It must be prepared in accordance with Annex A of this methodology.

- **'Geosphere'** means the soils, sediments, and rock layers of the Earth's outer crust, covering both continental and ocean floors.

- **'Injection Formation'** means a Geological Formation with sufficient porosity and Permeability to transmit and store fluids.

- **'Leakage'** means the net change of anthropogenic emissions by sources of greenhouse gases (GHG) which occurs outside the project boundary, and which is measurable and attributable to the CDM project activity.

- **'Liability'** means the responsibility including all ensuing legal, financial and other obligations for the Geological Storage Complex and the stored CO_2 and/or displaced fluids.

- **'Mode of Operation'** means the operational procedures and constraints that must be adhered to by the project participants in injecting CO_2 into a Geological Storage Complex (e.g. maximum injection pressure, delivery rate). It shall be set out on a project specific basis, based on the Geological Storage Complex characteristics determined according to this methodology and its Annexes.

- **'Migration'** means the lateral and vertical subsurface movement of injected CO_2..

- **'Operation'** of a Geological Storage Complex is the period that begins when CO_2 injection commences (the end of the Development period) and ends when CO_2 injection permanently ceases (the start of the Closure period).

- **'Natural Gas Processing Plant'** means an installation for the purpose of the treatment (or "sweetening") of natural gas for the production of sales specification pipeline gas or for liquefaction.

- **'Overburden'** means all Geological Formations lying above the selected Geological Storage Complex unto the uppermost surface of the Geosphere.

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[2] Seepage emissions should be accounted for as fugitive emissions in national greenhouse gas inventories in accordance with *Volume 2, Chapter 5 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

- **‘Permeability’** means the ability for flow or transmission of fluids through a porous media such as rock.

- **‘Permanent Emissions Certificate’** means assigned amount units (AAUs), certified emission reductions (CERs), emission reduction units (ERUs) or other permanent and fungible emission certificates that might be defined as equivalent by the UNFCCC at the point in time of any Compensation requirements.

- **‘Porosity’** means the proportion of a Geological Formation that is filled with fluids (rather than solid rock).

- **‘Post Closure’** means the period after Closure of a Geological Storage Complex, during which, the host Country holds the Stewardship of the Geological Storage Complex.

- **‘Saline Formation’** means a porous and/or permeable sedimentary Geological Formation saturated with brackish water or brine with high total dissolved solids (TDS) content in excess of 10,000 mg/L in its pore space.

- **‘Seepage’** means emissions of injected CO_2 from the subsurface Geological Storage Complex into the atmosphere (or inland water bodies or ocean/surface water in the case of offshore storage) arising as a result of the project activity.

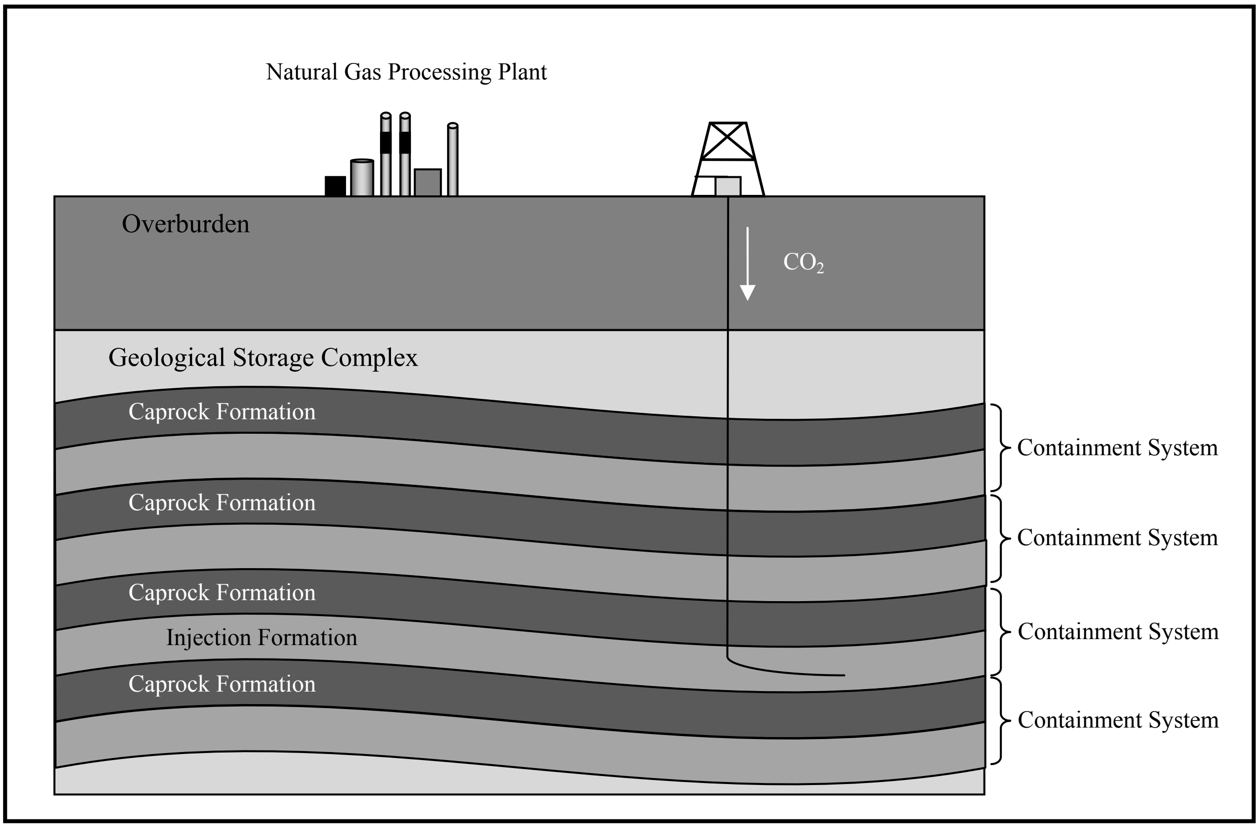
- **‘Significant Irregularity’** means any material change in the injection or storage operations and/or equipment or in the condition of the Geological Storage Complex that materially increases the risk of Seepage and/or Migration of CO_2 outside of the Geological Storage Complex.

- **‘Stewardship’** means responsibility for a Geological Storage Complex including management, operation and Subsurface Monitoring in addition to Liability in the event of a Significant Irregularity.

- **‘Subsurface Monitoring’** means the application of fit-for-purpose survey technologies to collect data and information that can be used to determine the disposition of the injected CO_2, and any significant irregularities or Seepage associated with the project activity. Such data can be collected above, on or below the ground surface.

4. In terms of understanding the subsurface Definitions applied in this methodology, the illustration below summarises the main components schematically (Figure 1).

Figure 1. Schematic of subsurface terminology applied in the methodology



Applicability conditions

5. This methodology applies to project activities that reduce greenhouse gas emissions to the atmosphere by capturing CO_2 Streams arising from the removal of Formation CO_2 at Natural Gas Processing Plants, transporting it via a pipeline and its injection into an appropriately selected and well-managed Geological Storage Complex for long-term isolation from the atmosphere.

6. This methodology applies under sectoral scope 10 ‘Fugitive emissions from fuels (solid, oil and gas)’. Some technical aspects of this project are such that the CDM Executive Board may wish to consider introducing a new sectoral scope 16 to cover ‘Carbon Dioxide Capture and Geological Storage’.

7. The methodology is applicable under the following conditions:

- For a CO_2 Stream from an existing Natural Gas Processing Plant, where removal of Formation CO_2 is an integrated part of an existing process and would typically result in separated CO_2 being vented to the atmosphere in the absence of the geological storage project activity.

- For a CO_2 Stream from a new Natural Gas Processing Plant, that removal of Formation CO_2 will be an integrated part of the planned process which would result in the CO_2 vented to the atmosphere in the absence of the project activity, and (i) that no modifications have been made to enhance the mass of the CO_2 Stream sent for injection and storage; and, (ii) the natural gas field would be developed absent of any additional revenues generated by the CDM as a result of the geological storage project activity.

- That the CO_2 Stream for injection consists overwhelmingly of CO_2, and that an allowed range of the composition of the CO_2 Stream as defined by the project participants is considered in the process of Geological Storage Complex selection, characterisation and operation.
- The Natural Gas Processing Plant, transportation pipeline and Geological Storage Complex are located in the same country.
- The Geological Storage Complex is supplied only with CO_2 Streams for geological storage from Natural Gas Processing Plants under the control of the project participants and included in the project activity;

8. Furthermore, the methodology is applicable if project participants meet the following requirements:

- The Geological Storage Complex is selected and managed in accordance with the appropriate steps, criteria and procedures described in Annex A, and the analysis suggests that with the proposed Mode of Operation Seepage is very unlikely and that no significant negative environmental or health impacts are likely to occur;
- The Geological Storage Complex characterisation, selection and management procedure – and attendant *Geological Storage Complex Selection & Characterisation Report* prepared in accordance with Annex A – is approved by the host country DNA (and/or competent authority appointed by the DNA) and subject to review and comment by the CDM EB and any panels appointed there under for this purpose.
- The host country DNA (and/or competent authority appointed by the DNA) has agreed to take over Stewardship of the Geological Storage Complex from the project participants in accordance with the modalities outlined in the *Project Emissions* section of this methodology. This agreement must be made in writing prior to Registration of the project activity.
- The project participants demonstrate that adequate provisions, by way of financial security (or equivalent), are in place to cover the requirements laid down in this methodology. This includes sufficient coverage for Compensation requirements laid out herein;

9. This methodology can be applied to the following subsurface formations/scenarios:

- Saline Formations
- Depleted or partially depleted oil and/or gas fields
- Onshore & offshore locations

10. This methodology does not apply to the following activities:

- Capture and geological storage of CO_2 from combustion sources;

- Ocean storage i.e. storage of CO_2 in the water column;
- Enhanced hydrocarbon recovery (EHR) of any type;

11. In addition, the applicability conditions included in the methodological tools referred to in Section B.2 apply.

12. Finally, this methodology is only applicable if the application of the procedure to identify the baseline scenario results in venting to the atmosphere of Formation CO_2 separated during natural gas processing being the most plausible baseline scenario.

II. BASELINE METHODOLOGY PROCEDURE

Project boundary

13. The **spatial extent** of the project boundary encompasses the Natural Gas Processing Plant from which the CO_2 Stream for injection and geological storage is derived and any components therein which have an effect on baseline and project emissions in the project activity. These include:

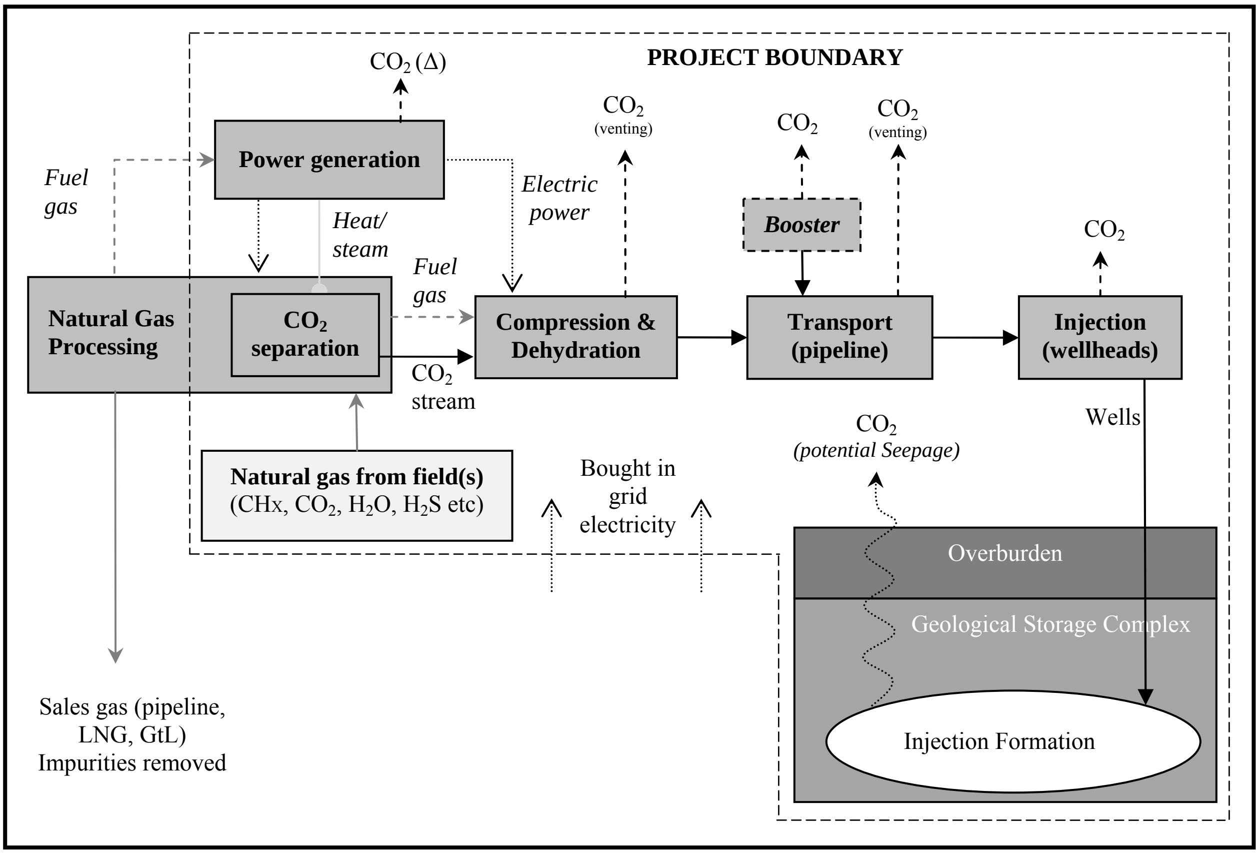
- The natural gas reservoirs (in order to determine the sources of Formation CO_2 for the CCS activity and to account for future tie-ins);
- The Natural Gas Processing Plant (if there is a change in fuel use within the plant as a consequence of the project activity compared with a standard plant configuration without CCS e.g. in relation to process optimisation for heat/steam use in amine regeneration);
- Any power plant used to generate power for CO_2 treatment and compression;
- Any treatment units used to treat CO_2 prior to injection (e.g. a dehydration plant);
- Pipeline(s) used to transport CO_2 from the Natural Gas Processing Plant to the Geological Storage Complex injection wellhead(s);
- The CO_2 injection wellheads and wells;

14. The spatial project boundary also extends into the subsurface to include the pre-defined Geological Storage Complex and Overburden. The CDM project boundary in relation to the subsurface shall be determined based on the following:

- Vertical boundary (which is the surface area of the Geosphere directly above the Geological Storage Complex and Overburden).
- Lateral boundaries (based on the lateral limits of the Geological Storage Complex, which is a an estimation based upon a characterisation of the Geological Storage Complex and predictive forward models of the CO_2 Plume Migration, Features and ultimate distribution of the CO_2 Plume in the target Injection Formation).

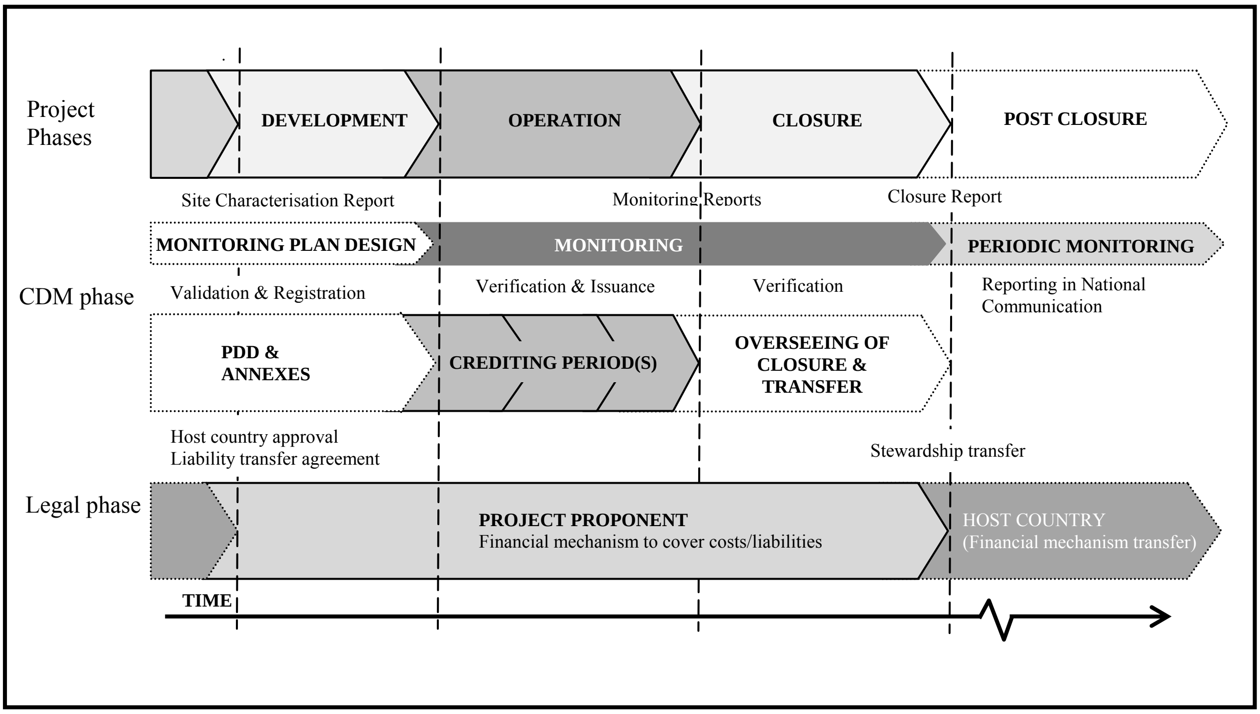
15. The boundaries of the Geological Storage Complex and associated Overburden are defined by the Geological Storage Complex characterisation procedures (See Annex A). Figure 2 presents the spatial extent of the project boundary visually (see also Figure 1 with respect to the subsurface components within the project boundary).

Figure 2. Spatial Project Boundary for a Natural Gas Processing CCS project activity



16. The **temporal extent** of the project boundary covers the Development, Operation, Closure and Post Closure phases of a CO_2 capture and geological storage project, including those that extend beyond the end of the CDM crediting period as summarised below (Figure 3).

Figure 3. Temporal Project Boundary for a Natural Gas Processing CCS project activity



17. The greenhouse gases included in or excluded from the project boundary are shown in Table 1.

Table 1: Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Venting of Formation CO_2 from Natural Gas Processing Plant.	CO_2	Yes	Main source of baseline emissions.
		CH_4	No	Excluded for simplification. Conservative assumption.
		N_2O	No	Excluded for simplification. Conservative assumption.
	Combustion emissions from fossil fuel use.	CO_2	Yes	Minor source of baseline emissions. Net changes in emissions from fossil fuel combustion can occur in the project scenario as a result of process optimisation.
		CH_4	No	Excluded for simplification. Conservative assumption
		N_2O	No	Excluded for simplification. Conservative assumption
Project activity	Combustion emissions arising from the provision of power for gas processing and	CO_2	Yes	Main source of project emissions. Net changes in emissions may occur from process optimisation compared with similar plant not employing CO_2 capture and storage.
		CH_4	No	Negligible, excluded for simplification.

	compression (gas or electric), boosters and injection of the CO_2 Stream.	N_2O	No	Negligible, excluded for simplification.
	Use of electricity (grid imports) for capture or compression and injection of the CO_2 Stream.	CO_2	Yes	Main source of project emissions.
		CH_4	No	Negligible, excluded for simplification.
		N_2O	No	Negligible, excluded for simplification.
	Fugitive emissions from capture, transport, injection of CO_2 Stream.	CO_2	Yes	Source of project emissions.
		CH_4	No	Negligible, excluded for simplification.
		N_2O	No	Negligible, excluded for simplification.
	Seepage emissions from CO_2 Geological Storage Complex.	CO_2	Yes	*Potential* source of project emissions. *Potential* source of non-permanence of emission reductions.
		CH_4	Yes	Only relevant if there is potential for subsurface CH_4 to be mobilised during injection and storage operations
		N_2O	No	Negligible, excluded for simplification.

Identification of the baseline scenario

18. This methodology uses the latest version of the "Combined tool to identify the baseline scenario and demonstrate additionality" (Version 02.2). Some project type/sector specific guidelines for application of Steps 1 and 3 of the tool are also outlined below.

Step 1: Identification of Alternative Scenarios

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

19. Identify all realistic alternative scenarios that are available to the project participants and that provide means for disposing of Formation CO_2 produced during natural gas processing operations. These alternative scenarios shall include:

- The proposed project activity undertaken without being registered as a CDM project activity;
- All other plausible and credible alternative scenarios to the project activity scenario, including the common practices in the relevant sector for handling Formation CO_2 produced during natural gas processing operations. These may consist of *inter alia*:
    - Venting (hot or cold) depending on the hydrocarbon or hydrogen sulphide (H_2S) content of the gas. The latter may require incineration, although methodological steps to cover incineration are not included in this methodology;

  - The undertaking of the co-injection of CO_2 with other acid gases (e.g. H_2S) as part of a waste disposal strategy (as opposed to incineration of the acid gas). In some circumstances, CO_2 may be incidentally co-removed with other acid gases present in the hydrocarbon gas, in particular H_2S. Where this occurs, it can involve the removed H_2S being injected into Geological Formations with an incidental benefit being the injection of CO_2. H_2S injection can be more costly than other forms of disposal, and needs to be evaluated on a project-by-project basis where applicable;

  - Capture for the purpose of producing sales grade CO_2 (e.g. for use in the food or beverage industry). The extent to which this will be possible is subject to factors such as the proximity of the Natural Gas Processing Plant to sources of demand for product CO_2, as well as the size of that demand relative to the amount of CO_2 potentially available. In practice, the demand for such products is likely to be much smaller than the available supply;

  - Capture for the purpose of using CO_2 for enhanced hydrocarbon recovery purposes. The possibility of using separated Formation CO_2 for enhanced hydrocarbon recovery will be dependent on the proximity of the Natural Gas Processing Plant to oil and/or gas reservoirs that are suitable for such operations, and the quantity of CO_2 required. Demand for CO_2 for enhanced oil recovery also tends to be sporadic, based on a “water alternating gas” method of recovery; or

  - Export of the natural gas without removing the CO_2. The extent to which this is feasible for a Natural Gas Processing Plant can be determined through analysis of gas supply contracts where the sales specification (grade) of the supplied natural gas (including its CO_2 concentration) will be determined.

- If applicable, continuation of the current situation.

20. For the purpose of identifying relevant alternative scenarios, provide an overview of other technologies or practices that have been implemented previously or are currently underway in the relevant geographical area in this sector. The relevant geographical area should in principle be the host country of the proposed CDM project activity. A region within the country could be the relevant geographical area if the legal or economical framework conditions vary significantly within the country. Alternatively, countries with similar economic frameworks within the region may also be considered within this analysis. If the project is undertaken as part of an acid-gas (i.e. H_2S) co-disposal strategy, project participants should demonstrate that other financial or technical barriers would prevent the co-injection of CO_2 in the absence of the incentive offered by the CDM.

21. For new build Natural Gas Processing Plants, project participants should provide evidence that (i) no modifications have been made to enhance the mass of the CO_2 Stream sent for injection and storage; and, (ii) the natural gas field would be developed absent of any additional revenues generated by the CDM as a result of the project activity. This may be achieved by *inter alia*:

- Providing evidence that the delivery specification of the gas is consistent with industry standard practice within the geographical region/market or is required for technical reasons (e.g. feedstock requirements for liquefaction);

- Providing evidence that plans to develop the gas field within the development timeline documented in the project design document were in place prior to a decision on eligibility of carbon dioxide capture and storage in Geological Formations as clean development mechanism project activities;

- Providing evidence that additional revenues from CERs has only minor impact on the economics of the underlying gas field development (e.g. through analysis and comparison of the internal rate of return of the project with and without geological storage of the Formation CO_2 Stream as a CDM project activity);

- Consideration of the average CO_2 emissions of similar project activities (i.e. natural gas field developments) undertaken in the previous five years, in similar social, economic, environmental and technological circumstances or in the same geographical region;

22. Similar considerations are necessary in the case of tie-ins of new fields to existing Natural Gas Processing Plants. Project participants should outline field development plans for existing Natural Gas Processing Plants to support consideration of these issues.

Outcome of Step 1a: A list of plausible alternative scenarios to the project activity

Step 3: Investment analysis

23. Providing that all criteria are met in Steps 1 and 2 of the “Combined tool to identify the baseline scenario and demonstrate additionality” (Version 02.2), then simplified investment analysis may be applied.

Step 4: Common Practice Analysis

24. Presently there are only three Natural Gas Processing Plants handling high CO_2 gas where CCS technology is employed: Sleipner and Snøhvit (Norway) and In Salah (Algeria). The two projects in Norway take place in an Annex I country where the Norwegian Offshore CO_2 Tax[3] makes these projects economically attractive to avoid venting the CO_2. All other such activities throughout the world vent the separated Formation CO_2 to atmosphere. Thus, it is likely that it will be straightforward to conclude that the application of CCS to separated Formation CO_2 from Natural Gas Processing Plants is not common practice. Data sources are available on estimates of current and future levels of CO_2 venting from Natural Gas Processing Plants, including from the IEA Greenhouse Gas R&D Programme, the IEA, the IPCC and ECN. These data suggest current levels of venting of CO_2 from this activity in non-Annex I countries are in the range 50 – 219 $MtCO_2$ per year. The size of the range reflects the paucity of CO_2 venting data from operators and in national greenhouse gas inventories for this emissions source, rather than uncertainty in the prevalence of the underlying activity itself. In some jurisdictions, natural gas grids and connected technologies (e.g. natural gas fired power plants) have been adapted to run on a lean gas mixture (i.e. natural gas with high levels of CO_2, for example Thailand). This reduces the level of separation required, thus potentially reducing levels of venting carried out at a particular Natural Gas Processing Plant.

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[3] *Act 21 December 1990 no 72 relating to tax on discharge of CO_2 in the petroleum activities on the continental shelf*. Last amended by Act 20 December 1996 no 100. The rate of the CO_2 tax in Norway in 2007 was NOK 0.8 per scm, equivalent to around €52-54/$68-70 per tCO_2 vented to the atmosphere. This has subsequently been reduced to NOK 0.45 per scm in 2008, and NOK 0.46 per scm in 2009 since offshore petroleum activities are now included in the EU Emissions Trading Scheme. It is unclear at present whether CO_2 venting is also covered by the EU ETS.

Additionality: Please describe the procedure for demonstrating additionality

25. This methodology uses the latest version of the “Combined tool to identify the baseline scenario and demonstrate additionality” (Version 02.2) to demonstrate additionality.

Baseline emissions

26. Baseline emissions are equal to the amount of Formation CO_2 separated and captured that would have been vented to the atmosphere in the absence of the project activity, calculated as follows:

$$BE_y = BE_{VE,CO2,y} \tag{1}$$

Where:

$BE_{VE,CO2,y}$ = the amount of CO_2 that would be vented to the atmosphere in the absence of the project activity in year y (tCO_2e/yr)

27. The amount of CO_2 that would be vented in the absence of the project activity is calculated as follows:

$$BE_{VE,CO2,y} = \sum_j FR_{GAS,CP,j,y} \times \rho_{GAS,CP,j,y} \times w_{CO2,CP,j,y} \times 10^3 \tag{2}$$

Where:

$BE_{VE,CO2,y}$ = the amount of CO_2 that would be vented to the atmosphere in the absence of the project activity in year y (tCO_2-e/yr)

$FR_{GAS,CP,j,y}$ = the flow rate of captured gas stream from capture process *j* in the Natural Gas Processing Plant in year *y* (in m^3).

$\rho_{GAS,CP,j,y}$ = the weighted average density of captured gas in the gas stream from capture process *j* in the natural gas processing (in kg gas/m^3)

$w_{CO2,CP,j,y}$ = the weighted average mass fraction of CO_2 in the captured gas from capture process *j* in the natural gas processing in year *y* (mass unit/volume unit ($kgCO_2/m^3$); %)

j = capture process operated in year *y*

28. Project participants should identify the natural gas field development plan associated with the Natural Gas Processing Plant (field name/reservoir; production commencement date; production rate; field life, CO_2 concentration), and describe how the different natural gas reservoirs will be produced (or “tied-in”) to the plant across its operating life.

Project emissions

29. Project emissions include the following sources:

- Combustion emissions from direct use of fuel gas in CO_2 compression (gas fired compressors, including booster stations), where applicable;

- Emissions from electricity consumption for CO_2 compressions (mechanical drives), dehydration plant, and any other auxiliary power requirements (e.g. booster stations) related to CO_2 transport and injection operations;

- Emission credit from cogeneration, where applicable;
- Indirect combustion emissions related to any bought in electricity used in the project activity;
- Fugitive emissions from imperfect capture, and leaks during transport and injection operations. It also includes operational venting emissions, and any accidental releases in the event of pipeline rupture;
- *Potential* emissions from the Geological Storage Complex due to Seepage or storage site breach;

30. Project emissions are calculated as follows:

$$PE_{y} = PE_{FC,y} + PE_{EC,y} + PE_{FUG,y} + PE_{OPR,y} + PE_{ACC,y} + PE_{SEEP,y} \tag{3}$$

Where:

PE_y = project emissions in year *y* (tCO_2/yr)
$PE_{FC,y}$ = project emissions from fossil fuel combustion in year *y* (tCO_2/yr)
$PE_{EC,y}$ = project emissions from electricity consumption in year *y* (tCO_2/yr)
$PE_{FUG,y}$ = project emissions from fugitive leaks in year *y* (tCO_2/yr)
$PE_{OPR,y}$ project emissions from operational releases (venting) in year *y* (tCO_2/yr)
$PE_{ACC,y}$ = project emissions from accidental releases in the event of a pipeline rupture in year *y* (tCO_2/yr)
$PE_{SEEP,y}$ = project emissions as a result of Seepage in year *y* (tCO_2/yr)

31. Project emissions are calculated in the following steps:

Step 1: Determination of project emissions from fossil fuel combustion.

Step 2: Determination of project emissions from electricity consumption.

Step 3: Determination of project emissions from fugitive losses, operational releases and accidental releases during CO_2 transport and injection.

Step 4: Determination of project emissions from Seepage from subsurface geological storage reservoirs.

Step 1: Determination of project emissions from fossil fuel combustion

32. Combustions emissions arising from fossil fuel use related to the CCS project activity should be calculated based on the quantity of natural gas and other fuels consumed for CO_2 compression (gas fired compressors, including booster stations), gas fired heaters and/or glycol re-boilers in the project activity, using the following calculation:

$$PE_{FC,j,y} = \sum_{i} FC_{i,j,y} \times COEF_{i,y} \tag{4}$$

Where:

$PE_{FC,j,y}$ = project emissions from fossil fuel combustion in process *j* (e.g. gas fired compressors/heaters) in year *y* (tCO_2/yr)

$FC_{i,j,y}$ = the quantity of fuel type *i* combusted in process *j* in year *y* (tonnes or m^3/yr)
$COEF_{i,j,y}$ = the CO_2 emissions coefficient of fuel type *i* used in year *y* (tCO_2/tonne or m^3)
i = fuel types combusted in process *j* during year *y*

33. The CO_2 emission coefficient of the natural gas[4] combusted in gas-fired compressors and/or heaters should be calculated based on sampling and analysis of the natural gas, as follows:

$$COEF_{i,y} = w_{C,i,y} \times \rho_{i,y} \times \frac{44}{12} \times 0.001 \qquad \textbf{(5)}$$

Where:
$COEF_{i,j,y}$ = the CO_2 emissions coefficient of fuel type *i* used in year *y* (tCO_2/m^3)
$w_{C,i.y}$ = the weighted average mass fraction of carbon in the fuel type *i* in year *y* (kgC/m^3)
$\rho_{i,y}$ = the weighted average density of fuel type *i* in year *y* (kg/m^3 or %)
i = the fuel types combusted in the process *j* in year *y*

Step 2: Determination of project emissions from electricity consumption

34. Project emissions arising from electricity consumption in the project activity includes the following sources:

- Electricity consumption for CO_2 compression (mechanical drives), dehydration and transportation (e.g. mechanically driven compressors in booster stations), and any emergency generation allocated to the project activity;
- Heat used in the Natural Gas Processing Plant raised by cogeneration, principally in relation to regeneration of rich amine solution during CO_2 separation, where applicable;
- Any bought-in power used for CO_2 compression, dehydration and/or in booster stations;

35. Project emission from these sources are calculated as follows:

$$PE_{EC,y} = PE_{EC,PP,y} + PE_{EC,grid,y} \qquad \textbf{(6)}$$

Where:
$PE_{EC,y}$ = project emissions from electricity consumption in year *y* (tCO_2/yr)
$PE_{EC,PP,y}$ = project emissions from electricity consumption from onsite (captive) power plants (tCO_2/yr)
$PE_{EC,grid,y}$ = project emissions from electricity consumption from bought-in (grid) electricity (tCO_2/yr)

36. Project emissions in relation to electricity consumption from processes using power from onsite (captive) power plant(s) should be calculated using the following calculation:

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[4] This methodology assumes that natural gas would be used as the fossil fuel in Natural Gas Processing Plants

$$PE_{EC,PP,y} = \sum_{j} EC_{PJ,j,y} \times EF_{EL,PP/PPc,y} \tag{7}$$

Where:

$PE_{EC,PP,y}$ = project emissions from electricity consumption of processes using power from onsite (captive) power plant(s) (tCO_2/yr)

$EC_{PJ,j,y}$ = the quantity of onsite generated electricity consumed by project electricity consumption source *j* in year *y* (MWh/yr)

$EF_{EL,PP/PPc,y}$ = the emission coefficient for electricity generated from onsite (captive) power plant(s) in year *y* (tCO_2/MWh) – either with ($EF_{EL,PPc,y}$) or without ($EF_{EL,PP,y}$) cogeneration benefit calculated.

j = sources of electricity consumption in the project

37. For new build projects, the emission factor for onsite (captive) power plant(s) must take into account:

- Whether, in the baseline scenario, additional heat to that available from cogeneration would need to be raised to meet the requirements for amine generation in the Natural Gas Processing Plant (i.e. for the level of power generation in the Natural Gas Processing Plant absent of CCS electricity requirements). This is dependent on the level of power required for gas processing and export and the level amine regeneration required, the latter being determined by the CO_2 content of the natural gas; or,

- Whether the level of cogeneration required in the baseline scenario provides sufficient heat for amine regeneration.

38. Engineering feasibility studies must be used to demonstrate the case of the former. Where the former can be demonstrated, cogeneration benefit can be included using an emission factor for onsite (captive) power plants(s) calculated using the following:

$$EF_{EL,PPc,y} = \frac{\sum_{n}\left[\sum_{i}\left(FC_{n,i,y} \times NCV_{i,y}\right) - \frac{HG_{n,y} - HG_{PP,BL}}{\eta_{boiler}}\right] \times EF_{CO2,n,y}}{\sum_{n} EG_{n,y}} \tag{8}$$

Where:

$EF_{EL,PPc,y}$ = the emission factor for electricity generated from onsite (captive) power plant(s) including cogeneration credit in year *y* (tCO_2/MWh)

$FC_{n,i,y}$ = the quantity of fuel type *i* fired in the onsite (captive) power plant *n* in year *y* (m^3/yr)

$NCV_{i,y}$ = the weighted average net calorific value of fuel type *i* used in year *y* (GJ/m^3)

$HG_{n,y}$ = the quantity of heat cogenerated in the onsite (captive) power plant(s) in year *y* (GJ)

$HG_{PP,BL}$ = the potential for heat cogeneration in onsite (captive) power plant in the baseline scenario (GJ)

η_{boiler} = the efficiency of the boiler in which heat is assumed to be generated in the baseline scenario to supplement cogeneration in the baseline scenario (%)

$EF_{CO2,n,y}$ = average CO_2 emission factor of the fossil fuel fired in the onsite (captive) power plant(s) *n* in year *y* (tCO_2/GJ)

$EG_{n,y}$ = the quantity of electricity generated in the onsite (captive) power plant(s) *n* in year *y* (MWh/yr)
n = onsite (captive) power plants installed at the site of the electricity consumption source
i = fuel type used in power plants *n* in year *y*

39. Note that the quantity of heat cogenerated in the onsite (captive) power plant must be corrected to account for the amount of cogeneration that would have occurred in the baseline scenario. This is achieved by subtracting the heat generation potential of cogeneration plant in the baseline scenario, determined as follows:

$$HG_{PP,BL} = \frac{PP_{CP,BL}}{\eta_{cogen}} \tag{9}$$

Where:
$HG_{PP,BL}$ = the potential for heat cogeneration in onsite (captive) power plant(s) in the baseline scenario (GJ)
$PP_{CP,BL}$ = the rated capacity for power generation that would be required the baseline scenario (GJ)
η_{cogen} = the efficiency of heat generation by cogeneration in the baseline plant (%)

40. Where engineering feasibility studies do not demonstrate that additional heat raising capacity would be needed in the baseline scenario, the emission factor for onsite (captive) power plant(s) is simplified to exclude cogeneration. The same method should also be employed to calculate the emissions factor for emergency generation, as follows:

$$EF_{EL,PP,y} = \frac{\sum_{n}\sum_{i} FC_{n,i,y} \times NCV_{i,y} \times EF_{CO2,i,y}}{\sum_{n} EG_{n,t}} \tag{10}$$

Where:
$EF_{EL,PP,y}$ = the emission factor for electricity generated from onsite (captive) power plant(s), including emergency generators, in year *y* (tCO_2/MWh)
$FC_{n,i,y}$ = the quantity of fuel type *i* fired in the onsite (captive) power plant *n* in year *y* (m^3/yr)
$NCV_{i,y}$ = the weighted average net calorific value of fuel type *i* used in year *y* (GJ/m^3)
$EF_{CO2,n,y}$ = average CO_2 emission factor of the fossil fuel fired in the onsite (captive) power plant(s) in year *y* (tCO_2/GJ)
$EG_{n,t}$ = the quantity of electricity generated in the onsite (captive) power plant(s) in year *y* (MWh/yr)
n = onsite (captive) power plants installed at the site of the electricity consumption source
i = fuel type used in power plants *n* in year *y*

41. Where projects buy-in electricity from the grid to provide power for the CCS project (either in full, to provide energy for booster stations, or as supplementary power to the captive power plant), project emissions from electricity consumption should be calculated using the following:

$$PE_{EC,grid,y} = EC_{PJ,grid,y} \times EF_{CM,grid,y} \tag{11}$$

Where:

$PE_{EC,grid,y}$ = project emissions from bought-in grid electricity consumption in year *y* (tCO_2/yr)
$EC_{PJ,grid,y}$ = the quantity of bought-in grid electricity consumed by the project in year *y* (MWh/yr)
$EF_{CM,grid,y}$ = the emissions factor for the combined margin for grid electricity in year *y* (tCO_2/MWh)

42. The emission factor for combined margin for the electricity grid from which electricity is purchased should be based on either:

- Calculating the grid emission factor following the latest version of the “Tool to calculate the emission factor for an electricity system”; or,

- Adopting a conservative default value of 1.3 tCO_2/MWh.

Step 3: Determination of fugitive emissions from transport, injection, operational venting and accidental release

43. Project emissions arising from leaks, operational venting and accidental release during transport and injection of the CO_2 stream should be calculated using a mass-balance approach, based on the mass of CO_2 captured (i.e. separated from the natural gas during processing) minus the mass of CO_2 injected at the wellhead.

$$PE_{FUG/OPR/ACC,y} = \begin{bmatrix} (\sum_{j} FR_{GHG,CP,j,y} \times \rho_{GHG,CP,j,y} \times w_{CO2,CP,j,y}) \\ - \\ (\sum_{k} FR_{GHG,INJ,k,y} \times \rho_{GHG,INJ,k,y} \times w_{CO2,INJ,k,y}) \end{bmatrix} \times 10^3 \qquad \textbf{(12)}$$

Where:
$PE_{FUG/OPR/ACC,y}$ = project emissions from fugitive leaks, operational venting, and accidental releases in year *y* (tCO_2/yr)
$FR_{GHG,CP,j,y}$ = the flow rate of captured gas stream from capture process *j* in the Natural Gas Processing Plant in year *y* (in m^3).
$\rho_{GHG,CP,j,y}$ = the weighted average density of captured gas in the gas stream from capture process *j* in the Natural Gas Processing Plant (in kg gas/m^3)
$w_{CO2,CP,j,y}$ = the weighted average mass fraction of CO_2 in the captured gas from capture process *j* in the Natural Gas Processing Plant in year *y* (mass unit/volume unit ($kgCO_2/m^3$); %)
$FR_{GHG,INJ,k,y}$ = the flow rate of CO_2 at injection wellhead(s) *k* in year *y* (m^3)
$\rho_{GHG,INJ,k,y}$ = The weighted average density of gas in the stream injected into the Geological Formation in injection well *k* in year *y* (in kg/m^3)
$w_{CO2,INJ,k,y}$ = the weighted average mass fraction of CO_2 in the injected gas stream in injection well *k* in year *y* (mass unit/volume unit ($kgCO_2/m^3$); %)
j = capture process in operation in year *y*
k = injection well(s) in operation in year *y*

44. If the metered amount of injected CO_2 is greater than the amount captured (i.e. $FR_{GHG,INJ,j,y} > FR_{GHG,CP,y}$), then this should be rounded to zero, and calibration of metering devices should be carried out.

Step 4: Avoidance, determination and quantification of Seepage emissions

45. Seepage of CO_2 from the Geological Storage Complex back to the atmosphere (or ocean/surface water in the case of offshore injection) can potentially occur at any time after injection commences. Seepage can arise as a consequence of subsurface processes occurring after injection such as diffusion (through cap rocks) and Migration (along fault planes and fissures or through operational or abandoned wells). All of these potential emission sources can be effectively managed through good site selection and management, including effective monitoring (which serves to support zero-Seepage assumptions), and the use of Corrective Measures to control any significant irregularities in the subsurface behaviour of the CO_2.

46. Potential Seepage emissions should be considered as project emissions if they occur within the crediting period. After the end of the crediting period, this emission source shall be considered under permanence, and handled according to *Sub-step 4d* of the methodology, as described below.

47. In order to firstly avoid – and secondly determine and account for – such potential emission source(s), project participants are required to implement a four-step process to support Geological Storage Complex selection, characterisation and management covering all phases of the project life-cycle (see Figure 3). This process serves to reduce the risk of Seepage occurring to extremely low levels.

48. These steps are as follows:

Sub-step 4a: Geological Storage Complex selection, characterisation and management;

Sub-step 4b: Monitoring and management of the subsurface Geological Storage Complex for assurance purposes;

Sub-step 4c: Quantification of the mass of any CO_2 released to the atmosphere from the Geological Storage Complex as a consequence of Seepage;

Sub-step 4d: Management for long-term permanence of CO_2 storage.

49. Further details on the procedures for each step are provided below.

Sub-step 4a – Geological Storage Complex Selection and Characterisation

50. In the Development phase, project participants shall employ appropriate Geological Storage Complex selection and characterisation procedures in order to support assumptions regarding zero-Seepage in the short-, medium- and long-term. Selection and characterisation must be supported by good management of the Geological Storage Complex following a prescribed Mode of Operation that shall be prepared based on the site characteristics. Geological Storage Complex selection, characterisation and management shall be determined following the format and guidance provided in Annex A, and documented in a *Geological Storage Complex Selection & Characterisation Report* submitted in conjunction with the CDM project design document as part of the overall project registration procedure.

51. The *Geological Storage Complex Selection & Characterisation Report* includes requirements for *inter alia*:

- **CO_2 Migration analysis:** describing the predicted fate and behaviour of CO_2 in the Geological Storage Complex, and the vertical and lateral boundaries of the dispersing CO_2 Plume over time;

- **Geological Storage Complex Features analysis:** describing the main Features within the Geological Storage Complex which could present the risk of Migration and Seepage outside the predicted Geological Storage Complex boundaries ($PB_{CO2,V/L,p,t}$);

- **Modes of Operation**: describing the way in which injection operations shall be undertaken in order to minimise the risk of Seepage, based on the specific characteristics of the Geological Storage Complex – in particular the Features – determined during characterisation;

52. CO_2 Migration analysis shall consist of time-series data and information that serves to pre-define Migration of the injected CO_2 Plume through the technical life-time of the project, including predictions of distribution, fate and behaviour of injected CO_2 over the very long-term. These data and information shall provide the basis for risk avoidance and zero-Seepage assumptions. In addition, they shall provide estimates of the vertical and lateral boundaries of the subsurface CO_2 Plume at given points in time and by mass of injected CO_2 through the project life, based on geological analysis, performance assessment and computer simulation modelling of CO_2 Migration ($PB_{CO2,V/L,p,t}$). Performance assessment shall include an evaluation of the trapping mechanisms present within the Injection Formation and any other reservoir-seal pairs in the surrounding Geological Storage Complex, using information gathered on formation geology, geophysics, geochemistry, geomechanics and hydrogeology, following guidance outlined in Annex A.

53. During the Operational and Closure phases, project participants shall monitor the CO_2 Plume and predictive data and information shall be compared to observed CO_2 Plume Migration (monitored data; $PB_{CO2,V/L,y}$). These data shall be used to calibrate predictions with observations (a process sometimes referred to as history-matching; see *Sub-step 4b* and Annex C, Section IV).

54. Geological Storage Complex Features analysis shall consist of a description of the main Features of the Geological Storage Complex. These include *inter alia*:

- Seal (caprock) Permeability, and its respective capillary entry pressure (CEP), fracture pressure, and dissolution properties (based on analysis of the geochemistry of CO_2-water-rock reactions);

- Abandoned and operational (planned) wells;

- Faults and fractures, and their respective characteristics including: fracture propagation pressure (FPP); fault reactivation pressure (FRP); fault valving pressure (FVP);

- Spill-points in hydrostatic traps;

55. Avoidance of risk Features, or adoption of appropriate Modes of Operation to avoid activation, should be primary guiding principle in Geological Storage Complex selection.

56. During the Operational and Closure phases, project participants shall monitor all identified Features within the Geological Storage Complex ($M_{SC,j/k/l,y}$) in order to detect any significant irregularities. This may involve the comparison of monitoring data with base-level data collected during site characterisation (BD_{SC}), as described in Annex B and C (see *Sub-step 4b*).

57. Appropriate Modes of Operation of the Geological Storage Complex shall be defined which ensure that pressure-driven geological processes in the Injection Formation are within accepted levels of safety i.e. within levels that avoid the risk of activating pressure-driven Seepage processes within the Geological Storage Complex (=$P_{PC,OL}$), following guidance outlined in Annex A. These shall include consideration of the following factors affecting pressure in the Geological Storage Complex:

- Formation injectivity: based on Porosity and Permeability (measured in milidarcy; mD) in the Injection Formation, and formation fracture pressure;

- Injection rate (mass of gas per day per well; derived from $FR_{GHG,INJ,j,y}$): based on CO_2 production and delivery rate and the number of injection wells in the Geological Storage Complex development design;

- Geological Storage Complex Features: as described previously.

58. During the Operational and Closure phases, project participants shall monitor injection rate ($FR_{GHG,INJ,j,y}$) and bottomhole (and wellhead where applicable) pressures ($P_{M,j/k/l}$) in each injection and observation well in the Geological Storage Complex during CO_2 injection operations and in the Closure phase, with the exception of where this cannot be achieved due to well abandonment measures (see *Sub-step 4b*).

59. The *Geological Storage Complex Selection & Characterisation Report* shall be approved by the host country DNA (and/or competent authority appointed by the DNA), subject to review and comment by the CDM EB, its panels, and possibly supported by a CGSCoE.

Sub-step 4b – Monitoring and management of the subsurface Geological Storage Complex

60. Project participants shall design a Subsurface Monitoring plan – following the guidance provided in Annex B – to support the analysis undertaken in *Sub-step 4a* (Geological Storage Complex selection, characterisation and management) in the Operational and Closure phases. Monitoring shall support Geological Storage Complex characterisation studies by serving the following purposes:

- **CO_2 Migration**: to generate images of the Geological Storage Complex which provide information regarding the behaviour of the injected CO_2 Plume so as to support reviews of the subsurface project boundaries post-commencement of injection operations;

- **Geological Storage Complex Features:** to provide early signs of significant irregularities within and outside of the Geological Storage Complex as defined during Geological Storage Complex characterisation, including recognized Migration and Seepage pathways; and;

- **Modes of operation**: to support zero-Seepage assumptions by avoiding conditions that could lead to activation of pressure-driven or other processes within the Injection Formation, which in turn could lead to Seepage;

61. The following analysis must be applied during monitoring to determine the nature of Migration in the subsurface and to support history-matching:

$$PB_{CO2,V/L,y} = \{M_{CO2,j,y}, M_{CO2,k,y} .....M_{CO2,l,y}\} \quad \textbf{(13)}$$

$$PB_{CO2,V/L,y} \approx PB_{CO2,V/L,p,t} \quad \textbf{(14)}$$

Where,

$PB_{CO2,V/L,y}$ = two and three-dimensional image(s) and description of the subsurface vertical and lateral boundary of the injected CO_2 Plume determined through monitoring in year *y* (indicative upper and lower vertical boundaries in metres (m) below the surface may be used; lateral boundary may be dimensionless/descriptive or latitude/longitude coordinates).

$M_{CO2,j/k/l,y}$ = Subsurface Monitoring technique *j/k/l* applied to determine the presence and Migration characteristics of the subsurface CO_2 Plume and to generate two and three-dimensional image(s) and descriptions of the vertical and lateral boundaries of the CO_2 Plume in year *y* (indicative upper and lower vertical boundaries in metres (m) below the surface may be used; lateral boundary may be dimensionless/descriptive or latitude/longitude coordinates)

$PB_{CO2,V/L,p,t}$ = two and three-dimensional image(s) and description of the subsurface vertical and lateral boundary of the injected CO_2 Plume determined through computer simulation modelling following guidance in Annex A at a either a given point in time or mass of injected CO_2 equating to year *y* (indicative upper and lower vertical boundaries in metres (m) below the surface may be used; lateral boundary may be dimensionless/descriptive or latitude/longitude coordinates)

62. Where monitoring of CO_2 Migration does not indicate any Significant Irregularities (i.e. $PB_{CO2,V/L,y} \approx PB_{CO2,V/L,p}$), storage operations can be assumed to be operating satisfactorily (subject to information gathered using other monitoring methods; $M_{SC,j/k/l,y}$).

63. Where deviations in observed and predicted behaviour occurs (i.e. $PB_{CO2,V/L,y} \neq PB_{CO2,V/L,p}$), modelled geological, geophysical, geochemical, geomechanical and hydrogeological properties should be recalibrated and scenarios re-run to improve the convergence of results (in accordance with Annex C, Section II). This may entail further geological survey work to include new data in the model. Where deviations are considered a Significant Irregularity injection operations may cease and the procedures defined below shall apply (see also Annex C).

64. Increasing convergence between predictions and observations over time (i.e. $PB_{CO2,V/L,y} = PB_{CO2,V/L,p,t}$) suggests a high-level of understanding of the subsurface, providing assurance over short, medium and long-term predictions of storage security (i.e. permanence).

65. If the results of analysis suggest that insufficient coverage is achieved in the monitoring plan design (e.g. gaps in knowledge regarding the subsurface project boundaries), the Subsurface Monitoring plan should be updated with new techniques and locations (see Annex C, Section II).

66. Other monitoring techniques shall be applied to Geological Storage Complex Features, based on comparison with base-level survey data collected during site characterisation. Examples include micro-seismic measurements in fault planes or fissures which could potentially be reactivated by CO_2 storage operations. These should be accounted for as follows:

$$F_{SC,x,y} = \{M_{SC,j,y}, M_{SC,k,y} .....M_{SC,l,y}\} \quad \textbf{(15)}$$

$$F_{SC,y} \approx BD_{SC} \quad \textbf{(16)}$$

Where,

$F_{SC,x,y}$ = Feature *x* within the Geological Storage Complex which can provide signs of irregularities as monitored in year *y* (dimensionless)

$M_{SC,j/k/l,y}$ = Subsurface Monitoring technique *j/k/l* applied to Features within the Geological Storage Complex which could detect potential irregularities in year *y* (dimensions dependent on the particular technique applied)

$BD_{SC,\ j/k/l}$ = base level survey data describing the condition of feature *j/k/l* in the subsurface generated during site characterisation following guidance in Annex A (dimensions specific to each feature and measurement technique)

67. Where monitoring of Features within the Geological Storage Complex do not indicate any Significant Irregularities (i.e. $F_{SC,y} \approx BD_{SC}$), storage operations can be assumed to be operating satisfactorily (subject to information gathered using other monitoring methods; $M_{CO2,j/k/l,y}$).

68. Where deviations in observed and predicted behaviour occurs (i.e. $F_{SC,y} \neq BD_{SC}$), further investigations should be undertaken to determine the source of the irregularity, and whether it poses a Seepage risk. Where a deviation is considered to be a Significant Irregularity injection operations may cease and the procedures defined below shall apply (also see Annex C).

69. If the results of analysis suggest that insufficient coverage is achieved in the present monitoring plan design (i.e. lack of information on key subsurface Features in the Geological Storage Complex), the Subsurface Monitoring plan should be updated with new techniques and locations (see Annex C, Section II).

70. Operational safety margins and appropriate Modes of Operation to avoid activating pressure-driven processes in the Injection Formation should be determined using the following calculation:

$$P_{PC,OL} = P_{PC,SL} \times P_{SF} \quad \textbf{(17)}$$

$$P_{PC,OL} < \{P_{M,j}, P_{M,k} .....P_{M,l}\} \quad \textbf{(18)}$$

Where,

$P_{PC,OL}$ = the maximum operational pressure limit of the Injection Formation (kPa)

$P_{PC,SL}$ = the pressure safety limit in the Injection Formation determined during Geological Storage Complex characterisation following Annex A, and laid down in the Modes of Operation. It is based on variations in key pressure-driven mechanical formation Features that can affect Seepage as described above (kPa)

P_{SF} = the pressure safety factor based on setting a safety margin between the operational limit and the safety margin (it is ratio that must always be less than 1)

$P_{M,j/k/l}$ = Bottomhole (and/or wellhead where applicable) pressure in the Injection Formation continuously monitored in well *j/k/l* (including injection and monitoring wells) during the project activity (kPa)

71. Pressure in the Injection Formation shall be monitored, and should not exceed levels which could induce the pressure driven processes which can affect storage security and Seepage risk. If monitoring shows the maximum operational pressure limit is exceeded ($P_{M,j/k/l} > P_{PC,OL}$), injection

may cease until pressure levels in the Injection Formation reduce below this level, after which injection may commence again.

72. In some circumstances, it may be necessary to increase CO_2 injection pressure in order to induce micro fracturing of the Injection Formation so as to enhance injectivity of CO_2 (a process referred to as fraccing). Such operations should be undertaken under controlled conditions, over short durations, and should be documented in the annual monitoring report(s), covering:

- The pressure levels induced in the Injection Formation for this purpose;
- The duration over which higher pressures were induced; and,
- Monitoring data to demonstrate that the operations had no impact on storage security and Features in the Geological Storage Complex.

Significant Irregularities

73. In the event that Significant Irregularities in the Geological Storage Complex are detected during the Operational or Closure phases, such as significant deviations between observed and predicted behaviour in terms of the delineated Geological Storage Complex project boundaries (i.e. $B_{CO2,V/L,y} \neq B_{CO2,V/L,p}$) or from other monitoring techniques applied to Features which suggest Significant Irregularities from base level conditions (i.e. $F_{SC,y} \neq BD_{SC}$), injection operations may need to cease and further investigations by the project participants (monitoring, geological survey and modelling) carried out. These investigations should serve to:

- Provide details of the Significant Irregularity and the reasons for it occurring, as described in Annex C;
- Determine whether the Significant Irregularity has or could lead to Seepage, including identifying actual or potential Seepage emission source(s), as described in Annex C;
- If Seepage has or could occur, initiate all practicable Corrective Measures required to prevent Seepage and restore the security of the Geological Storage Complex, including minimizing potential harm to humans and the natural environment as a consequence of Seepage. These should be cognizant of prevailing national laws and regulations, the *Geological Storage Complex Selection & Characterisation Report* and environmental impact assessment prepared as part of the project registration process; and,
- If required, initiate actions to quantify Seepage as described in *Sub-step 4c* and Annex C.

74. If Seepage is detected during the crediting period, no further Certified Emission Reductions (CERs) shall be issued until Corrective Measures to stop further Seepage have been carried out, and the following analysis undertaken to provide assurance that further Seepage is not anticipated:

- Reappraisal of the of the Geological Storage Complex assessment contained in the *Geological Storage Complex Selection & Characterisation Report,* Section IV;
- Update subsurface project boundary predictions where necessary ($PB_{CO2,V/L,p,t}$), as described in Annex C; and,

- Update the Subsurface Monitoring plan to include additional monitoring techniques and locations where necessary ($M_{CO2,j/k/l,y}$ and $M_{SC,j/k/l,y}$), as described in Annex C;

Where these indicate that storage security and Seepage risk are reduced to levels agreed at project registration, injection operations may re-commence.

75. Results of this investigation and analysis should be reported in the annual Monitoring Report (see Annex C).

76. Responsibility for performing monitoring and Corrective Measures shall rest with the project participants up to the date when Stewardship transfers from the project participants back to host country (i.e. during the Operational and Closure phases) and with the host country thereafter (i.e. during the Post Closure phase).

77. Project participants shall be required to continue to undertake periodic verification of monitoring, including in the *Closure Report*, by an accredited DOE until the point of Stewardship transfer (see Annex D).

Sub-step 4c - Quantification of any mass of CO_2 emitted to the atmosphere due to Seepage

78. The procedure outlined in *Sub-step 4b* provides the basis for detecting Seepage emissions from a CO_2 Geological Storage Complex. If application of the monitoring plan provides evidence of Seepage emissions, the level of emissions should be calculated using the following:

$$PE_{SEEP,y} = \left[\sum_{k} S_{FLX,k,y} \times S_{t,k,y} \times S_{k,area} \right] \times 10^{-3} \qquad \textbf{(19)}$$

Where,

$PE_{SEEP,y}$ = Seepage emissions in year *y* (tCO_2)
$S_{FLX,k,y}$ = the flux rate of Seepage source *k* in year *y* ($kgCO_2$-e/m² d^{-1})
$S_{t.k,y}$ = the duration that Seepage source *k* is estimated to have been occurring in year *y* (days)
$S_{k,area}$ = the area over which the Seepage from source *k* has been measured (m²)
k = Seepage sources determined in year *y*

79. A specific Seepage event for any Geological Storage Complex will need careful consideration of the most appropriate technologies and means to identify the emission pathway and source, estimate the flux rate, the areal extent of the Seepage zone, and to determine its duration. Flux rates and durations should be determined according to the guidance outlined in the monitoring methodology.

80. If Seepage is identified during monitoring and quantified accordingly, an amount equal to the mass of Seepage must either:

- Be added to the project emissions for the respective period since the last request for issuance (i.e. in the same way as for other project emissions); or,

- If project emissions exceeds the baseline emissions calculated for a given period (i.e. resulting in temporary negative emission reductions for a given year; $BL_y - PE_y = <0$), any further CERs will only be issued when the emissions increase has been compensated by subsequent emission reductions by the project activity in subsequent years. If the level of subsequent emission reductions would not meet the level of Compensation required (e.g. because the project is nearing the end of its applicable crediting period), then the procedure in the next bullet shall apply;

- In the event that Seepage occurs after the end of the crediting period, or conditions for subsequent emission deductions as described in the previous bullet cannot be met, then the level of negative emission reductions due to Seepage must be Compensated by surrender of an equivalent amount of Permanent Emissions Certificates to the UNFCCC CDM Registry Account, and verified accordingly.

81. The quantification of Seepage should take place according to the best practice at the time of occurrence. The obligation for Compensation must consider the uncertainty of the quantification process, and make appropriate adjustments to estimates of Seepage emissions, as outlined in Annex C.

Sub-step 4d - Management for Long-term Permanence

82. Following the cessation of CO_2 injection for the CDM project activity (i.e. in the Closure phase), project participants must continue to monitor, report and undertake any Corrective Measures in the event of any Significant Irregularities until conditions for Stewardship transfer to the host country are met. The terms of Stewardship transfer must be agreed with the host country prior to registration of the project activity, and any subsequent amendments thereof shall be communicated to the CDM EB. The terms of Stewardship transfer should be performance-based (i.e. based on the performance of the CO_2 Geological Storage Complex in terms of its capacity to retain the injected CO_2 stream from the atmosphere for very long periods of time), and should follow the conditions proposed in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5, Section 5.7.1, para. 4(v)*. This requires that once the CO_2 approaches its predicted long-term distribution within the reservoir (Injection Formation), and there is agreement between the models of CO_2 distribution and measurements made in accordance with the monitoring plan, it may be appropriate to decrease the frequency of (or discontinue) monitoring. On this basis, the convergence of observed and predicted behaviour, and the reduction or cessation of monitoring should provide a basis for Stewardship transfer (i.e. $PB_{CO2,V/L,y} = PB_{CO2,V/L,p,t}$ and $F_{SC,y} \approx BD_{SC}$).

83. A *Closure Report* should be produced outlining the conditions for Stewardship transfer (including descriptions of site closure measures) following guidance provided in Annex D. This shall be approved by the host country DNA (and/or competent authority appointed by the DNA), subject to review and comment by the CDM EB, its panels, and possibly supported by a CGSCoE.

84. During the Post Closure phase the host country shall retain the Stewardship of the Geological Storage Complex, including any requirements for undertaking *Sub-steps 4a, 4b* and *4c* for management of Significant Irregularities or Seepage, if necessary. After Stewardship transfer, the project participants are absolved of these responsibilities. If the terms of Stewardship transfer significantly reduce the monitoring requirements placed on the host country, the host country may still be required to perform periodic monitoring of the Geological Storage Complex, commensurate with the requirements laid down in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5, para. 4(v)* described above, and report these activities as part of its National Communication to Parties. These obligations shall be agreed as part of the terms of Stewardship transfer.

85. In order to ensure that the host country has sufficient financial means at its disposal to fulfil its responsibilities for monitoring and any Corrective Measures following Stewardship transfer, the project participants shall establish in agreement with the host country, an appropriate financial arrangement and mechanism to cover such potential costs. This shall be in place prior to project commencement, and shall provide assurances that funds are available to cover any additional cost associated with the Compensation described above, as well as – within reason – any other potential Corrective Measures necessary. This security shall be transferable to the host country in order that these assurances continue beyond the point of Stewardship transfer.

86. Because of the possibility of insolvency of the project participants during operation of the project activity, the financial arrangement shall also be set at a sufficient level in order that the host country may cover the costs of Closure of the CO_2 Geological Storage Complex, as well as the requirements outlined in the previous paragraph.

87. However, the level of the financial security agreed between the project participants and host country should be commensurate with the level of potential risk of project participant insolvency and risk of future Seepage posed by the Geological Storage Complex, based on *inter alia*: creditworthiness of the project participants, Geological Storage Complex characterisation, monitoring and closure plans pursuant to the approach outlined in this methodology and approval from the host country DNA and reviewed by the CDM EB, its panels, and possibly supported by a CGSCoE.

88. The financial mechanism may consist of either/or a combination of the following provisions, set at a suitable level to cover the costs associated with responsibilities described above:

- Host country participation in the CDM project activity (e.g. revenue raising linked to CER sales);
- The payment of tax revenues or royalties from the project participants to the host country (e.g. linked to revenues from CER sales);
- A credit reserve or fund in escrow established by the project participants, and transferable to the host country upon Stewardship transfer;
- A suitable insurance policy underwriting the potential financial requirements, transferable to the host country upon Stewardship transfer;

89. Upon Stewardship transfer, the project participants are absolved of the responsibility to maintain any financial arrangement or mechanism.

90. Project participants are required to describe the following in the CDM project design document:

- The terms of Stewardship transfer agreed with the host country prior to the commencement of the project activity;
- The financial arrangement and mechanism by which host country responsibilities will be underwritten;
- Supporting documentary evidence (e.g. supporting insurance policy documentation or letters of intent, or details of the bank escrow fund).

91. These should also be outlined in the host country DNA letter of approval.

Leakage

92. There is no Leakage associated with this type of project activity (see Section D for an explanation of this conclusion).

Emission reductions

93. Emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y - LE_y \quad \textbf{(20)}$$

Where:
ER_y = Emission reductions in year *y* (tCO_2e/yr)
BE_y = Baseline emissions in year *y* (tCO_2e/yr)
PE_y = Project emissions in year *y* (tCO_2/yr)
LE_y = Leakage emissions in year *y* (tCO_2/yr)

94. This is subject to the conditions of negative emission reductions and Compensation requirements described in paragraph *78*.

Changes required for methodology implementation in 2nd and 3rd crediting periods

95. Project participants shall assess the continued validity of the identified baseline scenarios and update the baseline parameters at the end of each crediting period. Key aspects for consideration include *inter alia*:

- National laws and regulations regarding venting of CO_2 emissions from natural gas processing.
- Common practice for new build natural gas processing production licenses and venting in similar regions.

Data and parameters not monitored

96. In addition to the parameters listed in the tables below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

Data / parameter:	η_{boiler}
Data unit:	%
Description:	Efficiency of the boiler in which heat is assumed to be generated in to supplement cogeneration in the baseline scenario
Source of data:	a) Assumed to equal 60% in the absence of any onsite gas-fired heaters; or b) Where gas fired heaters are present on site and are operational, then the efficiency may be measured and applied
Measurement procedures (if any):	a) Not applicable b) Once at the start of the project
Any comment:	Only applicable where it is demonstrated that additional onsite (captive) power plant rated capacity required for CCS displaces onsite gas-fired heaters that would be required to supplement cogeneration in the baseline scenario.

Data / parameter:	$PP_{CP,BL}$
Data unit:	GJ
Description:	Rated capacity for power generation that would be required in the baseline scenario
Source of data:	Engineering feasibility studies should be used to determine the rated capacity for onsite (captive) power plant(s) in the absence of the CCS project activity.
Measurement procedures (if any):	To be based on standard engineering modelling and calculation methods. These should be same methods as employed to calculate rated capacity requirements for cogeneration for the CCS activity.
Any comment:	Only applicable where it is demonstrated that additional onsite (captive) power plant rated capacity required for CCS displaces onsite gas-fired heaters that would be required to supplement cogeneration in the baseline scenario.

Data / parameter:	η_{cogen}
Data unit:	%
Description:	Efficiency of heat generation by cogeneration in the baseline plant
Source of data:	a) Measured for the project activity, and assumed to be the same as for the cogeneration plant in the project activity; or b) Assumed to equal 60%
Measurement procedures (if any):	a) Once at the start of the project b) Not applicable
Any comment:	Only applicable where it is demonstrated that additional onsite (captive) power plant rated capacity required for CCS displaces onsite gas-fired heaters that would be required to supplement cogeneration in the baseline scenario.

Data / parameter:	$P_{PC,OL}$
Data unit:	kPa (kilopascal)
Description:	Maximum operational pressure limit of the Injection Formation
Source of data:	To be determined based on pressure safety limit and safety factor.
Measurement procedures (if any):	As described in Annex A
Any comment:	A key parameter for technical review by a CCS Panel and/or CGSCoE.

Data / parameter:	$P_{PC,SL}$
Data unit:	kPa (kilopascal)
Description:	Pressure safety limit in the Injection Formation.
Source of data:	Determined during Geological Storage Complex characterisation following the procedures outlined in Annex A, and laid down in the Modes of Operation for the Geological Storage Complex. Based on variations in key pressure-driven mechanical Features that can affect Seepage. Will vary according to project specific Containment System conditions.
Measurement procedures (if any):	Determined through leak-off, formation integrity and/or stem tests undertaken during well drilling. Pressure should be determined for the Caprock Formation in Containment System..
Any comment:	A key parameter for technical review by a CCS Panel and/or CGSCoE.

Data / parameter:	P_{PF}
Data unit:	%
Description:	Pressure safety factor based on setting a safety margin on the operational limit and the safety margin (it is ratio that must always be less than 1)
Source of data:	To be determined as part of the Geological Storage Complex characterisation procedure outlined in Annex A, and laid down as a safety limit in the Modes of Operation for the Geological Storage Complex. It should be based on expert judgment regarding the margins of error in the safety limit measurements.
Measurement procedures (if any):	Determined based on the Geological Storage Complex characteristics and expert judgment.
Any comment:	A key parameter for technical review by a CCS Panel and/or CGSCoE.

Data / parameter:	$PB_{CO2,V/L,p,t}$
Data unit:	Various
Description:	Two and three-dimensional image(s) and description of the subsurface vertical and lateral boundaries of injected CO_2 Plume at a given point in time or mass of injected CO_2 equating to year *y* (indicative upper and lower vertical boundaries (in metres (m) below the surface may be used; lateral boundary may be dimensionless/descriptive or latitude/longitude coordinates)
Source of data:	Computer simulation modelling of Geological Storage Complex
Measurement procedures (if any):	Determined through computer simulation modelling based on Geological Storage Complex specific characteristics following guidance in Annex A.
Any comment:	A key parameter for technical review by a CCS Panel and/or CGSCoE.

Data / parameter:	$BD_{SC,j/k/l}$
Data unit:	Dimensions specific to each feature and measurement technique
Description:	Base level survey data describing the condition of feature *j/k/l* n the subsurface generated during site characterisation following guidance in Annex A
Source of data:	Onsite measurements
Measurement procedures (if any):	Determined through geological survey of the Geological Storage Complex conditions following guidance in Annex A.
Any comment:	A key parameter for technical review by a CCS Panel and/or CGSCoE.

III. MONITORING METHODOLOGY

97. This methodology requires three elements to be considered in respect of Subsurface Monitoring:

- *Detection*: monitoring to detect the presence and behaviour of CO_2 in the subsurface, including detection of any Significant Irregularities; and,

- *Quantification*: in the event that Seepage is detected, more intensive monitoring may be needed to determine the source, emission pathway, flux rate and duration.

- *Knowledge retention*: support for long-term containment assurance and transfer of knowledge/learning from project operation by retention of the full monitoring history over the extended technical life-cycle of a Geological Storage Complex.

98. In the case of *detection*, the methodology does not define a set of standard of monitoring parameters that must be collected. Rather, these should be defined through a set of monitoring techniques developed on a project-specific basis, and through an iterative approach for Geological Storage Complex monitoring, based around the principle of “adaptive learning”. This is because after injection commences, there may be a need to adapt a monitoring plan as the understanding of the subsurface behaviour of the CO_2 Plume evolves, whilst new techniques may be applied in line with emerging best practice. The main consideration is, therefore, that sufficient flexibility is

allowed for in the methodology which provides the opportunity for project participants to adapt their monitoring plan for a particular Geological Storage Complex.

99. In terms of *quantification*, a calculation is described, although specific techniques will need to be established on a case-by-case basis, depending on the nature of the emission source and pathway.

100. In the case of *knowledge retention*, in addition to the standard procedures regarding data acquisition and archiving as applied for all CDM project activities, all monitoring data collected should be archived electronically, and form part of a structured handover that occurs when Stewardship transfers from project participants to host country.

101. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards and emerging best practice.

102. In addition, the monitoring provisions in the tools referred to in this methodology apply.

Data and parameters monitored

103. The following data must be collected and archived when implementing this methodology.

Data / parameter:	$FR_{GAS,CP,j,y}$
Data unit:	m^3 (cubic metres)
Description:	Flow rate of captured gas stream from capture process *j* in the Natural Gas Processing Plant in year *y*
Source of data:	Meter at the take-off point from CO_2 removal unit in the Natural Gas Processing Plant
Measurement procedures (if any):	Volumetric flow meter(s) should be regularly tested and calibrated to ensure a high level of data accuracy. The highest standard meter should be employed, with a metering accuracy of ±2.5%. Metered flow rates must be corrected for temperature and pressure.
Monitoring frequency:	Continuous
QA/QC procedures:	Calibrated and collated with other meter data across the CO_2 transport and injection system
Any comment:	

Data / parameter:	$\rho_{GAS,CP,j,y}$
Data unit:	kg gas/m³
Description:	Weighted average density of captured gas in the gas stream from capture process *j* in the Natural Gas Processing Plant
Source of data:	Onsite (or offsite) measurement and analysis
Measurement procedures (if any):	Based on regular sampling and analysis at the take-off point from CO_2 removal unit in the Natural Gas Processing Plant. To be calculated using ideal gas law using measurements of molar mass (mm), pressure (P in atm), the universal gas constant (R = 0.082057459 $L/atm/K^{-1} . mol^{-1}$) and temperature (K) where: $\rho = mmP/RT$.
Monitoring frequency:	Monthly or quarterly, from which weighted average values should be calculated
QA/QC procedures:	The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards.
Any comment:	The density of the gas, as calculated using the ideal gas law, will provide the most accurate method of calculating mass flows of captured CO_2 across the project activity.

Data / parameter:	$w_{CO2,CP,j,y}$
Data unit:	mass unit/volume unit (kg CO_2/m³) or percent (%)
Description:	Weighted average mass fraction of CO_2 in the captured gas from capture process *j* in the natural gas processing in year *y*
Source of data:	Onsite (or offsite) measurement and analysis
Measurement procedures (if any):	Based on regular sampling and analysis at the take-off point from CO_2 removal unit in the Natural Gas Processing Plant, and sampling should be based on international fuel standards
Monitoring frequency:	Monthly, from which weighted average values should be calculated
QA/QC procedures:	The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards
Any comment:	-

Data / parameter:	$FC_{i,j,y}$
Data unit:	m³/yr
Description:	Quantity of fuel type *i* combusted in process *j* (e.g. gas fired compressors/heaters or emergency generators) in year *y*
Source of data:	Onsite measurement of metered fuel use
Measurement procedures (if any):	Use volumetric flow meters for natural gas use. For any diesel for use in emergency generators rulers can be used to determine mass or volume of the fuel consumed, with the following conditions: The ruler gauge must be part of the daily tank and calibrated at least once a year and have a book of control for recording the measurements (on a daily basis or per shift)
Monitoring frequency:	Continuous
QA/QC procedures:	The consistency of metered fuel consumption quantities should be cross-checked using any allocation method employed for metering and cross-referencing at the project site. Where purchased fuel invoices can be identified specifically for the CDM project, the metered fuel consumption quantities should also be cross-checked with available purchase invoices from the financial records.
Any comment:	Only applicable where the project uses gas fired compressors for CO_2 compression, require additional gas fired heaters to raise heat for amine regeneration, or for use in emergency generators.

Data / parameter:	$w_{C,i,y}$
Data unit:	kgC/m^3
Description:	Weighted average mass fraction of carbon (C) in the fuel type *i* in year *y*
Source of data:	Onsite sampling and analysis of fuel feed to any gas fired compressors used for CO_2 compression, gas fired heaters or emergency generation, based on international fuel standards
Measurement procedures (if any):	Measurements should be undertaken in line with national or international fuel standards
Monitoring frequency:	Monthly, from which weighted average values should be calculated
QA/QC procedures:	The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards
Any comment:	Only applicable where the project uses gas fired compressors for CO_2 compression, gas fired heaters or emergency generation.

Data / parameter:	$\rho_{i,y}$
Data unit:	mass unit/volume unit; %
Description:	Weighted average density of fuel type *i* in year *y*
Source of data:	Onsite sampling and analysis of fuel feed to the captive power plant at the Natural Gas Processing Plant. Sampling should be based on international fuel standards
Measurement procedures (if any):	Measurements should be undertaken in line with national or international fuel standards
Monitoring frequency:	Monthly, from which weighted average values should be calculated
QA/QC procedures:	The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards
Any comment:	

Data / parameter:	$EC_{PJ,j,y}$
Data unit:	MWh/yr
Description:	Quantity of electricity generated onsite and consumed by project electricity consumption source *j* in year *y*
Source of data:	Electricity meter readings
Measurement procedures (if any):	Processes consuming electricity and associated with the project activity must be identified prior to project registration. These consumption sources must have electricity meters fitted.
Monitoring frequency:	Continuous
QA/QC procedures:	The consistency of metered electricity consumption quantities should be cross-checked by an annual energy balance that is based on gas consumed in the power plant, site wide energy consumption, and estimates of overall plant electrical conversion efficiency. Cross check with metering allocation and against $EG_{n,y}$
Any comment:	Consumption sources can include CO_2 compressors, dehydration plant and any other auxiliary equipment linked with the CCS project activity.

Data / parameter:	$FC_{n,i,y}$
Data unit:	tonnes and/or m³ per year
Description:	Quantity of fuel type *i* fired in the onsite (captive) power plant *n* in year *y*
Source of data:	Onsite measurement of metered fuel use (in captive power plants)
Measurement procedures (if any):	Use volumetric flow meters
Monitoring frequency:	Continuous
QA/QC procedures:	The consistency of metered fuel consumption quantities should be cross-checked using any allocation method employed for metering and cross-referencing at the project site. Where purchased fuel invoices can be identified specifically for the CDM project, the metered fuel consumption quantities should also be cross-checked with available purchase invoices from the financial records.
Any comment:	

Data / parameter:	$NCV_{n,i,y}$
Data unit:	GJ/m³
Description:	Weighted average net calorific value of fuel type *i* fired in the onsite (captive) power plant *n* in year *y*
Source of data:	Onsite measurements
Measurement procedures (if any):	Measurement procedures should be undertaken in line with national or international fuel standards
Monitoring frequency:	Quarterly or monthly, from which weighted average values should be calculated.
QA/QC procedures:	Verify values are within uncertainty range of the IPCC default value as provided in *Table 1.2 of Chapter 1, Vol. 2 of the 2006 IPCC Guidelines*. If the values fall out this range collect additional information from the testing laboratory to justify the outcome or conduct additional measurements. The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards.
Any comment:	

Data / parameter:	$HG_{n,y}$
Data unit:	GJ/yr
Description:	Quantity of heat cogenerated in the onsite (captive) power plant *n* in year *y* in year *y*
Source of data:	Onsite measurements
Measurement procedures (if any):	Heat generation is determined as the difference of the enthalpy of the steam or hot water generated minus the enthalpy of the feed-water and any condensate return. The respective enthalpies should be determined based on the mass (or volume) flows, the temperatures and, in case of superheated steam, the pressure. Steam tables or appropriate thermodynamic equations may be used to calculate the enthalpy as a function of temperature and pressure.
Monitoring frequency:	Continuous by way of meters
QA/QC procedures:	Cross check against calculated heat requirements for amine regeneration.
Any comment:	Only applicable if engineering feasibility studies show that additional heat to that available from cogeneration would need to be raised to meet the requirements for amine generation in the Natural Gas Processing Plant in the baseline scenario.

Data / parameter:	$EF_{CO2,n,y}$
Data unit:	tCO_2/GJ
Description:	Average CO_2 emission factor of the fossil fuel fired in the onsite (captive) power plant(s) *n* in year *y*
Source of data:	Onsite measurements
Measurement procedures (if any):	Measurement procedures should be undertaken in line with national or international fuel standards
Monitoring frequency:	Monthly, from which weighted average values should be calculated
QA/QC procedures:	Verify values are within uncertainty range of the IPCC default value as provided in Table 1.4 Chapter 1, Vol. 2 of the 2006 IPCC Guidelines. If the values fall out this range collect additional information from the testing laboratory to justify the outcome or conduct additional measurements. The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards.
Any comment:	Similar procedures as used in equation 5 of this methodology may be used, but calculating the GJ/m^3 rather than tCO_2/m^3

Data / parameter:	$EG_{n,y}$
Data unit:	MWh/yr
Description:	Quantity of electricity generated in the onsite (captive) power plant(s) *n* in year *y*
Source of data:	Onsite measurements
Measurement procedures (if any):	Electricity meters
Monitoring frequency:	Continuously, aggregated at least annually
QA/QC procedures:	Cross check measurements with measured onsite consumption (e.g. $EC_{PJ,j,y}$ and other electricity consumption meters) and the metering allocation system for the site.
Any comment:	

Data / parameter:	$EC_{PJ,grid,y}$
Data unit:	MWh/yr
Description:	Quantity of bought-in grid electricity consumed by the project in year *y*
Source of data:	Electricity meter readings
Measurement procedures (if any):	
Monitoring frequency:	Continuous
QA/QC procedures:	The consistency of metered fuel consumption quantities should be cross-checked by an annual energy balance that is based on purchased quantities and stock changes. Where the purchased fuel invoices can be identified specifically for the CDM project, the metered fuel consumption quantities should also be cross-checked with available purchase invoices from the financial records.
Any comment:	

Data / parameter:	$EF_{grid,CM,y}$
Data unit:	tCO_2/MWh
Description:	Emissions factor for the combined margin for grid electricity in year *y*
Source of data:	
Measurement procedures (if any):	Calculated based on *ex ante* calculation of the grid emission factor from which bought-in electricity is purchased, following the latest version of the “Tool to calculate the emission factor for an electricity system”
Monitoring frequency:	As per the “Tool to calculate the emission factor for an electricity system”
QA/QC procedures:	As per the “Tool to calculate the emission factor for an electricity system”
Any comment:	-

Data / parameter:	$FR_{GHG,INJ,k,y}$
Data unit:	m^3
Description:	Flow rate of injection gas stream at injection wellhead *k* in year *y*
Source of data:	Meter(s) at injection wellhead(s)
Measurement procedures (if any):	Volumetric flow meter(s) should be regularly tested and calibrated to ensure a high level of data accuracy. The highest standard meter should be employed, with a metering accuracy of ±2.5%. Metered flow rates must be corrected for temperature and pressure.
Monitoring frequency:	Continuous
QA/QC procedures:	The consistency of metered fuel consumption quantities should be cross-checked using any allocation method employed for metering and cross-referencing at the project site. Calibrated and collated with other meter data across the CO_2 capture and transport system
Any comment:	-

Data / parameter:	$\rho_{GHG,INJ,k,y}$
Data unit:	kg GHG/m^3
Description:	Weighted average density of gas in the stream injected into the Containment System in injection well *k* in year *y*
Source of data:	Onsite (or offsite) measurement and analysis
Measurement procedures (if any):	Based on regular sampling and analysis at the take-off point at injection wellhead(s)
Monitoring frequency:	Monthly or quarterly, from which weighted average values should be calculated
QA/QC procedures:	The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards.
Any comment:	The density of the gas, as calculated using the ideal gas law, will provide the most accurate method of calculating mass flows of captured CO_2 across the project activity.

Data / parameter:	$w_{CO2,INJ,k,y}$
Data unit:	mass unit/volume unit (kg CO_2/m^3) or percent (%)
Description:	Weighted average mass fraction of CO_2 in the injected gas stream in injection well *k* in year *y*
Source of data:	Onsite (or offsite) measurement and analysis
Measurement procedures (if any):	Based on regular sampling and analysis at the take-off point from CO_2 removal unit in the Natural Gas Processing Plant, and based on international fuel standards
Monitoring frequency:	Monthly or quarterly, from which weighted average values should be calculated
QA/QC procedures:	The laboratories should have ISO17025 accreditation or justify that they can comply with similar quality standards
Any comment:	-

	$M_{CO2,j/k/l,y}$
Data unit:	Indicative upper and lower vertical boundaries in metres (m) below the surface may be used; lateral boundary may be dimensionless/descriptive or latitude/longitude coordinates
Description:	Subsurface Monitoring technique *j/k/l* applied to determine the presence and Migration characteristics of the subsurface CO_2 Plume and to generate two and three-dimensional image(s) and descriptions of the vertical and lateral boundaries of the CO_2 Plume in year *y*
Source of data:	Onsite measurement
Measurement procedures (if any):	To be developed in accordance with the guidance in Annex B and detailed in the project design document
Monitoring frequency:	Intermittent and continuous
QA/QC procedures:	Observations of subsurface CO_2 Migration characteristics must be regularly compared with predicted behaviour of the CO_2 as made through computer simulation modelling prior to commencing injection operations. See Annex C for further QA/QC considerations.
Any comment:	To be determined on a project-by-project basis and subject to technical expert review by a CCS Panel and/or CGSCoE.

Data / parameter:	$M_{SC,j/k/l,y}$
Data unit:	Dimensions dependent on the particular technique applied
Description:	Subsurface Monitoring technique *j/k/l* applied to Features within the Geological Storage Complex which could detect potential irregularities in year *y*
Source of data:	Onsite measurement
Measurement procedures (if any):	To be developed in accordance with the guidance in Annex B and detailed in the project design document
Monitoring frequency:	Intermittent and continuous
QA/QC procedures:	Observations of Geological Storage Complex Features must be regularly compared with base level survey data as determined through site characterisation prior to commencing injection operations. See Annex C for further QA/QC considerations.
Any comment:	To be determined on a project-by-project basis and subject to technical review by a CCS Panel and/or CGSCoE.

Data / parameter:	$P_{M,j/k/l}$
Data unit:	kPa (kilopascal)
Description:	Bottomhole (and/or wellhead) pressure in the Injection Formation continuously monitored in well(s) *j/k/l* at all times
Source of data:	Onsite measurement
Measurement procedures (if any):	Bottomhole and wellhead pressure should be monitored in all injection and observation wells within the Geological Storage Complex
Monitoring frequency:	Continuous and/or intermittent
QA/QC procedures:	Individual readings to be cross-checked against wellhead pressure and other bottomhole measurements of pressure to ensure consistency of data. Pressure monitors to be calibrated frequently to ensure accuracy of readings.
Any comment:	To be cross-checked continuously against $P_{PC,OL}$

Data / parameter:	$S_{FLX,k,y,}$
Data unit:	kgCO$_2$-e/m² d^{-1}
Description:	Flux rate of Seepage source *k* in year *y*
Source of data:	Specific measurements undertaken in response to the detection of Seepage
Measurement procedures (if any):	Where Seepage is detected, further investigations should be carried out to identify and characterise the Seepage emission pathway (e.g. Seepage through an active or abandoned well-bore; Seepage along a fault plane; Seepage due to permeation of the Caprock Formation and diffusion through the Overburden). Emission pathways could consist of: • *Direct Seepage or breach*: in a confined pathway such as a well-bore or fault plane; or • *Diffuse Seepage*: through the pore system of the Overburden in the absence of effective sealing strata, through Caprock degradation, or dissolution into pore fluids. The emission pathway and the resultant source(s) at the surface must be fully described and characterised during monitoring. The flux rate of each emission source linked to Seepage should be estimated using methods appropriate for the identified pathway/emission source(s). These might require the application of a range of techniques including *inter alia*: • direct metering in well-bores (for confined Seepage pathways such as within a well casing); • acoustic imaging techniques to provide areal assessment of potential sites of Seepage; • use of submersibles vehicles (offshore) to identify and characterise bubbles or a CO$_2$ Plume on the sea-bed; or • soil gas meters (onshore), corrected to account for background fluxes. A range of novel techniques or other proxy measures may be employed on a case-by-case basis, depending on the nature of the identified emission source(s).
Monitoring frequency:	To be initiated on the detection of Seepage during Geological Storage Complex monitoring ($M_{CO2,j/k/l,y}$; $M_{SC,j/kl,y}$)
QA/QC procedures:	
Any comment:	For all methods employed to determine the flux rate of a Seepage emission source, the project participants shall document the following in the monitoring report: • the rationale for the choice of method employed, and • an assessment of the accuracy of the data collected with a description of the major sources of uncertainty in the estimates. In estimating flux rates, account should be taken of both gaseous and dissolved CO$_2$ e.g.CO$_2$ dissolved in water.

Data / parameter:	$S_{t.k,y}$
Data unit:	days
Description:	Duration that Seepage source *k* is estimated to have been occurring in year *y*
Source of data:	Onsite measurement
Measurement procedures (if any):	The duration of the Seepage event in days should be determined from the date when it was first detected, back dated to one of the following reference points: • the last date when the monitoring plan showed no evidence of Seepage from the identified emission source. This maybe up to one calendar year, based on the submission of annual monitoring reports, or, • the date of commencement of CO_2 injection, when there is no available evidence to show that no Seepage was previously detected, or, • other evidence which may be used to provide an estimate of the start date of leak.
Monitoring frequency:	To be initiated on the detection of Seepage during Geological Storage Complex monitoring
QA/QC procedures:	Subject to verification.
Any comment:	

Data / parameter:	$S_{k,area}$
Data unit:	Square metres (m²)
Description:	The area over which Seepage from source *k* has been measured
Source of data:	Onsite measurement
Measurement procedures (if any):	The areal extent of the Seepage zone should be determined from subsurface and surface monitoring data. Specific detailed investigations may be needed where the areal extent of the Seepage source cannot be determined.
Monitoring frequency:	To be initiated on the detection of Seepage during Geological Storage Complex monitoring
QA/QC procedures:	Subject to verification.
Any comment:	

IV. REFERENCES AND ANY OTHER INFORMATION

104. This methodology draws from and makes references, *inter alia*, to:

- BERR (2007) CO_2 Capture and Storage in the EU Emission Trading Scheme. Monitoring and Reporting guidelines for inclusion via Article 24 of the EU ETS Directive. Report No: R312 BERR/Pub URN 07/1634

- European Union. Directive 009/.../EC of the European Parliament and Council on the geological storage of carbon dioxide and amending Council Directives 85/337/EEC, 2000/60/EC 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006; Brussels 26/03/2009.

- IEA GHG (2007), Greenhouse Gas R&D Programme (IEA GHG), "ERM – Carbon Dioxide Capture and Storage in the Clean Development Mechanism", 2007/TR2, April 2007

- IPCC (2005), IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

- IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5

- IEA (2007). Carbon Capture and Storage in the CDM. [Philibert, C. Ellis, J. and Pokanski, J.] Organisation for Economic Co-operation and Development/International Energy Agency.

- UNFCCC (2008)a. Synthesis of views on issues relevant to the consideration of carbon dioxide capture and storage in geological formations as clean development mechanism project activities: Note by the Secretariat. Document number: FCCC/ SBSTA/2008/INF.1

- UNFCCC (2008)b. Synthesis of views on technological, methodological, legal, policy and financial issues relevant to the consideration of carbon dioxide capture and storage in geological formations as project activities under the clean development mechanism. Note by the Secretariat Document number: FCCC/SBSTA/2008/INF.3

- US EPA (2008). Proposed Rule for Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide Geologic Sequestration Wells: 40CFR Parts 144 and 146.c

Section D. Explanations / justifications to the proposed new baseline and monitoring methodology

Selected approach from paragraph 48 of the CDM modalities and procedures

105. This methodology has been written for applicability to existing and new build gas processing plants. For existing Natural Gas Processing Plant, "existing actual or historical emissions" will provide an accurate description of the baseline scenario and emissions because the venting of these emissions is avoided by the application of CCS to the separated CO_2 offgas stream. Similarly, at new build Natural Gas Processing Plants, the separated CO_2 offgas stream will also be analogous to the baseline emissions in the absence of the project activity, and hence "existing actual or historical emissions" also applies. It is important to note that – unlike industrial gas destruction project activities such as in HCFC-22 manufacture and the destruction of HFC-23 offgas – process modifications cannot be made to enhance the amount of CO_2 in the offgas as this is dictated by the concentration of Formation CO_2 present in the natural gas reservoir. It is reasonable to assume that demand for natural gas will remain, and there will be no incentive to produce more natural gas in response to the inclusion of these operations as a CDM project activity. However, production of a higher delivery specification in sales gas could lead to higher CO_2 offgas production at a specific site, whilst the incentive offered by CCS application could lead to development of higher CO_2 content natural gas fields ahead of lower content ones. Therefore, notwithstanding the possible case for new build plants applying the same baseline approach as existing plants, there is a need to avoid perverse incentives to either/both modify delivery specifications or incentivise development of high CO_2 gas fields specifically because of the incentive offered by CCS inclusion within the CDM. Therefore, the baseline approach also includes consideration of "emissions from a technology that represents an economically attractive course of action, taking into account barriers to investment" when determining the baseline scenario. These issues are also considered as a potential source of Leakage, as described below (paragraph 169).

Definitions

106. CCS is an emerging area of scientific and technological research. Consequently, regulatory and legal structures are emerging which can help create an enabling framework for CCS deployment. In designing this proposed methodology, a variety of definitions from existing literature available at the time of writing have been selected, including the *European Union's Directive on the geological storage of carbon dioxide*, the *IPCC Special Report on Carbon Dioxide Capture and Storage*, the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5 on Carbon Dioxide Transport, Injection and Geological Storage* and the *US EPA Proposed Rule for Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells.* To these, BP's in-house expertise on surface and subsurface engineering has also been applied in order to provide terminology consistent with industry practice and understanding. All of these definitions are dynamic and subject to future changes as the regulatory and greenhouse gas accounting frameworks continue to evolve. As such, it can be expected that these proposals will be subject to future modifications as understanding regarding the legal and regulatory issues presented by CCS emerges through greater dialogue and implementation.

107. The definitions included within this NM have been subject to legal review by expert counsel.

Applicability conditions

108. As few places in the world require operators to install CCS at Natural Gas Processing Plants, it is considered relevant to include new build plants within the applicability conditions, subject to consideration of potential perverse incentives for new build projects, as described above (paragraph 103). In order to avoid such perverse incentives, the methodology is only applicable to new build projects which can show that the modifications to delivery specifications have not been made, and more importantly, that the gas field would be developed even in the absence of the potential revenues offered by the CCS CDM project activity.

109. There has been a significant level of debate regarding the acceptability of levels of impurities in CO_2 Streams to be injected. The methodology reflects the present status of the debate by restricting the scope to material for injection consisting overwhelmingly of CO_2, and provides further elaboration in the definitions ("CO_2 Stream"). The proposed methodology follows a similar approach to prohibitions as applied in amendments to the 1972 London Convention and 1996 protocol thereto regarding the storage of CO_2 in the sub-seabed, and as reflected in the EU CCS Directive.

110. CO_2 can be captured from a wide variety of installations, transported continuously via pipeline or discontinuously by ships or lorries and finally be stored in very different geological media including for enhanced hydrocarbon recovery (EHR) and Geological Formations that may cross national borders. However, respecting the need to limit complexity in the methodology because of ongoing uncertainty about how to deal with such aspects of CCS accounting[5], in particular joint storage of CO_2 from several sources and projects which cross national boundaries, these types of issues have been scoped out via the applicability conditions set down in the methodology. Complications over liability for storage sites accepting CO_2 from variable sources also means that applicability has been restricted to projects where the sources are under the control of project participants. Furthermore, this methodology is not applicable to the capture of CO_2 from combustion sources, as this presents additional baseline considerations which are not covered within this methodology (for example, choices regarding the power source displaced by the power plant to which CCS is applied). It also excludes oceanic CO_2 storage, and the use of CO_2 for enhanced hydrocarbon recovery, the former being subject to considerable uncertainty regarding the legality under international maritime law and ecological impacts, whilst the latter presents additional emissions accounting and additionality considerations that are not covered in the methodology.

111. A range of other applicability conditions are included as these form the basis for managing permanence of emission reductions generated from CCS project activities (e.g. financial security and Stewardship transfer). These provisions are designed to provide assurance of the long-term environmental integrity of CCS projects in the CDM by ensuring that the host country is fully aware of its longer term responsibility prior to agreeing to host such a project activity. This forms an important component of the proposed four-step model for management of permanence, which also includes appropriate site selection and management, the justification of which is described further below under "Project Emissions".

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[5] For example, as highlighted in the various decisions of the Conference of Parties serving as the Meeting of the Parties to the Kyoto Protocol on the topic of carbon dioxide capture and geological storage as CDM project activities.

Project boundary

112. The methodology includes consideration of both a spatial boundary (in the same way as for other CDM project activities) and a temporal boundary (reflecting the need to consider the permanence of emission reductions created by CCS projects).

113. The spatial boundary includes the surface features – covering CO_2 capture (separation), compression, dehydration, transport (pipeline only), injection wellheads – in a CCS project which are potentially anthropogenic sources of greenhouse gases that are under the control of project participants and are significant and reasonably attributable to the project activity.

114. The methodology also proposes that the project boundary extend into the subsurface to include the CO_2 Geological Storage Complex. The concept of a Containment System is an Injection Formation and Caprock Formation pairing, the combination of which is suitable for the long-term secure storage of CO_2. The concept of a Geological Storage Complex comprises one or more Containment Systems. The upper most seal within the Geological Storage Complex is known as the ultimate seal and provides the vertical boundary of the Geological Storage Complex. The lateral boundary of a Geological Storage Complex is an estimate based upon a characterisation of the Geological Storage Complex and predictive forward models of the CO_2 Plume Migration, potential Seepage pathways and ultimate distribution of the total amount of CO_2 planned to be injected in the targeted Geological Storage Complex. Information and data on the forward predictions of lateral and vertical boundaries must be generated by project participants as part of the project registration process (=$PB_{CO2,V/L,p}$), and outlined in a *Geological Storage Complex Selection & Characterisation Report* that accompanies the project design document. This aspect of the methodology forms an important component of the Subsurface Monitoring plan, described below.

115. The Geological Formations above the ultimate Caprock Formation (i.e. directly above the Geological Storage Complex) until the upper limit of the Geosphere are known collectively as the Overburden. The intention within a CCS project is to inject CO_2 into the Injection Formation of the Geological Storage Complex. If selected and managed appropriately the CO_2 is very likely to remain in the Injection Formation and not migrate into additional Containment Systems within the Geological Storage Complex. The Mode of Operation of the Geological Storage Complex, developed according to the guidance outlined in Annex A of this methodology, should serve to ensure that these preconditions are met. A range of mandatory Subsurface Monitoring requirements are set down in the methodology to demonstrate that a good understanding of subsurface CO_2 Migration behaviour is maintained by the project participants, including vertical and lateral boundaries of the CO_2 Plume ($PB_{CO2,V/L,y}$). Reservoir pressure is one of the key determinants of safe Geological Storage Complex management, and is included as a mandatory monitoring requirement (=$P_{M,j/k/l}$), based on setting a maximum operational pressure safety limit for injection activities (=$P_{PC,OL}$). However, if CO_2 does breach a Caprock Formation and migrate into additional Containment Systems within the Geological Storage Complex this could still provide secure storage if additional Containment Systems are present. These procedures, coupled with monitoring, are designed to support zero-Seepage assumptions in the first instance.

116. The approach adopted is consistent with views of Parties and NGOs, as expressed in the UNFCCC Secretariat's first synthesis report of views on CCS as a CDM project activity (UNFCCC, 2008a)[6]. This suggests that project boundaries should include:

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[6] Paragraph 45.

"(a) **The above-ground components** such as the industrial installation where the CO_2 is generated, the capture plant, any additional CO_2 treatment facilities, the compression facility, the transportation equipment and booster stations along a pipeline, any reception facilities or holding tanks at the injection site, and the injection facility;

(b) **Wells and other potential direct seepage pathways** such as injection, observation and abandoned wells, mineshafts and boreholes. These potential seepage pathways will need to be monitored as part of the overall project monitoring plan [termed "Features" within the scope of this methodology];

(c) **The reservoir where the CO_2 is stored.** Site characterization and storage performance assessments carried out as part of the feasibility study in advance of CO_2 injection operations will define the project boundary for the reservoir;

(d) **The locations around the reservoir** such as the cap rock or spill points at the lateral edges of a geological structural trap [also covered as "Features" within the scope of this methodology];"

117. In the proposed NM, if injected CO_2 migrates across either the vertical or lateral boundaries of the Geological Storage Complex or activates any Features, this is deemed to be a Significant Irregularity ($PB_{CO2,V/L,y} \neq PB_{CO2,\ V/L,p}$; $F_{SC,y} \neq BD_{SC}$). In the event of a Significant Irregularity indicating vertical Migration of CO_2 out of the Geological Storage Complex (i.e. across the ultimate Caprock Formation into the Overburden), the Overburden may provide additional attenuating pore-space for storage of CO_2 but without a clear seal present it is possible that some of the CO_2 will migrate to the surface of the Geosphere and be released as Seepage emissions. Such effects are dealt with in the methodology in *Sub-steps 4(b), (c)* and *(d)* of *Project Emissions – Avoidance, determination and calculation of Seepage emissions.*

118. In the event of a Significant Irregularity indicating lateral Migration of CO_2 out of the Geological Storage Complex, additional subsurface assessment as per the procedure presented in Annex C should be applied. If the assessment shows that there are no significant Seepage pathways or associated risk of Seepage and that the injected CO_2, remains securely stored then it is proposed to modify the defined lateral boundaries of the Geological Storage Complex accordingly. This assessment and any resultant requirement for the lateral boundary to be redefined should be approved by the host country (DNA and/or competent authority appointed by the DNA), subject to review and comment by a DOE during verification and also the CDM EB, its panels and possibly by an CGSCoE as part of a project's request for issuance.

119. The approach adopted in this proposed methodology leads to the possibility of applying dynamic CDM project boundaries for projects where Significant Irregularities arise resulting in Migration of CO_2 beyond the lateral boundaries of the Geological Storage Complex predicted in forward modelling. There are three reasons for adopting the proposed approach:

- Migration across lateral boundary of the predefined Geological Storage Complex does not necessarily compromise storage security and/or lead to Seepage;

- Project participants and regulators alike need certainty when defining the lateral boundaries within which a Subsurface Monitoring plan is to be developed and conducted. Hence, the proposed approach delimits the area within which project participants would be responsible for undertaking monitoring and within which they would remain liable for any Seepage emissions, based on defining the CDM project boundary as described;

- Flexibility is required in order for the limits of the area for monitoring to be extended in the event of Significant Irregularities which lead to Migration of the CO_2 Plume beyond the predefined lateral Geological Storage Complex and CDM project boundary. Thus, there is a need to ensure that the project lateral boundary can be extended and re-drawn in the event of such irregularities. This allows project participants to continue to undertake monitoring and be liable for any Seepage emissions within the extended areas within which Migration or Seepage could occur.

120. This flexible approach to project boundaries is considered to be consistent with views of Parties and organizations as expressed in the UNFCCC Secretariat's first synthesis report (UNFCCC, 2008a), where it is concluded that: "*project boundaries would be defined by the emissions sources, as described in the context of emissions sources and potential leakage pathways*" and that *"that project boundaries should be flexible enough to accommodate a range of storage types and different geological conditions*". These views suggest that the dynamic approach to setting project boundaries is coherent with current policy perspectives on these matters. Furthermore, paragraph 57 of the Modalities and Procedures for the CDM allow for the revision of monitoring plans by project participants in order to improve accuracy and/or completeness of information. Subsurface Migration of CO_2 out of the predicted boundaries will inherently require an update to the monitoring plan to take account of new locations, a procedure which is in accordance current CDM (subject to the procedures agreed at the 26th Meeting of the CDM Executive Board, Annex 34).

121. It is also important to note that the need to redefine project boundaries would only arise in the event of Significant Irregularities, which this methodology sets out to minimise through the principle of Avoidance, coupled to appropriate Geological Storage Complex selection, characterisation and management. Furthermore, it circumvents an issue raised by one Party in the UNFCCC Secretariat's second synthesis report (UNFCCC, 2008b)[7] regarding the possibility of monitoring occurring outside of the project boundary, as the dynamic requirements serve to ensure that monitoring will always be undertaken within the project boundary.

122. In addition to the above concept, the definition of subsurface boundaries (as performed in the Geological Storage Complex characterisation requirements as set out in guidance in Annex A) take into consideration the subsurface characteristics of the Geological Storage Complex into which CO_2 is to be injected, and project specific engineering factors, including[8]:

- A definition of primary (and secondary, tertiary etc) boundaries and components of the proposed "Geological Storage Complex";
- Capacity estimation of the overall Geological Storage Complex, Injection Formation, and any overlying Geological Formations;
- Injectivity estimation in the Injection Formation;
- A description of the Porosity / Permeability distribution and of the geological homogeneity/heterogeneity of the Geological Storage Complex;
- A thorough understanding of the Geological Storage Complex Migration and Seepage pathways (Features) and processes (e.g. fault activation pressures);

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[7] UNFCCC (2008)b Paragraph 30.
[8] Amended from: IEA GHG (2007)

- Definition of economic, safety and environmentally sensitive zones which surround or overly the Geological Storage Complex. This should include an assessment of “other users” activities and of appropriate separation distances;

- An assessment of existing and future activities in the Overburden and surrounding areas (e.g. potable/agricultural/industrial water extraction, land-fill etc);

- Interaction with and location of, above ground installations and pipeline systems;

- The nature of CO_2 trapping mechanism(s) including structural/physical trapping, mineral trapping, solubility trapping, ionic trapping, residual trapping and the rate at which these processes might occur;

- CO_2 delivery and injection rates through time and total anticipated mass/volume;

- Phase state of the CO_2 in the Geological Storage Complex (actual and simulated, which depends on a variety of factors such as depth, pressure and temperature);

- The distribution of the injected CO_2 Plume within the Geological Storage Complex and adjacent domains;

- Technical feasibility for reliable subsurface CO_2 monitoring.

123. Temporal project boundaries are also described in this proposed methodology due to the long-term nature of CCS projects, and more specifically the issues presented by the permanence of emission reductions which is the primary objective of CCS project activities. As such, it is necessary to consider the temporal boundaries for project activities, as illustrated in Figure 3 in the methodology. The key elements of this approach are that obligations are created for project participants and host country beyond the project’s crediting period, creating a chain of custody for the CO_2 across the technical life-cycle of the project activity. This is designed to maintain the environmental integrity of the CDM. Furthermore, ongoing support for verification and other approvals by various institutions is also needed over this period such that assurances over long-term containment can be provided by an appropriate long-term entity. In this context, the methodology requires the following to be considered in order to manage permanence:

- Selection of Geological Storage Complexes which show evidence of long-term secure containment of CO_2;

- Agreement of the host country to retain Stewardship for the Geological Storage Complex Post Closure, and appropriate definition of the terms for Stewardship transfer between project participants and host country prior to project commencement;

- Obligations to Compensate for any Seepage from Geological Storage Complex and for remediation and Corrective Measures in the event of any Seepage of CO_2 from the Geological Storage Complex occurring after Stewardship transfer, based on the procedures described in *Project Emissions*.

- Arrangements for periodic monitoring of the Geological Storage Complex occurring after Stewardship transfer and reporting of these activities to Parties, commensurate with the requirements laid down in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5, Section 5.7.1, para. 4(v)*;

124. An appropriate financial arrangement is to be used in order to cover potential costs to the host country in fulfilling its Stewardship obligations during the Post Closure phase. Prior to the transfer of Stewardship, the project participants shall be liable for fulfilling these obligations.

Identification of the baseline scenario

125. The procedure for identifying the baseline scenario follows the methodology set out in the "Combined tool to identify the baseline scenario and demonstrate additionality".

126. Further guidance on the other plausible and credible alternatives for handling Formation CO_2 are provided. The list of options for handling offgas emissions is based on detailed knowledge of industry practice, as well as drawing from published and peer reviewed literature, namely the IEA GHG 2007[9]. It also notes that in some circumstances, CO_2 may be co-injected with hydrogen sulphide (H_2S) as part of a co-disposal strategy. In order to avoid the methodology incentivising standard business activities of this type, project participants are required to demonstrate that there are financial or technical barriers to co-injection in the absence of the CDM.

127. In addition, sector/project specific elements are included in the assessment of baseline scenario options as a means to avoid creating perverse incentives for gas field developments with CCS, as described under *Applicability Criteria* (see paragraph 106). This requires project participants to provide evidence that the CDM is not the key motivating factor in enhancing the level of CO_2 separation or for making investments in the underlying gas field development project; rather, that the CDM is a key factor affecting the decision to make incremental investments into CCS technologies at the field. The criteria deemed suitable for achieving this is as follows:

- *Standard practice in the region for CO_2 separation*: common practice for CO_2 removal in the region is considered a suitable indicator to determine whether the project participants have modified practices to enhance the amount of CO_2 separated in the project activity. It should be noted, however, that it may be preferable from an environmental perspective to separate and store as much of the CO_2 possible at the point of gas production, rather than it being emitted to the atmosphere at the point of use, or captured and stored at the point of use (e.g. passing through as ballast in a gas-fired power plant) as this is less energy efficient;

- *Gas field development plans*: one of the most challenging aspects for this type of project activity within the CDM is the potential to generate CDM revenues by simply producing and injecting CO_2 gas. It is conceivable that if the economics are right, a very high (up to 99%) CO_2 content gas could be economically recovered and reinjected in order to raise revenues. Whilst this is unlikely, it is considered prudent to put in place within the methodology steps which are able to take account of this possibility. Two approaches are considered: firstly, that proponents provide evidence that the decision to develop the gas field within the timelines outlined in the PDD were in place prior to a decision on eligibility of CCS in the CDM; and/or, that the revenues from the

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[9] IEA GHG (2007) *ERM – Carbon Dioxide Capture and Storage in the Clean Development Mechanism*, 2007/TR2, April 2007. IEA Greenhouse Gas R&D Programme. See Chapter 5, pg 42/43.

CCS/CDM element of the field development has only minor implications for the overall projects internal rate of return (IRR) through comparison of project IRR with and without the CCS/CDM element. Consideration of similar projects within the region undertaken in the previous 5 years can also provide a useful indication of the nature of gas fields in the area, and thus provide information about whether the CO_2 content of the field is within the normal levels for that geographical area.

128. A simplified investment analysis is proposed to be allowed under the NM. This is because – providing that other baseline scenario and additionality criteria are met – the project should present a wholly “end of pipe” solution to reducing the venting of Formation CO_2 to atmosphere. In a Natural Gas processing Plant using CCS, the plant would still require a vent to be installed to allow venting where compression and/or injection is not possible (e.g. for technical or maintenance reasons). Consequently, the same technology that would be installed in the baseline scenario would be installed as under the project scenario (at the same cost) meaning that a comparative cost analysis between the baseline scenario and project scenario is unnecessary.

129. These aspects of the methodology are considered to provide a robust approach to avoiding perverse incentives to develop gas field projects with very high CO_2 solely in response to the incentive offered by applying CCS to the field and the associated CDM revenues. It is noted by the authors of this methodology that latest thinking from the CDM Methodology Panel on similar issues (*Draft Guidance on Expansion of Industrial Gas Recovery Methodologies to New Facilities*) does not provide any further guidance on this matter. Furthermore, and as described previously, unlike industrial gas destruction project such as in HCFC-22 manufacture and the destruction of HFC-23 offgas, process modifications cannot be made to enhance the amount of CO_2 in the offgas as this is dictated by the concentration of Formation CO_2 present in the natural gas reservoir.

Additionality

130. The proposed methodology refers to the latest version of the “Combined tool to identify the baseline scenario and demonstrate additionality” (Version 02.2) agreed by the CDM Executive Board as the most appropriate means by which project participants may demonstrate additionality. The tests are subject to the provisions proposed for the baseline scenario determination, as described therein.

131. By applying the “Combined tool to identify the baseline scenario and demonstrate additionality” (Version 02.2)”, a review of mandatory applicable laws and regulations is required. In this context, it is worth noting that, according to the IEA GHG 2007 (*op. cit*) there are few or any legal, regulatory of financial incentives for CO_2 capture and geological storage anywhere in the world. Given the huge potential of CCS technologies for achieving emission reductions globally, this project type can significantly contribute to achieving the ultimate objective of the UNFCCC.

132. Further, the Tool also requires common practice analysis to be carried out for the demonstration of additionality. However, it should be noted that presently only three Natural Gas Processing Plants in the world currently apply CCS technologies: Sliepner and Snøhvit (Norway) and In Salah Gas (Algeria; this project). All other Natural Gas Processing Plants treating high CO_2 gas known to the authors vent CO_2 direct to atmosphere. Thus, it is likely that it will be straightforward to conclude that the application of CCS to separated CO_2 from Natural Gas Processing Plants is not common practice. Data sources are available on estimates of current and future levels of CO_2 venting from natural gas processing, including from the IEA Greenhouse Gas R&D Programme, the IEA, the

IPCC and ECN. These data suggest current levels of venting of CO_2 from this activity in non-Annex I countries are in the range 50 – 219 $MtCO_2$ per year[10]. The size of the range reflects the paucity of CO_2 venting data from operators and in national greenhouse gas inventories for this emissions source, rather than uncertainty in the prevalence of the underlying activity itself. In some cases, natural gas grids and connected technologies (e.g. natural gas fired power plants) have been adapted to run on a lean gas mixture (i.e. natural gas with high levels of CO_2).

Baseline emissions

133. Under this methodology, the baseline scenario for the project activity is the venting of Formation CO_2 separated from natural gas at Natural Gas Processing Plants. In the absence of the CDM, Formation CO_2 would be separated and then vented to atmosphere. Therefore, baseline emissions are equivalent to the mass of Formation CO_2 captured and sent for long-term secure geological storage, measured at the point of capture in the Natural Gas Processing Plant. This is considered relevant for this type of emission source as no combustion emission sources are included in the baseline. The same approach is taken to measure the baseline for avoided flare of venting emissions in AM0009 “Recovery and utilisation of gas from oil wells that would otherwise be flared or vented” (version 3.2), and is therefore considered relevant for this methodology.

134. The methodology also considers the use of cogeneration to displace gas-fired heaters in the project scenario. This is accounted for by applying an emissions credit, consistent with the procedures outlined in the latest version of the “Tool to calculate baseline, project and/or leakage emissions from electricity consumption” (version 01) as described further below under *Project Emissions.*

135. In order to determine the mass of CO_2 captured (i.e. the baseline), the methodology requires project participants to meter the flow rate of gas from the separation plant (volume to be corrected for temperature and pressure), and also the weighted average density of the gas (kg/m^3; noting that captured gas may be under very high pressure if the metering takes place downstream of compression units), and the concentration of carbon dioxide (CO_2) in the gas (%; noting that the CO_2 Stream may contain some contaminants such as trace hydrocarbon gas, nitrogen, nitrous oxides and hydrogen sulphide due to inefficiencies in the CO_2 capture process). These measurements should allow for precise determination of the mass of CO_2 captured – corrected for impurities in the gas stream – and thus atmospheric emissions avoided. Hydrocarbon gases are only likely at trace levels, and are not considered to affect the accuracy of monitored total carbon measurements. Nevertheless, in order to comply with applicability conditions, and also to ensure safe operating conditions of the transport and storage system, project participants are required to monitor the properties of the gas stream, and correct mass flow measurements accordingly.

136. By way of alternative, it would be possible to simply monitor the mass of CO_2 injected into the Geological Storage Complex and use these data as the baseline emissions. This would avoid complications regarding the measurement of fugitive emissions from CO_2 capture and transport. However, for completeness purposes, and in order to provide better understanding of the efficacy of CCS technologies in respect of emission reductions, the methodology proposes a more

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[10] See: Zakkour, P. “Reducing emissions from natural gas production” presentation at the World Bank Extractive Industries Week, Washington DC, March 2009. Available at: http://siteresources.worldbank.org/EXTOGMC/Resources/336929-1237387264558/5930373-1237390630288/zakkour_ggfr.pdf

comprehensive greenhouse gas accounting methodological approach by measuring the baseline at the point of capture, and correcting the emissions reductions achieved by accounting for any fugitive emissions as project emissions.

137. As noted previously, the separation of CO_2 from natural gas is not 100% efficient, resulting in the carry-over of trace hydrocarbon gas with the separated CO_2 Stream. Operators are incentivised to reduce this to as low a level as possible in order to maximise the amount of sales gas produced. Typical ranges of carry-over are 1 – 4%, depending on the efficiency of the separation process used. These levels of methane (CH_4) carry-over with the CO_2 Stream represents an additional source of emissions in the baseline – equating to between 0.212 – 0.875 tCO_2-e for each tonne of CO_2 separated, or an additional 200,000 – 900,000 tCO_2-e for a project venting 1 million tonnes of separated Formation CO_2 each year. Adopting the principle of conservativeness, this methodology does not account for the reduction in these emissions to atmosphere from the application of CCS technologies. This significantly reduces the emission reductions potentially generated by this type of project activity.

138. The methodology also requires project participants to describe the natural gas fields that will export gas to the Natural Gas Processing Plant. This step is included to ensure that transparency over the sources of CO_2 separated and injected in Geological Formations is made clear by project participants. Transparency on this issue is required to support the baseline test Step 1 to show that no modifications have been made to enhance the mass of CO_2 available for injection through manipulation of the producing field(s) and that the field would be developed in the absence of the project activity. This is particularly pertinent in the case of existing projects where new natural gas fields could be tied-in to production in response to the development of the project activity. These cases must be subject to the same consideration as new field projects, and thus transparency over field developments is important to support such cases.

Project emissions

139. The methodology accounts for all incremental greenhouse gas emissions potentially arising from the capture, transport, injection and storage of separated CO_2 Streams in Natural Gas Processing Plant. It also accounts for emissions credit where cogeneration in the project scenario displaces gas-fired heaters that would be present in the baseline scenario.

140. Combustion emissions arising from fossil fuel consumed in gas-fired compressors used for CO_2 compression (in either the Natural Gas Processing Plant or in booster stations on the CO_2 pipeline) are accounted for by employing similar methods set out in the "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion" (currently version 2). As the methodology is restricted to natural gas processing operations, it is likely that only natural gas would be used as a fossil fuel in this type of project activity, so the formulas could be modified to include only natural gas-specific calculations.

141. Emissions arising from electricity consumed in the project activity are calculated by employing similar methods to those presented in the "Tool to calculate baseline, project and/or leakage emissions from electricity consumption" (version 01). The method includes two options:

- One where gas-fired heaters used to raise heat for amine regeneration in the baseline scenario are displaced by cogeneration power plants in the project scenario; and,

- One where no displacement of gas-fired heaters occurs.

142. For retrofit projects, the appropriate method will be apparent from the engineering design and whether gas-fired heaters are present prior to the retrofit of the Natural Gas Processing Plant, and whether they will be displaced in the project scenario. For new build projects, project participants must select the appropriate approach through analysis of project engineering design/feasibility studies. The rationale for this approach is that the addition of CCS projects with mechanical drives for CO_2 compressions etc. adds significant incremental electrical power requirements compared to the same Natural Gas Processing Plant absent of CCS (projects employing gas-fired CO_2 compressors will not require major additions to power generating capacity). Regeneration of amines requires a large amount of heat to strip the captured CO_2 from the amine. Additions of new onsite power plants presents the opportunity for additional cogeneration of heat to be carried out. If, in the baseline scenario, the electrical power requirements of the Natural Gas Processing Plant do not provide sufficient heat output from cogeneration to regenerate all the amine, the heat must be supplemented by gas-fired heaters. In the project scenario, additional power requirements for CCS (with cogeneration) could displace the need for gas-fired heaters to be installed. The exact amount of heat required will depend on the level of Formation CO_2 present in the natural gas, and thus the size of amine removal plant/volume of amine required, which must be determined on a project specific basis. Where gas-fired heaters can be shown to be displaced, the methodology allows for an emissions credit to be gained for the displacement by cogeneration. The amount of credit must be corrected by the level of cogeneration that would occur in the baseline scenario, hence the calculation presented in equation (9).

143. Where project participants are unable to demonstrate that gas-fired heaters would be present in the baseline scenario, no emission credit can be gained for cogeneration in the project scenario, hence the alternative calculation method for emissions from electricity consumption presented in equation (10).

144. The methodology requires that any bought-in electricity associated with the CCS project activity must be accounted for employing methods as set out in the “Tool to calculate baseline, project and/or leakage emissions from electricity consumption” (version 01) and the “Tool to calculate the emission factor for an electricity system” (currently version 01.1) referred to therein. This ensures that accurate and conservative methods are employed to take account of additional electricity consumption arising from the CCS project activity.

145. Fugitive emissions, including operational or accidental venting across the capture, transport or injection system, must be accounted for by applying a mass balance approach i.e. subtracting the calculated mass of CO_2 injected into Geological Storage Complex from the calculated mass of CO_2 captured from natural gas processing (equation 12). This approach is considered to provide an accurate and conservative means of calculating for any routine or accidental emissions occurring. An alternative would be to adopt an emission factor based approach to estimating fugitive leaks, using similar methods as set out in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5.*

146. However, a mass balance approach is considered to be preferable to an emission factor based approach as the latter is not able to take account of any routine venting that may be required during

pipeline repairs or venting due to any pressure build up in the transport or injection system. A mass balance approach is used in AM0009 "Recovery and utilisation of gas from oil wells that would otherwise be flared or vented" (version 3.3) for the determination of project emissions from venting, leaks or flaring during transport and processing of recovered gas, and is therefore considered relevant for these same purposes within this methodology. In addition, a similar approach has been proposed for calculating fugitive emissions from CCS within the EU's emission trading scheme[11] (BERR, 2007).

147. Several Parties and observers to the UNFCCC have raised concerns that emission reductions achieved by CCS projects may not be permanent because of the potential for Seepage (or storage site breach; UNFCCC 2008a *op. cit.*) emissions to occur in the future, in both in the short, medium and long-term. In the event of Seepage in the long-term (i.e. a very long time after closure of a CCS project and end of the CDM crediting period), it would mean that CERs would have been issued for a CCS project activity, but – due to Significant Irregularities occurring – a proportion of the injected CO_2 would be emitted to the atmosphere (a proportion, as pressure equalisation in a Injection Formation would make it impossible for all injected CO_2 to be released to the atmosphere). The proposed methodology acknowledges this as a risk that would compromise the environmental integrity of the CDM, and outlines an appropriate commercial approach to handle this issue based on accounting for the potential short-, medium- and long-term non-permanence by including Seepage as a source of project emissions as described below.

148. Three main types of analysis to support zero-Seepage assumptions are set out for the development, operation and aftercare phases of project activities: (i) computer simulation and monitoring of CO_2 Migration; (ii) identification and monitoring of Features within the Geological Storage Complex which pose a potential risk to storage security; and (iii) defining Modes of Operation and which avoid triggering processes in the Geological Storage Complex which could create the risk of Seepage.

149. In the *Development* phase of the project activity, the methodology sets down the following requirements (Sub-step 4a):

- To undertake analysis of CO_2 Migration within the Geological Storage Complex. The analysis must provide estimates of storage performance over the short-, medium- and long-term using computer reservoir simulation software packages. These packages should be used to generate dynamic images and data on the fate and behaviour CO_2 in the subsurface according to geological, hydrogeological, geochemical and geomechanical properties in the Injection Formation, and planned CO_2 Stream properties, injection rates and locations. Multiple scenario's must be run adopting variations of key factors including: planned injection design and sensitivities in the geological data. Each must include time-series predictions of the Migration of CO_2 within the Injection Formation (e.g. Migration rate and direction; rate of dissolution in formation water), with attendant estimates of the vertical and lateral boundaries of the subsurface CO_2 Plume over time (based on the point in time/mass of CO_2 injected). Guidance on key issues to consider in designing scenarios and compiling dynamic simulations is provided in Annex A. This requirement is the principle mechanism for compiling *ex ante* estimates of storage security.

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[11] BERR (2007) CO_2 Capture and Storage in the EU Emission Trading Scheme. Monitoring and Reporting guidelines for inclusion via Article 24 of the EU ETS Directive. Report No: R312 BERR/Pub URN 07/1634

- To assess the main geological Features within the Geological Storage Complex. Features may not directly affect CO_2 Migration, however, the analysis will be linked to analysis of CO_2 Migration because site-specific geological, hydrogeological, geochemical and geomechanical properties in the primary geological storage formation will inherently require that such Features are taken into account. Such Features can potentially become emission pathways if conditions in the formation lead to their activation (i.e. inappropriate management of the Geological Storage Complex). Characterisation of the Features allows an understanding of their properties (activation and Seepage risk, referred to as Base-level survey data in this methodology) prior to injection, and to subsequently design appropriate Modes of Operation to avoid their activation. It is also a key element in the design of a Subsurface Monitoring plan to ensure that appropriate technologies are included that can monitor properties of identified Features in the Geological Storage Complex.

- To define appropriate Modes of Operation. Specific characteristics of the Geological Storage Complex, namely Porosity and Permeability, must be measured in order to understand injectivity of the primary storage formation. Formation injectivity is one of the major controlling factors for CO_2 Migration, fate and behaviour, pressure changes in the Geological Storage Complex, and, subsequently, the potential to activate Seepage risk Features. Thus, Modes of Operation must be defined by both the Migration behaviour of the CO_2, the effects on pressure dynamics, and the possible effects that this could have on Seepage risk Features in the Geological Storage Complex. Thus, project participants are required to define safe Modes of Operation, primarily relating to pressure in the Injection Formation, in order to minimise the risk of activating potential emission pathways.

150. Analysis of this type is the primary basis for assessing storage security as it allows the effectiveness of trapping mechanisms in the Geological Storage Complex (physical, chemical etc.) under the assumed Modes of Operation to be assessed, based on analysis of the fate and behaviour of CO_2. It also allows key risk Features in the Geological Storage Complex to be identified and measures put in place to mitigate potential risks by adopting the principle of Avoidance. Such approaches can support zero-Seepage assumptions over the short-, medium- and long-term by only allowing Geological Storage Complexes (with specific Modes of Operation) that indicate long-term secure storage can be achieved to be approved as CCS CDM project activities.

151. Project participants are required to document this analysis in a *Geological Storage Complex Selection & Characterisation Report* prepared in accordance with guidance provided in Annex A. The *Geological Storage Complex Selection & Characterisation Report* must be reviewed and approved by the host country prior to submission – with the PDD – for registration with the CDM EB. In order to supplement the technical competencies of the approvals process, the NM also proposes that a centre of expertise may be engaged to support in the review and approvals process. Centres of expertise can include national geological surveys, university departments, or dedicated CCS specialist centres such as the recently announces Australian Global CCS Institute, the South African National Energy Research Institute (SANERI), and the International Performance Assessment Centre for Geologic Storage of CO_2 (IPAC-CO_2) with its Secretariat based in Canada.

152. During the *Operational* phase of the project activity, the NM sets down the following requirements (Sub-step 4b):

- History-matching of observed and predicted CO_2 Migration. Results of modelling analysis must be compared with observed fate and behaviour of the CO_2 Plume in the subsurface (i.e. monitoring results, a process sometimes referred to as history-matching). In the event of deviations from predicted and observed results, the model geological, hydrogeological, geochemical and geomechanical properties should be recalibrated and scenarios re-run to improve the convergence of results (“history-matching”). This process serves to enhance the understanding of the subsurface. Changes in the Modes of Operation may be initiated in response to Subsurface Monitoring results, where necessary. Convergence of predicted and observed results indicates increasing understanding about the subsurface behaviour of the CO_2, providing greater assurance regarding long-term predictions of secure storage. Equations 13 and 15 outline a methodological procedure that creates a systematic obligation for project participants to undertake this type of analysis during the project. Further guidance for updating monitoring plans, where necessary, is provided in Annex C.

- Monitoring of Features. Features within the Geological Storage Complex (e.g. caprock integrity, faults, fissures, wells etc.) must be monitored and results compared with base-level data in order to determine whether Significant Irregularities are occurring within the Geological Storage Complex. This type of analysis serves to provide early warning signs for potential occurrence of Seepage events, and thereafter, to stimulate responses including actions to remediate irregularities so as to avoid Seepage and update monitoring plans to include any new Features identified during monitoring. Equations 15 and 16 provide a methodological approach to ensure systematic monitoring of the properties of Features and their comparison with base-level data. Significant deviations between observations and base-level data provide indications of significant irregularities. Further guidance is for updating monitoring plans is provided in Annex C.

- Monitoring of compliance with appropriate Modes of Operation. Site characterisation provides the basis for designing appropriate Modes of Operation. As part of appropriate Geological Storage Complex management, key parameters in the Injection Formation must be monitored to ensure compliance with these Modes of Operation. Key to this is the monitoring of pressure in the Injection Formation, and maintenance of pressure levels below those which could activate Features in the Geological Storage Complex which could become emission pathways, thus leading to Seepage. Equations 17 and 18 create an obligation for project participants to undertake systematic review of these factors.

153. Such monitoring activities are vital to support zero-Seepage assumptions that are established through appropriate Geological Storage Complex selection. Monitoring reports prepared for the project activity must include the results of these monitoring activities, and be subject to verification, review and approval prior to issuance. Where significant irregularities are detected, issuance may not be able to proceed until Corrective Measures have been undertaken and further verification, review and approval has been carried out. This provides a means for effective regulatory control of Geological Storage Complex performance.

154. The approach to Geological Storage Complex selection proposed in Sub-step 4a and in Annex A is consistent with scientific and political consensus on the matter. In this respect, firstly the 2005 IPCC Special Report on Carbon Dioxide Capture and Storage (IPCC, 2005; SRCCS) suggests that: “*the fraction retained appropriately selected and managed geological reservoirs is very likely to exceed than 99 percent of the stored CO_2 over 1000 years and may retain it for up to millions of years*”[12]. Within the SRCCS, Figure 5.19 in Chapter 5 describes the information flow across a CCS project’s technical life-cycle, including *“site specific characterisation and assessment”* including characterisation of the geology, numerical modelling, reservoir simulation and risk assessment. These steps are consistent with the guidance provided in Annex A of this methodology. Second, the *2006 IPCC Guidelines for National Greenhouse Gas inventories,*

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[12] Summary for Policy-Makers, page 14.

Volume 2, Chapter 5, (2006 IPCC GLs) suggest that Site Characterisation and Assessment of the Risk of Leakage, the latter through the use of *"..site characterisation and realistic predictive models that predict movement of* CO_2 *over time and locations where emission might occur*" are essential components for a procedure for estimating emissions from CO_2 geological storage sites. It suggests such procedures can: "*...help build confidence that there will be minimal leakage, improve modelling capabilities and results, and ultimately reduce the level of monitoring needed*". Moreover, the method outlined in the 2006 IPCC GLs (§ 5.7.1) implies that a site characterisation report is a pre-requisite for the compilation of a national greenhouse gas inventory that includes CO_2 storage. Such an approach is also supported by the views of most Parties and observers to the UNFCCC, which, in the first synthesis of views (UNFCCC, 2008a, *op. cit.*), broadly concluded that: "*Site characterisation and selection are the most critical elements in ensuring long-term or permanent* CO_2 *emission reductions from CCS, and should provide the basis for ensuring that fugitive emissions, seepage or storage site breach are unlikely to occur. Thus, the main objective of site characterisation is to identify the ability of the geological formation to structurally, physically or chemically trap* CO_2".

155. On this basis, and following the guidance outlined in these documents plus the procedures for the Characterisation and Assessment of Storage Sites outlined in Annex I of the EC's new CCS Directive; this methodology includes in Annex A a procedure for selecting and characterising Geological Storage Complexes in order to significantly reduce the risk of Seepage as described previously. The approach outlined therein should support the compilation of compliant national greenhouse gas inventories employing CO_2 storage and reporting stored CO_2 as not emitted.

156. In terms of expert approvals support, the proposed approach is consistent with approaches outlined in the 2006 IPCC GLs which suggests that "*expert opinion is needed to assess whether the geological and numerical modelling are valid representations of the storage site and surrounding strata and whether subsequent simulations give an adequate prediction of site performance*" (page 5.14). The European Union has agreed similar arrangements for CO_2 geological storage site licensing, by requiring all applications for storage site licenses in the European Union to be reviewed by the Commission with support of a Scientific Panel made up of experts across Europe. Hence, the suggestion of including additional support for approvals from a CGSCoE.

157. In terms of monitoring, Figure 5.19 of the SRCCS (IPCC, 2005) suggests that monitoring should include *"Monitor the mass distribution of* CO_2*; carry out simulation history matching"* and *"Monitor for potential Migration of* CO_2 *outside containment area"*, which equates respectively to the CO_2 Migration and Geological Storage Complex Features monitoring requirements outlined in this proposed methodology. Wellhead and bottomhole pressure is a standard monitoring parameter for different types of subsurface operations (e.g. oil & gas extraction; enhanced oil recovery operations; liquid waste injection), and maximum levels are often limited by regulatory agencies to avoid fracturing of Caprock and Injection Formations (IPCC, 2005). The SRCCS highlights that empirical data have been used to set maximum levels of bottomhole pressure and pressure gradients (in kPa m^{-1}) for specific provinces and basins around the world (§ 5.5.3 and 5.6.2).

158. In addition to the Geological Storage Complex selection and characterisation (Sub-step 4a), and monitoring and management of the Geological Storage Complex (Sub-step 4b), the methodology also sets down monitoring requirements for accounting and quantifying Seepage as a source of project emissions in the event that it occurs (Sub-step 4c). This also includes requirements to make good any such emissions firstly by undertaking Corrective Measures, and secondly through the Compensation procedure described in the methodology to make up for CERs awarded for secure storage. The approach outlined is designed to ensure the integrity of the CDM is maintained

in applying this methodology i.e. by ensuring that net emission reductions from CCS projects are appropriately accounted for.

159. In terms of Seepage quantification, the currently best available knowledge and approach to this is the work undertaken by the UK Government in respect of the EU Emission Trading Scheme monitoring and reporting frameworks for CCS (BERR, 2007). The BERR report is providing the basis for including CCS in the EU's emissions trading scheme, which is likely to be adopted within the next few months. The quantification method adopted in this NM is similar to that developed in this work. Seepage quantification could be an area for further assurance by a CGSCoE highlighted in this methodology.

160. In terms of Seepage emissions over the long-term i.e. permanence, Sub-step 4d outlines a method for handling such concerns. The proposed approach does not involve the application of default factors or discount rates to account for potential non-permanence of emissions reductions beyond the crediting period. Such an approach would only be applicable if Seepage was certain to take place, however, this would contradict the basis for proper Geological Storage Complex selection to avoid Seepage upon which this methodology is predicated[13]. Further, there is no basis upon which to decide these rates, as supported by the 2006 IPCC GLs, which states that: "*…at the time of writing, the small number of monitored storage sites means that there is insufficient empirical evidence to produce emission factors that could be applied to Seepage from geological storage reservoirs*." This implies that such factors cannot be readily developed. Furthermore, as pointed out by the IEA (op cit), discounting the credits would provide no incentive for remediation of leaks (pg. 20).

161. This proposed methodology also does not propose the use of temporary CERs for CCS projects. This is because the time frames and likelihood of Seepage from geological storage of CO_2 is considered to be significantly longer and lower than for those project activities to which temporary credits currently apply, namely afforestation/reforestation projects. For this reason, such an approach is not considered appropriate. Further, as the IEA 2007 (op cit.) has suggested, using temporary CERs would not provide any incentive for avoiding Seepage over the longer term (i.e. post expiry of the CERs), and thus weaken rather than incentivise proper Geological Storage Complex selection, monitoring and remediation, the tenets upon which this methodological approach is based.

162. Thus, this methodology proposes a model of project participant and host country liability associated with Seepage from Geological Storage Complexes developed under this NM. This is based on project participants taking on liability for any Seepage during operational and closure phases, up to a point where Stewardship is transferred back to the host country. Any Seepage emissions must either be subtracted as project emissions or if this is not possible because of net differences in the baseline and project emissions, or the crediting period has ended, then permanent emission reduction certificates must be surrendered in order to Compensate for the balance of the difference.

163. While the approach proposed to handle negative emissions reductions is consistent with existing CDM procedures (from guidance on negative emissions reductions from CDM EB 21, para 18), a more conservative approach may be to impose Compensation requirements for any Seepage emissions (i.e. by not including any allowance for negative emissions to occur). However, this

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[13] See also: Philibert, C. Ellis, J. and Pokanski, J. Carbon Capture and Storage in the CDM. Organisation for Economic Co-operation and Development/International Energy Agency. 2007. page 20

would present a deviation away from current practice and therefore was not adopted in this proposed methodology.

164. The proposed methodology also proposes a framework for Stewardship transfer from project participants to host country, based on the following elements:

- Agreement of Stewardship transfer provisions between project participants and host country, and review by the CDM EB and/or its appointed experts in this field (e.g. a CGSCoE); and,
- The use of financial mechanisms to provide assurance that funds exist to cover the costs associated with any Corrective Measures and Subsurface Monitoring, both during project participant's and host country's Stewardship phases.

165. The provisions outlined are designed to optimise appropriate Geological Storage Complex selection, monitoring and management. They also recognize the constraints on private entities taking on perpetual liability, based on the fact that they are likely to be shorter in life span than sovereign states, and are also under fiduciary duties to manage liabilities on their balance sheets, which presents challenges for taking on open-ended liability. Despite this constraint, the NM sets down obligations for project participants to provide adequate financial support for host countries in fulfilling longer-term liabilities for the Geological Storage Complex by way of the requirement to take out a transferable financial mechanism at project commencement. This shall be transferred to the ownership of the host country (DNA or otherwise designated national regulator) upon Stewardship transfer.

166. Prior to Stewardship transfer from project participant to host country, project participants must prepare a *Site Closure Report* outlining evaluations of long-term CO_2 storage security. This must be based on the site history, and in particular results of history-matching and measures taken to close the site to appropriate standards. Stewardship transfer can only commence upon approval of the *Site Closure Report* by the host country, and subject to review by the CDM and potentially supporting technical expertise. This is designed to ensure that a robust regulatory approach is in place that avoid host countries taking on Stewardship for Geological Storage Complexes with a high risk of future Seepage. No time limit is specified as the approach is *performance based* i.e. the Stewardship transfers when there is regulatory comfort, within reason, regarding the level of risk posed by the storage complex in terms of long-term seepage. This approach allows the length of time for the Closure period to be determined according to site-specific and operator-specific characteristics and competencies. This is designed to: firstly promote best practice in Geological Storage Complex selection so as to minimise seepage risk from the start; and, second to promote best practice in Geological Storage Complex operation, management and Closure procedures.

167. The model proposed is consistent with agreed legislation on the geological storage of CO_2 in the European Union, and approaches proposed by the *World Resources Institute* (WRI) in its CCS workstream. In the case of the former, the CCS Directive Article 18 outlines terms for liability transfer from project participants to EU member state, whilst Article 19 sets out provisions for financial securities. The WRI project is initiating a dialogue on guidelines and recommendations to ensure that CCS projects are undertaken safely and effectively. One of the models they are considering within their dialogues is summarized below (Figure 3). This diagram follows the tenets upon which this methodology is proposed.

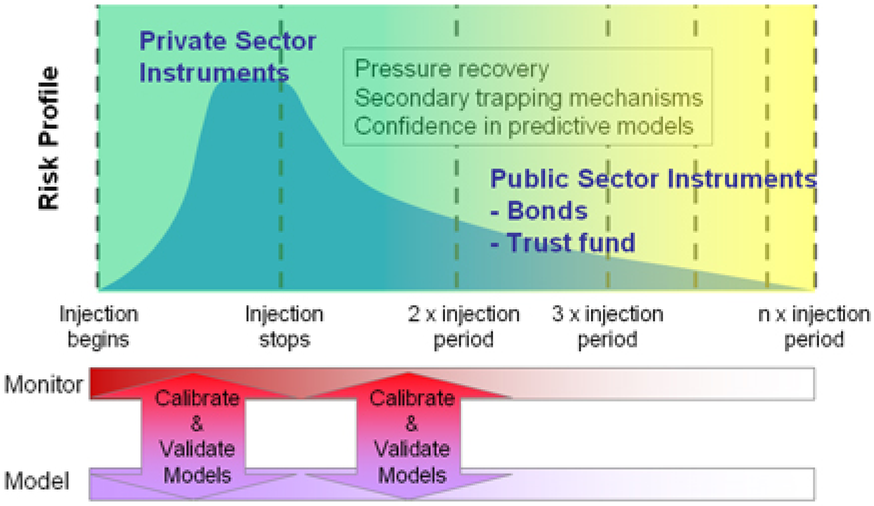

Figure 3 – Conceptual Risk Profile for Carbon Storage[14]

168. The proposed approach is also consistent with approaches to emissions accounting for geological storage of CO_2 outlined in the 2006 IPCC guidelines. The approach outlined therein describes a model for long-term management of a Geological Storage Complex based on: "*Once the CO_2 approaches its predicted long-term distribution within the reservoir and there is agreement between the models of CO_2 distribution and measurements made in accordance with the monitoring plan, it may be appropriate to decrease the frequency of (or discontinue) monitoring. Monitoring may need to be resumed if the storage site is affected by unexpected events, for example seismic events.*" (pg 5.15). This proposal naturally lends itself to consideration of similar terms for Stewardship transfer, which would result in the host country subsequently facing considerably less onerous monitoring obligations compared to that faced by the project participants prior to Stewardship transfer.

169. Similarly, this approach is supported by a number of Parties to the Convention and Kyoto Protocol, as highlighted by the first CCS CDM synthesis report (UNFCCC, 2008a). This suggested that: "*Discounting approaches are not a suitable way of handling permanence*" (pg. 25) and that "*the majority of submissions supported the view that the ultimate liability for any long-term seepage emissions needs to be with the host country...*[because they are most able to ensure the operating conditions of the project and to undertake an necessary remediation, and the long-term nature of projects means that this is the most practical approach]" (pg. 18-19).

170. More generally, three other considerations must be taken into account:

- Firstly, that flexibility is key given that future modifications to this NM could be expected as experience with CCS evolves through development of projects in a variety of geological settings. Again, this view is consistent with that of Parties and observers to the UNFCCC where the synthesis of views concludes that: "*For the most part, Parties and organizations believe that flexibility is required to allow for improvements in knowledge of and experience in CCS, and to accommodate different geological conditions and the distinct storage characteristics thereof, the latter potentially presenting different capacities of different geological formations to isolate CO_2*

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[14] Available at: http://www.wri.org/chart/conceptual-risk-profile-sequestration

from the atmosphere. One organization noted that such differences could also be present within a single geological formation. Most submissions agreed that these differences mean that sound characterisation of reservoirs and good site selection procedures are needed to ensure long-term integrity of storage."

- Secondly, that the proposal is commercially workable. This is considered important because it will be vital to leverage private sector finance if a large proportion of the significant abatement potential offered by CCS technologies[15] will be harnessed.

- Thirdly, it is also important to note that it is impossible for all stored CO_2 to be released back to the atmosphere under nearly any circumstance because pressure equilibrium in a geological storage formation will be reached prior to the release of all CO_2 from the subsurface.

Leakage

171. The authors considered theoretical potential sources of Leakage for this type of project activity, and concluded that the project activity would not give rise to any source of Leakage for the following reasons:

- It is reasonable to assume that demand for natural gas will remain, and there will be no incentive to produce more natural gas in response to the inclusion of these operations as CDM project activities. This is because such activities, whilst increasing overall revenues for gas production due to the sale of generated CERs, are unlikely to significantly offset the costs associated with the project activity; CCS projects are inherently expensive and require advanced technical skills to design, develop and operate. This is means that the revenues from CER sales will have only minor effects on overall project economics, and is also likely to perturb many operators from making such investments. To counter this possibility, for new build projects, the methodology requires project proponents to show the project IRR with and without CER revenues in order to show that the CCS CDM component of the project activity does not have a significant effect on the overall project economics i.e. the gas field project would be developed anyway even without CCS CDM revenues. The aim of the CDM must be to incentivise the incremental investment into CCS technologies in this sector, not the development of high CO_2 gas fields.

- The production of a higher delivery specification in sales gas could lead to higher CO_2 venting production at a specific site, whilst the incentive offered by CCS application could lead to development of higher CO_2 content natural gas fields ahead of lower content ones. To counter this possibility, and notwithstanding the possible case for new build plants applying the same baseline approach as existing plants, the methodology includes conditions which avoid the creation of perverse incentives to either/both modify delivery specifications or incentivise development of high CO_2 gas fields specifically because of the incentive offered by CCS inclusion within the CDM. As outlined previously, the baseline approach also includes consideration of "emissions from a technology that represents an economically attractive course of action, taking into account barriers to investment" when determining the baseline scenario.

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[15] As per the IPCC Special Report on CCS, it is likely that there is a technical potential of at least about 2,000 $GtCO_2$ of storage capacity in Geological Formations (IPCC 2005, Summary for Policymakers, p. 12). The IEA Energy Technology Perspectives (2008) BLUE Map scenario (for a 450 ppm0 stabilisation level) estimates that CCS could contribute 19% of the mitigation effort in 2050 comprising annually 4.8 $GtCO_2$ stored from the power sector and 4.3 $GtCO_2$ from industry and fuel transformation sectors in 2050.

- The proposed NM excludes CCS with enhanced hydrocarbon recovery (EHR), as the consideration of potential leakage from such activities has not been fully undertaken as yet.

172. No other potential sources of Leakage were identified.

Emission reductions

173. In the same way as for other types of CDM project activities, emission reductions are calculated as the difference in baseline and project emissions. Note that CO_2 captured (= Baseline emissions, main source) is not equal to CO_2 avoided (= Emission reductions), as project emissions account *inter alia* for fugitive emissions, additional project emissions related to the utilization of fossil fuel and electricity consumption, and potential Seepage. All potential sources of emissions are included in the calculation of emission reductions and mainly based on direct measurements, which should provide a sound basis for a high level of accuracy.

174. It may be possible to move Sub-step 4d (Permanence) to the section entitled emission reductions, as the permanence issue is related to the efficacy of *emission reductions* achieved over the long-term. However, to maintain continuity with other aspects of Seepage accounting, it is included under the *Project Emissions* section here.

Changes required for methodology implementation in 2nd and 3rd crediting periods

175. The methodology requires that the project participants may need to update the monitoring plan, especially the Subsurface Monitoring plan, on a regular basis through the project Operational and Closure phase, which may correspond to changes in the 2nd and 3rd crediting period. The rationale for this approach is based on the fact that Subsurface Monitoring technologies and approaches are likely to continue to evolve over coming years, and that the monitoring period for the project type will be long. With the proposed provisions, the methodology ensures that a project activity applies the best available knowledge and monitoring approach throughout its lifetime.

Monitoring methodology, including data and parameters not monitored

176. CCS differs from other technologies in that the generation of CO_2 is not avoided but rather its release into the atmosphere is avoided. Consequently, monitoring cannot end at the end of the crediting period as for other CDM project activities, but rather must be continued until available evidence indicates that the stored CO_2 will be completely contained for the indefinite future. On this basis, and given the dynamic nature of the technology (and its development), the methodology differentiates between (i) monitoring of parameters that are 'standard' to the existing project types under the CDM, and (ii) monitoring of parameters that are specific to geological CCS projects.

177. With regard to (ii), a well defined and executed Subsurface Monitoring plan is of crucial importance with regard to both effectiveness of this mitigation option and its acceptance by third parties/ the public. This proposed methodology does not lay down a prescriptive approach (i.e. it does not designate specific monitoring technologies, their location or the frequency of application). Rather it infers to potential ranges of technologies to determine CO_2 Migration behaviour and Features ($M_{CO2,j/k/l,y}$ and $M_{SC,j/k/l,y}$). Specific technologies must be determined on a project specific basis, according to the geological conditions of the planned Geological Storage Complex, and following guidance provided in Annex B. This approach is consistent with the present scientific

consensus on the matter; the IPCC SRCCS states, "*There are currently no standard protocols or established network designs for monitoring leakage* [seepage] *of CO_2. Monitoring network design will depend on the objectives and requirements of the monitoring programme, which will be determined by regulatory requirements and perceived risks posed by the site*" (pg. 241). Additionally, the 2006 IPCC GLs suggest that a range of techniques for Subsurface Monitoring have been developed over the last 30 years, and that: "*the suitability and efficacy of these technologies can be strongly influenced by the geology and potential emission pathways at individual storage sites, so that the choice of monitoring will need to be made on a site-by-site basis*". It also adds that "*Monitoring technologies are advancing rapidly and it would be good practice to keep up to date on new technologies*". Similar approaches are suggested in the EC's CCS Directive, Annex II on establishing and updating a monitoring plan. The proposed methodology is consistent with these perspectives and approaches.

178. Considering this, the methodology provides a clear framework for the establishment of the Subsurface Monitoring plan allowing for consideration of Geological Storage Complex-specific circumstances rather than prescribing specific technologies to be used. This provides the required flexibility to the project participants in developing a Subsurface Monitoring plan for a CCS project activity. At the same time, specific parameters for monitoring are proposed, guidance for preparing monitoring plans (Annex B) is included, and proposed approvals procedures that should ensure robust consideration of proposed approaches are laid down.

179. Apart from the need for Geological Storage Complex specific Subsurface Monitoring plans, the development of new monitoring concepts and technologies for CCS projects must also be considered. This, together with the results of the history matching, provide the basis for updating Subsurface Monitoring plans. In order to assure good execution and updating of the Subsurface Monitoring plan, responsibilities must be defined clearly and assigned within the project participants organization(s).

180. Significant guidance on measurement procedures for Seepage quantification is provided (in relation to the parameter $S_{FLX,k,y,}$ and $S_{t,k,y}$). This guidance has been developed from the approach proposed by BERR (2007), and is considered current best practice on these matters (as described previously).

181. The following outlines the considerations necessary for design of Subsurface Monitoring (based on IEA GHG 2007):

- **"The storage complex specific characteristics of any sub-surface monitoring plan**. Because of the heterogeneous nature of the sub-surface environment, a CO_2 storage activity will need a project specific monitoring plan and implement monitoring technologies tailored to the characteristics of the geology, recognising site-specific identified potential seepage pathways [features];

- **The need to take a risk-based approach**. Different storage complexes have different seepage risk features, based on the nature of the Injection Formation, potential migration pathways within the storage complex and seepage pathways from the storage complex to the surrounding environment, the attendant magnitude of potential exposure, and sensitivity of potential receptors;

- **The range of monitoring techniques available**. There is a wide range of monitoring techniques that are able to detect the presence and vertical and lateral distribution of CO_2 in the sub-surface, migration within the various containment formations within the storage complex and seepage from the storage complex (see Annex B). Many monitoring techniques are presently being refined, while new concepts and applications are under development. Prior to any widespread implementation of CO_2 injection, a monitoring and verification framework must be demonstrated to successfully assess the consequence of seepage for a given storage complex. The monitoring and verification framework should be an integral part of the project's operating philosophy and show clear links to an HSE management system that outlines the mitigation and remediation actions should CO_2 containment mechanisms fail.

- **The frequency of application**. Some techniques may involve continuous monitoring, whilst others may only be periodically applicable. This is dependent on the range of techniques applicable within a given sub-surface environment, their detection thresholds and economic factors;
- **The need for quality assurance and quality control**. Any proposed CO_2 storage complex monitoring plan will require a careful assessment by suitable experts. Sub-surface monitoring is an emerging area of study, and specific worldwide expertise is limited, although oil and gas exploration activities offer some important analogues."

182. Building on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 5, and the 2008 EU Commission's CCS Directive, Annex B of this methodology outlines a framework for Subsurface Monitoring while leaving enough flexibility for the project participants to consider Geological Storage Complex-specific circumstances.

ANNEX A. GEOLOGICAL STORAGE COMPLEX SELECTION & CHARACTERISATION REPORT

A. General Guidance for Geological Storage Complex Characterisation and Selection

1. Appropriate Geological Storage Complex selection is the most important factor in supporting zero-Seepage assumptions and ensuring the long-term secure storage of CO_2 in subsurface Geological Formations. The Geological Storage Complex Selection & Characterisation Report ("the report") is thus a key component in the design of a carbon dioxide capture and storage CDM project activity. It forms an important input to various components of the CDM project cycle, covering:

    - Approval by the Designated National Authority (and its competent bodies) of the host country for the project activity;
    - Validation and Registration with the CDM Executive Board;
    - Verification of monitored emission reductions generated by the project activity, in respect of history matching requirements posed by the methodology; and,
    - Considerations regarding long-term liability and the agreement of an appropriate level of financial security as required by this methodology.

2. Project participants should complete the report following the guidance provided in this document and submit it as an addendum to the CDM project design document for review and by the host country DNA (and its appointed bodies), and validation by a designated operational entity.

3. The report should contain the key findings from subsurface appraisal activities employed following guidance provided in this Annex. The guidance provided herein is designed to support the selection of appropriate Geological Storage Complexes that are able to retain injected CO_2 for very long periods of time – 1,000's to 100,000's of years or more.

4. The selection and characterisation process must take account of the main components of the CDM methodology that relate to the subsurface, namely the requirements outlined in *Step 4* on *Avoidance, determination and quantification of Seepage emissions* through:

    - Analysis of CO_2 Migration, and definition of subsurface project boundaries;
    - Analysis of Geological Storage Complex Features;
    - Defining appropriate Modes of Operation;

    This analysis also provides direct support to project approvals, in particular host country approval, Stewardship transfer, and the establishment of an appropriate financial mechanism.

5. The guidance covers six key components for selection and characterisation of an appropriate Geological Storage Complex for a CCS CDM project activity, as follows:

I. **Introduction:** the name of the Geological Storage Complex and Containment System, and a summary of the planned storage activity;

II. **Screening and Selection:** a review of all potential options for capturing and storing the CO_2 associated with the project activity;

III. **Characterisation:** the steps, criteria and data needs required to appropriately characterise the selected storage option and assess its performance in terms of its suitability for long term secure containment of the injected CO_2;

IV. **Risk Assessment:** identifying and characterising the main Features of the selected Geological Storage Complex that could have an effect on security and Seepage, and potential human and environmental impacts of CO_2 Seepage, and how these have been avoided. It includes consideration for Subsurface Monitoring as part of the overall project risk management measures;

V. **Operating Plan Design:** the proposed basis for design and Modes of Operation for the selected storage option to maximise long-term secure CO_2 storage and minimise the risk of Seepage and damage to human health and the environment;

6. A Quality Assurance and Quality Control procedure is outlined at the end of the Annex which is designed to ensure that effective decision-making has been employed after each stage of Geological Storage Complex characterisation. The procedures outlined there must be followed when preparing the report.

7. Best-practice for Geological Storage Complex selection and characterisation is still an emerging area of scientific and commercial development. The approach outlined here includes the major components for storage site selection and characterisation as broadly agreed by various stakeholders. It also follows an approach which is similar to hydrocarbon asset appraisal. Derogations, deviations and additions from the approach are permissible, and the rationale for such modifications should be elaborated by project participants, drawing on experiences in developing a commercial project.

8. The analysis requirements outlined in this guidance document should only be implemented by specialist teams that include qualified geologists, geophysicists, geomechanics, geochemists and petroleum and reservoir engineers.

B. Specific Guidance for Completing a Geological Storage Complex Selection & Characterisation Report

I INTRODUCTION

A.1 Name of the selected Geological Storage Complex

Please indicate:

(a) The name and location of the Containment System (Injection and Caprock Formation) and Geological Storage Complex

(b) The version number of this report

(c) The date the report was completed

A.2 Problem definition

Provide a summarised problem definition (no more than one page) outlining the main aspects of the planned CO_2 capture and storage activity describing the total mass of CO_2 to be stored, required injection rates (per hour/day/year), and compositional – including changes in composition of the injection stream over time;

A.3 Brief description of the Geological Storage Complex

Provide a brief overview (no more than half a page) describing the appropriately selected Geological Storage Complex for the project activity, highlighting:

(a) the name/number and brief description of the geology of the Injection Formation(s) in which CO_2 is to be injected, its respective Caprock Formation and Overburden;

(b) Injection Formation characteristics (thickness; porosity; Permeability; structure; fluid content; pressure; estimated total storage potential; type of CO_2 trapping mechanism(s));

(c) Features in the Geological Storage Complex (wells; faults; fissures etc in the formation);

(d) other uses of the subsurface, surface conditions and surface activities in surrounding domains.

II GEOLOGICAL STORAGE COMPLEX SCREENING AND SELECTION

B.1 Options identification

A range of options for handling the situation described in A.2 (Problem definition) should be considered at a high-level. Project participants should provide brief descriptions of the various potential configurations for CO_2 capture, transport and storage which could mitigate the emissions associated with the activity and achieve long-term secure storage of the captured CO_2. This could include:

(a) separation of CO_2 at the wellhead and reinjection at each field associated with the project activity (if applicable);

(b) separation at an alternative location after shipping with CO_2 content in the gas;

(c) centralised separation of CO_2 from natural gas from several fields (if applicable);

In terms of Geological Storage Complex identification in early stages of project design, sufficient basin wide data should be acquired which allows for screening of Geological Storage Complexes that exhibit the presence of the components that support CO_2 storage (Injection Formation, Caprock Formation, structure). The process should also provide indications of available data and knowledge gaps, so as to provide initial ideas on data acquisition needs/appraisal activities (e.g. seismic surveys, test wells etc.) and studies.

B.2 Options evaluation and selection

Options identified in B.1 should be evaluated against the following criteria to test for their suitability for CO_2 capture, transport and storage:

(a) **Geological considerations:** assess the availability of suitable Geological Storage Complexes. This can be achieved by undertaking a broad basin-wide screening process to identify geological components that indicate potentially appropriate CO_2 storage (e.g. Injection Formation, Caprock Formation, structure) and macro-level risk Features (e.g. potential for induced seismicity or active tectonic regime);

(b) **Technical considerations:** assess whether the potential configuration within each option is technically feasible (e.g. storage capacity required/available; number and location of injection wells; injection pressures achievable with available compression and pipeline construction; length of CO_2 pipeline required) and whether further data acquisition will be achievable;

(c) **Legal and regulatory considerations:** assess whether the potential Geological Storage Complex option would be allowed under local legal and regulatory regimes (e.g. local laws on potable aquifer protection; pipeline rights of way etc.);

(d) **Economic considerations:** assess whether the project is economically viable in terms of surface configuration, data acquisition needs, and also in terms of competing users of the subsurface and other subsurface interests (e.g. the cost of connecting the CO_2 source to Geological Storage Complex; cost of further data acquisition compared to initial potential; presence of wells etc; subsurface users such as mining, hydrocarbon extraction and potable water supply) ;

(e) **Environmental, health and safety considerations:** assess whether the storage site could pose a potential threat to any sensitive ecosystems or human populations or have access challenges for development and maintenance (e.g. indicative issues could include location of national parks; red list species or important fisheries or cetacean feeding grounds; conurbations overlying the Geological Storage Complex etc.)

Options evaluation should be compiled in Table A.1. with the option(s) passing all criteria highlighted taken forward for further characterisation.

Table A.1. High-level storage options evaluation and selection

Option	**Criteria**					**Select?**
	Geological	**Legal and Regulatory**	**Technical**	**Economic**	**Environment, health and safety**	
Option A						Yes/No
Option B						Yes/No
Option C						Yes/No
....						....

III GEOLOGICAL STORAGE COMPLEX CHARACTERISATION

Selected option(s) from the high-level screening exercise should be taken forward for further characterisation and analysis to assess suitability for long-term secure storage of CO_2 through application of the following steps:

(a) Storage Characterisation

(b) Performance assessment

(c) Sensitivity analysis

Employing these steps will allow for potential Geological Storage Complex option(s) to be screened for capacity, injectivity, life-cycle containment criteria, and acceptability of the proposed CO_2 source.

C.1 Storage Characterisation

Following the guidance outlined in the next sections, project participants should outline the data acquired to determine the key characteristics of the selected Geological Storage Complex option(s). These data are the building blocks for determining the suitability of the Geological Storage Complex for long-term secure storage of CO_2. Sources of data for storage characterisation – including data acquisition activities – should be documented. These could include *inter alia*:

- Geological maps and mapping activities;
- Seismic data and reports, including seismic acquisition;
- Well core analysis, including details of any test wells drilled;
- Analysis of drill cuttings;
- Well logs;
- Well tests; etc .

Data collected in this phase of the activity must be sufficient to allow for performance assessment studies to be undertaken, as described below.

Geological Storage Complex geology, geophysics and geochemistry

Provide data and information on the following intrinsic geological and geophysical criteria and underlying properties in the Geological Storage Complex and Overburden (where applicable):

(a) **Regional geology:** geological description of the Injection Formation, Caprock Formation, other Containment Systems, Geological Storage Complex and Overburden, paleogeography, stratigraphy, age, and formation fluids;

(b) **Geophysics, geomechanics and geochemistry:** physical characteristics of Injection Formation (e.g. depth, structure, thickness, spill-points) and any secondary Containment Systems and Features in the Geological Storage Complex. Pressure and temperature conditions. Mineralogy of the Injection Formation;

(c) **Formation fluids and Hydrogeology:** information on formation fluids, properties, presence of hydrocarbons and CO_2, including evaluations of groundwater flow conditions and the presence and distribution of potable groundwater in proximity of the Geological Storage Complex;

Derogations from one or more of the underlying properties are permitted so long as characterisation and performance assessment indicates that under the proposed Mode of Operation there is no significant risk of Seepage and that no significant negative environmental or health impacts are likely to occur.

Containment and Features identification

Provide information on key Features within the Geological Storage Complex(es) that could have an impact on storage security and Seepage. Such Features include:

(a) **Existing and future wells etc:** presence and condition man-made Features which could provide pathways for CO_2 Migration and Seepage (e.g. wells, boreholes, deep mines);

(b) **Caprock/seal:** presence, condition and regional continuity of the Containment System (Injection Formation and Caprock Formation);

(c) **Faults and fractures:** presence, condition and location of natural Features which could provide pathways for CO_2 Migration and Seepage, including faults, fissures, spill-points (physical traps);

(d) **Lateral boundaries** i.e. controlling factors on lateral CO_2 Plume Migration such as structural spill points, faults, hydrodynamics etc.

(e) **Seismicity:** assessment of regional seismicity, covering the potential for tectonic activity in the region and the potential to induce fault movement through injection activities.

Inferences of the potential emission pathway (surface connectivity) from a particular feature should also be documented (e.g. the scope for Seepage into overlying strata with remote connectivity to the surface). In the context of a storage project, ‘existing’ wells mean pre-existing wells that have been either abandoned or suspended or remain in operation. Wells are considered to have significant risk of Seepage for the following reasons:

- Annular pressures are common phenomena in oil field operations throughout the world. The likelihood of communication and flow, even through long sections of well bores may be significant, but can be adequately managed by adopting good oil-field practices;

- There is limited industry experience with abandonment of wells for extended containment periods or with follow-up, long term monitoring to assure sustained integrity, and hence the need to identify wells as key Seepage risk Features;

Features should be documented in a risk register as described in *Section IV Risk Assessment*.

Base-level survey data acquisition should also be carried out in accordance with Section III in Annex B.

Surrounding domains

The following characteristics of the potential Geological Storage Complex(es) should also be documented:

(a) Domains surrounding the Geological Storage Complex that may be affected by the storage of CO_2 in the Geological Storage Complex;

(b) Population distribution in the region overlying the Geological Storage Complex;

(c) Proximity to valuable natural resources (including but not limited to potable groundwater and hydrocarbons);

(d) Possible interactions with other activities (e.g. exploration, production and storage of hydrocarbons, geothermal use of aquifers);

(e) Proximity to other potential CO_2 source(s) (including estimates of the total potential mass of CO_2 economically available for storage). This can provide an indication of the long-term potential offered by development of the Geological Storage Complex in addition to the single CDM project activity.

In order to allow for a comprehensive risk assessment the surface and near surface environment should be characterised with regard to:

- Terrestrial environment (e.g. topography, soils and sediments, surface water bodies etc.)
- Human behaviour (e.g. land and water use, community characteristics, buildings etc.

Base-level survey data acquisition should also be carried out in accordance with Section III in Annex B.

C.2 Performance assessment

Characterisation studies undertaken in section C.1 must be used to compile an assessment of storage performance based on evaluation of the Injection Formation trap, geological analysis, and reservoir engineering and modelling assessments of containment performance and geochemical Migration modelling within the Geological Storage Complex(es). This shall be undertaken through the compilation of static (volumetric) and dynamic three-dimensional (3-D) computer earth models that include the Caprock Formation and the surrounding Containment Systems and hydraulically connected Features and domains. Constructed models shall be used to undertake computer simulated assessments of CO_2 Migration following injection into the Geological Storage Complex, and performance assessment over a variety of times-scales, including near- and very long-term (>1,000 years+; see below). These shall be used to determine the following Geological Storage Complex characteristics:

(a) Capacity estimates

(b) CO_2 Migration analysis (and pressure distribution)

(c) Features analysis

Uncertainty associated with each of the parameters used to build models shall also be assessed by developing a range of scenarios and sensitivities for each parameter and calculation of the appropriate confidence limits. Any uncertainty associated with the model itself should also be assessed.

The model or set of models and the sensitivity analysis used by the project participants must be approved by the host country DNA (and/or competent authority appointed by the DNA) and be subject to review and comment by the CDM EB, its panels and possibly by a CGSCoE.

Storage capacity estimation

Computer simulation should be undertaken which can facilitate estimations of the volumetric capacity of the selected Injection Formation. Results of such analysis should be documented, and include:

(a) Estimates of total effective storage capacity (volume/mass) of CO_2 in the identified Injection Formation. This analysis should take account of planned injection rates, pressure volume behaviour over time within the Geological Storage Complex, formation geometry (shape and size of trap), pore space volume, and economically viable well count and trajectory;

CO_2 Migration analysis

Building on volumetric capacity estimations undertaken, assessments should be made of CO_2 Migration/transport behaviour and trapping mechanisms over time and/or injection mass using dynamic computer simulation models (i.e. CO_2 fate and behaviour assessments). Injection mass as well as time should be included to allow for post-injection comparison of predictions when injection rates are different to those employed in modelling. This should show that the structure and stratigraphy (the caprock/seal entry pressures and Caprock Formation geometry effects) of the primary Containment System should constrain upward Migration through buoyancy (physical trapping). As the injected CO_2 migrates, residual gas will be left behind and immobilised as the CO_2 Plume migrates through pore space, with some components of the gas dissolving in formation waters (residual/solution trapping). This further attenuates mobile volumes with potential mineral precipitation fixing a further proportion of the injected gas (mineral trapping).

The nature of CO_2 Migration means that assessments must take an integrated approach that is able to assess the continuity/sustainability of CO_2 injection in terms of whether the injection rates and well design can be sustained over the life-cycle of the project activity. Analysis should account for the following aspects:

(a) **CO_2 Stream injection rates and composition:** operating envelopes for injection covering volumes and pressures, and assessment of changes in formation fluid chemistry following CO_2 injection (e.g. pH change, mineral formation) and subsequent reactions;

(b) **Injection Formation injectivity:** assessing Permeability and Porosity, including where possible under reactive flow conditions by including geochemistry effects (CO_2 mineralisation and dissolution rates) and geomechanics (pressure conductivity, pore space attenuation, formation fracture properties, formation compartmentalisation) and time dependent estimates of pressure distribution in the Geological Storage Complex;

(c) **Short-term near-well bore impairment:** this may occur whilst injecting CO_2 under certain Injection Formation/brine conditions, restricting injection rates;

(d) **Ultimate constraints on injectivity:** assess respective constraints imposed on CO_2 injection by fracture propagation pressures, fault reactivation pressures, caprock capillary entry pressures, fluid displacement etc. These may require specific additional data acquisition programs and modelling capabilities that may extend beyond standard present oilfield practices;

Best practice can involve the use of **coupled process modelling**, which can model the way various single effects in the simulations interact, and **reactive process modelling**, which can model the way reactions of the injected CO_2 and other compositions with *in situ* fluids and minerals feedback in the simulations, to the extent possible with existing technology and at reasonable cost.

Reservoir homogeneity/heterogeneity, compartmentalisation, fluid displacement and reactive effects will all impact long-term injection sustainability, although there is inherent uncertainty about the precise nature of these aspects until injection commences and throughout the initial injection period. Over time, monitoring the CO_2 Plume Migration and behaviour will provide a better understanding of the subsurface geology, structure and other characteristics of the Containment System, thus reducing these uncertainties. The requirement to review initial findings with monitoring results is systematically included within the methodology, as described in *Sub-step 4b* and in *Annex C*.

The results of CO_2 Migration modelling should be able to provide initial time-series predictions of the subsurface lateral and vertical boundaries of the injected CO_2 Plume(s) from injection wells reflecting future points in time in the project life-cycle (operational and aftercare phases and over the very long-term). These should also be cross-referenced with the corresponding total injected CO_2 mass at the given point of time to arrive at sets describing parameter $PB_{CO2,V/L,p,t}$. Typical time-series might cover 5, 10, 15, 30, 50, 100, 500 and 1,000 and 10,000 year estimates of pressure distribution, CO_2 Plume Migration and CO_2 fate and behaviour. Outputs will include graphical depictions generated from model simulations.

During the project, outputs from simulation shall be compared with observations of CO_2 Plume Migration compiled during monitoring (history-matching), and simulations shall be updated where monitored data provides additional information about the nature of the subsurface Geological Storage Complex (e.g. compartmentalisation, flow etc.; see Annex B, Section IV). This shall be used to fulfil methodological *Sub-step 4b – Monitoring and management of the subsurface Geological Storage Complex.*

Features and processes analysis

Identified containment and risk Features should be analysed to determine their properties, to identify processes (or ‘events’) which could activate them as Seepage emission pathways, and establish appropriate Modes of Operation to avoid activation. This should include an analysis of:

(a) **Existing and future wells (at all depths):** construction and completion characteristics, including resistivity to CO_2 corrosion/dissolution of wellbore cements. Particular focus should be given to existing wells in order to test their integrity;

(b) **Faults and fractures:** pressure-driven processes including fault propagation pressures (FPP), fault reactivation pressure (FRP); fault valving pressure (FVP) and fracture sealing rates. Note that reservoir stimulation through controlled fracture prior to injection should not be prohibited, provided that the caprock is unaffected;

(c) **Caprock Formation properties:** pressure-driven processes including caprock fracture pressure and caprock capillary entry pressure (CEP). Dissolution of the caprock (local or extensive);

(d) **Lateral boundaries:** conditions under which spill-points might be exceeded (e.g. over-filling or injection rates in excess of CO_2 Plume Migration rates) or estimates of ultimate lateral distribution of CO_2 exceeded (in open-ended containment formations), incorrect reservoir engineering estimates (e.g. compartmentalisation; baffles etc) that could reduce storage capacity, and/or incorrect interpretation of dip and flow in the Injection Formation (leading to Migration into unknown areas). This could result in CO_2 migrating into poorly characterised areas or into the domain of other subsurface users;

(e) **Formation fluids:** displacement and potential mobilisation of minerals;

(f) **Seismicity:** induced seismicity due to deformation of the Overburden;

Information should be used to determine safe bottomhole injection pressure operating envelopes within the Geological Storage Complex (used to determine $P_{PC,SL}$), and for compiling a risk register as described in *Section IV Risk Assessment*.

Determining a safe operating pressure envelope for a specific primary containment operation needs to account for the four key pressure-governed processes identified (FPP, FRP, FVP, CEP), as well as technical limitations of compressor discharge pressure and injection well count. It is important to note, however, that in CO_2 injection operations these pressures may not remain constant over time. Therefore, each pressure should be considered to consist of two terms:

- A ‘standard’ evaluation term under initial conditions i.e. before the injection of CO_2;
- A ‘delta’ term that represents the time dependent change in these pressures resulting from reactive flow and reactive transport under dynamic injection conditions.

This can be summarised for each constraining pressure as:

$$P_{x,y,z} = P_{x,y,z} + \Delta P_{RF,t} \quad \textbf{(21)}$$

Where,

$P_{x,y,z}$ = Initial pressure conditions at point *x/y/z* before injection of CO_2
$\Delta P_{RF,\, t}$ = Change in pressure at point *x/y/z* resulting from reactive flow and reactive transport under dynamic conditions at point in time *t*

Unidentified risks (e.g. faults, fractures or wells not identified during characterisation) will also need to be considered during Geological Storage Complex monitoring activities.

C.3 Sensitivity analysis

Multiple simulations should be undertaken, drawing on estimates of uncertainty in the subsurface interpretation, to identify the sensitivity of Geological Storage Complex characterisation and *Performance Assessment* to assumptions made about particular parameters. The simulations shall be based on identifying and applying sensitivities to key parameters in the static geological earth model(s), and varying rate dependent functions and assumptions in the dynamic modelling exercise (scenarios).

Any significant sensitivity shall be taken into account and incorporated in the *Risk Assessment*.

IV RISK ASSESSMENT

Risk assessment involves the analysis of the combination of Features, events and processes that could lead to Migration outside of expected CO_2 Plume boundaries and resulting Seepage. Risk is assessed by understanding the characteristics of CO_2 Plume Migration and the Features of the Geological Storage Complex identified during Storage Characterisation, estimating the likelihood of certain processes occurring based on Performance Assessment modelling work, and their potential magnitude and consequences under certain ‘events’ (scenarios). The main components of the risk assessment include:

(a) **Hazard characterisation:** identified hazards are those combinations of identified Features and analysed processes within the Geological Storage Complex which could potentially lead to a loss of CO_2 containment. These should be same as the Features and processes identified during *Performance Assessment* (there is no need to repeat the analysis in this step). Results of findings should be summarised in an *Initial Risk Register* following the template outlined in Table A.2;

(b) **Scenarios and sensitivities:** expert judgment should be used to estimate the likelihood of certain combinations of Features and processes occurring, which should be built into a range of scenarios with attendant sensitivities for individual parameters. The scenario’s and sensitivities should be simulated in the reservoir model;

(c) **Consequence analysis:** *Performance Assessment* modelling should be used to simulate scenario’s that exceed the key parameters associated with each characterised hazard in order to gain an understanding of the uncertainties in key parameters and potential effects of inappropriate operation of the Geological Storage Complex (i.e. forced Seepage should be modelled). Data on surrounding domains must be used to assess possible impacts of Migration and/or Seepage;

(d) **Risk management:** measures to be taken to mitigate the risk of certain events happening (this includes monitoring to identify whether processes are occurring within given Features as described in Annex B)

Results of the analysis should be compiled into an *Initial Risk Register*, summarizing the Features/hazards, the events (scenarios) which could trigger their activation (and the conditions there under i.e. the sensitivities) and the potential consequences.

D.1 Scenario's and sensitivities

Provide a description of events (or scenarios) that could lead to a Significant Irregularity, including Migration outside of agreed project boundaries or Seepage, in order to characterise risks associated with the CO_2 injection operation. This should include:

- Consideration of different combinations of processes that could lead to activation of Features (scenario's);
- Expert assessment of the factors/parameters (sensitivities) employed to asses such effects; and,
- An assessment of the probability of the injected CO_2 intersecting with identified Features, or the probability of the Features intersecting the compartments in which CO_2 is injected (based on modelled CO_2 Plume Migration and Features and the sensitivity analysis).

Where possible, the effects of scenarios should be simulated in the computer reservoir model and include model runs involving Modes of Operation which could lead to Seepage/storage site breach (e.g. unforeseen reservoir compartmentalisation; overfilling; excessive injection rate(s); over-pressuring of the reservoir). Results should be documented in terms of Seepage locations and potential flux rates (in $tCO_2/m^2\ hr^{-1}$).

Identified scenarios and sensitivities should be summarised in an *Initial Risk Register* following the template outlined in Table A.2.

D.2 Consequence analysis

The results of the risk assessment (hazards and scenario analysis) should be used to support the development of an impact assessment for the proposed CCS project activity, covering the following sensitivities in Surrounding Domains:

(a) **Hydrosphere sensitivities:** possible communication and contamination affecting water extraction e.g. for potable, agricultural or industrial uses;

(b) **Biosphere/hydrosphere sensitivities:** possible flora and fauna that could be impacted;

(c) **Atmospheric sensitivities:** such as releases of toxic material.

Where sensitivities are identified, further analysis should include the following:

(a) **Exposure assessment:** based the potential behaviour and fate of seeping CO_2 from Features and the characteristics of the surrounding domains, including other users, distribution of flora and fauna and of human population above the Geological Storage Complex;

(b) **Effects assessment:** based on the sensitivity of particular species, communities or habitats linked to potential Seepage events (locations and flux rates) identified. Where relevant it shall include effects of exposure to elevated CO_2 concentrations in the biosphere (including soils, marine sediments and benthic waters (asphyxiation; hypercapnia) and reduced pH in those environments as a consequence of seeping CO_2). It shall also include an assessment of the effects of other substances that may be present in seeping CO_2 Streams (either impurities present in the injection stream, mobilised through injection, or new substances formed through storage of CO_2). These effects shall be considered at a range of temporal and spatial scales, and linked to a range of different magnitude Seepage scenarios.

Identified potential consequences should be summarised in an *Initial Risk Register* following the template outlined in Table A.2.

D.3 Risk management

Risk management comprises four components to minimise the risk of Seepage and damage to human health and the environment, covering:

(a) **Avoidance:** ensuring that sufficient spatial and temporal separation exists between the Geological Storage Complex and identified and characterised Seepage risk Features/ processes and sensitive surrounding domains. Thus, a degree of confidence that the areal extent of the CO_2 Plume and the 'CO_2 Plume separation margin' is sufficient to avoid potentially sensitive domains and other uses to the maximum extent possible is required. Given the uncertainty about the long-term performance of wells, avoidance and separation by distance of intersecting or nearby existing wells, future wells and future field developments will be important considerations for the design of the Geological Storage Complex. However, this requires a balance to be struck between the principle of Avoidance and data acquisition needs where well data is required to reduce uncertainty regarding the suitability of the Geological Storage Complex in the first instance. Thus risk management will also play an important role in minimising Seepage from wells. This could entail re-entering and re-plugging wells prior to injection to ensure integrity.

(b) **Management:** ensuring that appropriate Modes of Operation are established to avoid activating Seepage Features which could become Seepage pathways to the surface and surrounding domains. This includes design considerations in the *Development* phase (e.g. planned injection and production wells count and design; tubular connections; materials selection; cement integrity; well trajectory planning and zonal isolation, in particular best-in-class cementing practices), risk management measures (such as re-entering and re-plugging existing wells) and *Operational* considerations (maximum tolerable injection pressures; monitoring);

(c) **Monitoring** (detection and surveillance): in order to detect early signs of irregularities (e.g. unintended/unanticipated CO_2 Plume Migration; Feature activation), determine their significance, and implement measures to mitigate the effects (remediation). Monitoring will also involve Seepage quantification if necessary. The procedures for design and updates of monitoring plans is described in Annex B.

(d) **Secondary containment:** an assessment of any additional subsurface Containment Systems present within the Geological Storage Complex. This introduces an enhanced safe-storage concept with increased operating safety margins that is analogous to an engineered storage system such as an oil storage tank farm. In subsurface terms this may mean a primary Geological Storage Complex with primary Caprock Formation with additional containment potential provided by subsequent (non-sensitive) Containment Systems or through extensive connected pore-space that allows attenuation (in open-ended formations). These additional Containment Systems (secondary, tertiary etc.) are safety features designed in such a way that Migration across the boundaries of the Injection Formation does not lead to Migration of injected CO_2 to areas with known Features that could have connectivity to the atmosphere/hydrosphere (i.e. Seepage pathways).

Containment risk management should be first weighted towards mitigation by Avoidance, by minimising potential exposure to other wells and by reduction in the number of puncture points. It is subsequently followed up rigorously by best-in-class well design, construction and operational excellence.

Identified risk management measures should be summarised in an *Initial Risk Register* following the template outlined in Table A.2.

Table A.2 Initial Risk Register for Planned Geological Storage Complex

	Feature	**Process**	**Consequence**	**Risk management**
Feature j	Provide a description of the feature as identified during data collection. Include a description of its location and characteristics.	Provide a description of the potential scenarios that could lead to certain process occurring and the sensitivities/critical parameters driving potential Migration or activation of a feature as a Seepage pathway (e.g. maximum pressure in the reservoir; maximum injection rate/fill volume). Provide a summary of the outcome of the process in terms of Migration direction, rate and/or flux rate for a given feature/process)	Provide a summary description of the consequence of identified (e.g. lateral Seepage beyond the boundary of the eastern spill point of the Injection Formation).	Describe risk management measures to be employed (e.g. how the feature has been best avoided through separation distance). Describe the means by which the feature and/or process may be monitored (e.g. include observation well at point XX).
Feature k				
Feature l				
Feature …				

QUALITY ASSURANCE AND QUALITY CONTROL

The decision-gates described in Figure A.1 below should be applied to the data and modelling exercise throughout. The tests must be carried out by different bodies in the following order of priority:

(a) Project participants

(b) Host country DNA/regulator

(c) DOE at validation stage

(d) CGSCoE

It is important to note that the technical maturity of any estimates of storage security and risk follow a structured progression. Confidence in long-term containment increases progressively through:

(a) Early, simple lab-work and models using analogues and regional data interpretations;

(b) More representative core tests in ‘in-situ’ conditions;

(c) Sophisticated numerical geo-mechanical, geochemical and flow modelling;

(d) Further well-related appraisal activity and/or testing for containment-critical data;

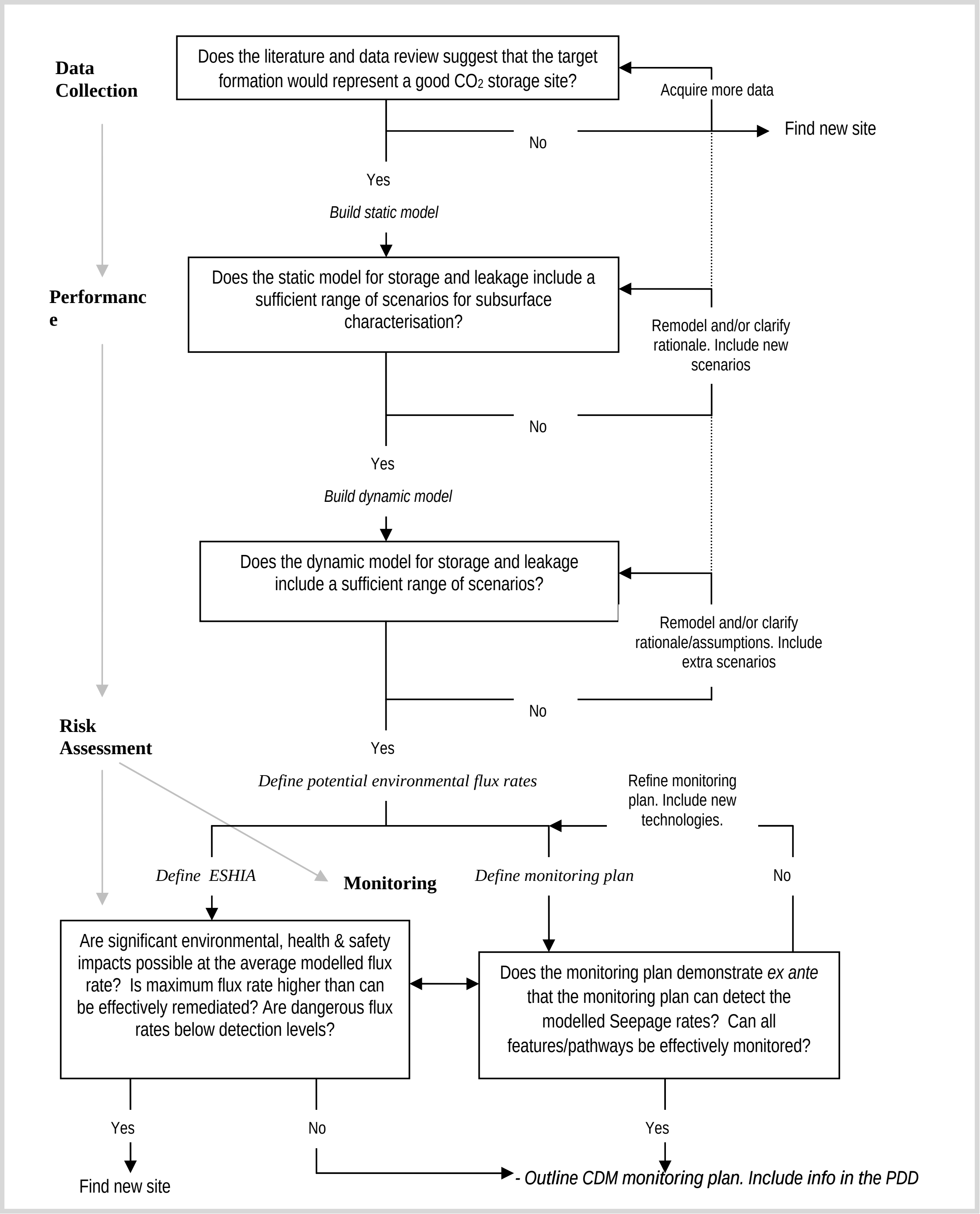
(e) Additional data gathering and baselining (e.g. 3D seismic, new wells);

(f) Intensive monitoring during early injection operations;

(g) Repeated monitoring and continually updating models and predictions (history-matching and adaptive learning).

Fundamentally, the timeframe required to confidently deliver a CO_2 injection and containment solution, depends on the early availability of quality information and the ability to consider both depleted oil and gas field and saline aquifer storage options. Updating of reservoir simulations based on monitored data, and subsequent updating of monitoring plans (techniques; locations; frequencies) is also critical, as described in Annex B.

Figure A.1 Quality assurance and quality control for Geological Storage Complex selection



VI GEOLOGICAL STORAGE COMPLEX OPERATING PLAN DESIGN

In the first instance, following the QA/QC procedures outlined in Section V project participants should confirm that the geological, technical, and environmental health and safety considerations do not preclude the use of the Geological Storage Complex for the long term containment of CO_2.

Subsequently, based on *Storage Characterisation*, *Performance Assessment* and *Risk Assessment* studies undertaken, an injection plan should be developed covering the basis for design and Modes of Operation of the following aspects of the Geological Storage Complex development:

(a) **CO_2 supply:** CO_2 Stream supply rate (m^3 hour, day and year), pressure and composition (including isotope analysis so as to support 'fingerprinting' during monitoring), based on the design of the above ground facilities for gas supply (CO_2 removal efficiency and compression operations), date of first gas and injection commencement;

(b) **Well design:** number of wells, locations, depth, trajectory (vertical/deviated/horizontal), type (injection/observation) and materials selection. Based on the injectivity of the Injection Formation(s), potential heterogeneity and compartmentalisation, and risk management considerations (maximum injection rates and pressures; Migration rates and flow direction etc.);

(c) **Modes of Operation:** maximum injection rate and operational bottomhole pressures ($P_{PC,OL}$) for each well must be determined and described. Based on injectivity of the Injection Formation and fracture pressure of the Caprock Formation and the outcomes of risk assessment;

(d) **Monitoring:** description of any penetrations or engineering needs linked to monitoring design (e.g. observation wells; permanent seismic arrays);

(e) **Contingency measures:** consideration of further field development options in the event that the proposed development plan needs modification following the commencement of injection operations (e.g. additional well locations in the event of injectivity problems or to manage pressure distribution in the subsurface);

(f) **Closure:** estimated dates for well-shut-in and abandonment. Indications of Closure measures and provisions to be carried by the operator following the cessation of injection operations. Provide an indication of the anticipated trapping mechanisms that will take place, and the time scale in which they might occur.

Information outlined in this section of the report shall form the basis for design of the project during Development, Operation and Closure. Deviations from the proposed project Geological Storage Complex Operating Plan must be submitted for approval by the host country DNA/ regulator and the CDM Executive Board as addendums to this report.

Modifications during the Operational phase of the project activity must be notified to the host country DNA/ regulator, and submitted as addendums to this report along with project Monitoring Reports.

ANNEX B. GEOLOGICAL STORAGE COMPLEX MONITORING PLAN DESIGN

A. General Guidance for Geological Storage Complex Monitoring Design

1. Appropriate Subsurface Monitoring the most important method for assessing CO_2 storage performance in Geological Storage Complexes. Subsurface Monitoring serves three main purposes:

   (a) **Risk management:** to detect early warning signs of Significant Irregularities (including unanticipated Migration and/or Seepage emissions) and to activate Corrective Actions that may be put in place to bring the irregularity under control where necessary;

   (b) **History-matching:** validation and verification of *Performance Assessments* in the short term to provide information on the long-term fate and behaviour of CO_2 Plume. This can include the provision of information on any necessary revisions to the Subsurface Monitoring plan to include additional or new techniques, locations and/or changes to the frequency of application in order to better to confirm secure containment and detect Significant Irregularities; and,

   (c) **Accounting:** in order to quantify and compensate for any Seepage of CO_2 to the atmosphere.

2. These all serve to provide regulatory and public confidence in CO_2 geological storage activities. Without fulfilling these aims project participants cannot be considered to act as a responsible operator, and is unlikely to run a well managed Geological Storage Complex. Subsurface Monitoring is therefore an important input to host country approval of the project activity, its validation, registration, and verification.

3. Subsurface Monitoring activities must be risk-based, and designed according the to the initial risk register developed in the *Geological Storage Complex Selection & Characterisation Report*. This should inherently link to the main components of the CDM methodology relating to the subsurface, namely the requirements outlined in *Step 4* on *Avoidance, determination and quantification of Seepage emissions* through:

   - Monitoring of CO_2 Migration, and definition of subsurface project boundaries;

   - Monitoring of Geological Storage Complex Features;

   - Monitoring appropriate Modes of Operation;

   Subsurface Monitoring can also include direct monitoring of surface and near-surface sensitive domains surrounding to the Geological Storage Complex (Geosphere, hydrosphere, biosphere and atmosphere).

4. Subsurface Monitoring is only useful if results can be calibrated against agreed base level conditions. Therefore, base level survey data must be collected prior to commencing CO_2 injection operations, guidance for which is described below.

5. The guidance covers the three main components for designing an appropriate Geological Storage Complex monitoring plan for a CCS CDM project activity and report, covering:

I. **Introduction:** the name of the Geological Storage Complex and Injection Formation to which the monitoring plan applies, and a summary of the planned monitoring activities;

II. **Monitoring plan design and implementation:** identifying the specific techniques which can monitor CO_2 Migration, Features, and Modes of Operation in the Geological Storage Complex. Techniques for monitoring surrounding domains should also be identified and described in terms of location and frequency;

III. **Base-level survey:** measurements of background readings prior to injection as required for the calibration of monitoring results from certain techniques;

6. The Quality Assurance and Quality Control procedure outlined at the end of the Annex A presents an integrated QA/QC approach to storage characterisation and the design of the Geological Storage Complex monitoring plan (Figure A.1). The procedures outlined there must be followed at each stage of preparing a Geological Storage Complex Monitoring Plan Report.

7. Project participants are required to complete the each section of the report and submit it as an addendum to the CDM project design document for the project activity for review and by the host country DNA (and its appointed bodies), and validation by a designated operational entity. Specific monitoring techniques determined following this guidance should be described in detail in the CDM project design document, Section B.7.1.

8. During implementation, monitoring reports should be prepared in accordance with the guidance provided in Annex C of this methodology: Monitoring Reports and Updating Monitoring Plans.

9. It is important to note that Subsurface Monitoring technologies are evolving rapidly as experience with different techniques at existing CO_2 storage projects takes place. Consequently, the guidance provided here should be regularly updated to reflect the evolution in learning.

10. The analysis requirements outlined in this guidance document should only be implemented by specialist teams that include qualified geologists, geophysicists, geomechanics, geochemists and reservoir engineers.

B. Specific Guidance for Compiling a Geological Storage Complex Monitoring Plan

I INTRODUCTION

A.1 Name of the selected Geological Storage Complex

Please indicate:

(a) The name of the Geological Storage Complex and Injection Formation to which the monitoring plan applies

(b) The version number of this report

(c) The date the report was completed

A.2 Brief description of the monitoring plan

Provide a brief overview (no more than half a page) describing the base level data collected and the main techniques to be employed for Subsurface Monitoring.

II MONITORING PLAN DESIGN AND IMPLEMENTATION

Subsurface Monitoring plan design and implementation consists of the process for selecting various monitoring techniques, locations, and frequencies of application. The monitoring plan should adopt a risk-based approach to its design. The risk assessment compiled for the Geological Storage Complex (described in Annex A.IV, and Table A.2) should be used to identify the range of monitoring needs for risk management purposes. This should include techniques which can determine:

(a) **CO_2 Migration:** vertical and lateral boundaries of the subsurface CO_2 Plume in order to detect Migration and Seepage of CO_2 in or out of the complex;

(b) **Features:** various Features which can indicate Significant Irregularities in the Geological Storage Complex;

(c) **Modes of operation:** principally bottomhole pressure in injection and observation wells to ensure that the Caprock Formation and faults do not become fractured or activated as Seepage pathways;

(d) **Surrounding domains:** to detect for Significant Irregularities, and potential damages to the environment or other subsurface users.

B.1 Technique selection

A wide range of potential techniques should be considered. As a minimum, techniques listed in Table A 5.1. of Annex 5.1 of the *2006 IPCC Greenhouse Gas Inventory Guidelines, Volume 2, Chapter 5* should be considered for their suitability. Choices of technique, their base level data needs, locations and frequency of application should be carefully considered, recognising the data needed to support implementation of the CDM methodology (equations 13 to 18). Each techniques listed in Table A 5.1 should be assessed, and the following documented:

(a) **Rationale:** the rationale for the choice of technique in terms of its capacity to detect CO_2 Migration (including lateral and vertical boundaries); changes in the characteristics of identified Features; to support appropriate Modes of Operation; and, analysis of surrounding domains. This should include generalised descriptions of the rationale for not including certain techniques listed in Table a 5.1. The rationale can include technical limitations and cost considerations where applicable;

(b) **Locations:** a description of the locations in the Geological Storage Complex where the technique will be applied (for *in situ* passive techniques) or broader descriptions for intermittent mobile techniques;

(c) **Frequency:** a description of how often the technique will be applied;

(d) **Base level survey:** an indication of the base-level data needs and sources in order to calibrate monitoring results should be provided. These should provide the basis for the data collected under Section III;

These data should be compiled following Table B.1 below. Specific details for each monitoring technique data type/unit, location, frequency etc. should be provided in the PDD for the CCS CDM project activity, under Section 7.1. Provide maps and other graphical data which can assist in describing the monitoring technique choice and location.

The Subsurface Monitoring techniques employed should be cross-checked against the initial risk register compiled in Table A.2.

Table B.1 Geological Storage Complex Monitoring Technique Selection Matrix

Technique	**Rationale**				**Base level data**	**Locations**	**Frequency of application**
	CO_2 Migration ($M_{CO2,j/k/l,y}$)	**Features ($M_{SC,j/k/l,y}$)**	**Modes of operation ($P_{M,j/k/l}$)**	**Surrounding domains**			
Technique j	Describe the rationale for the choice of method in terms of detecting CO_2 Plume Migration and vertical and lateral boundary locations, where applicable (if not applicable insert “n/a”). Information should be related to the risk management measures, where applicable, compiled in Table A.2.	Describe the rationale for the choice of method in terms of detecting changes in Features, where applicable (if not applicable insert “n/a”). Information should relate directly to the initial risk register of Features compiled in Table A.2.	Describe the rationale for the choice of method for monitoring appropriate Modes of Operation (if not applicable insert “n/a”). Information should be related to the risk management measures, where applicable, compiled in Table A.2.	Describe the rationale for the choice of method for monitoring surrounding domains (if not applicable insert “n/a”). Information should link to consequence analysis compiled in Table A.2.	Identify and describe any base level data needs. Indicate if available from other survey activities or whether new data acquisition is required.	Describe the number of sensors needed (where applicable) and their locations. Details for each monitoring location should be provided in the PDD for the project activity, Section 7.1.	Describe the frequency of application (e.g. passive/continuous; quarterly; once per year; every five years etc.) Details should be included in the PDD for the project activity, Section 7.1.
Technique k							
Technique l							
... Technique z							

III BASE LEVEL SURVEY

A base level survey involve data collection activities in the *Development* phase of a CCS CDM project activity which can be used to calibrate data collected during the *Operational* phase of the project. In some cases it may be supported by existing datasets from site characterisation or require additional data collection activities. Data may also be available from broader environmental impact assessment activities, although EIA procedures cannot be relied on to gain suitable data for base level data needs. Prior to commencing base level survey activities, an evaluation of the data needs should be carried and cross-referenced with existing datasets from site characterisation and EIA activities.

Key data needs for base-level survey measurements in relation to the risk management needs may include *inter alia*:

(a) **Subsurface**: data which can support analysis of CO_2 Plume Migration and Features monitoring. This includes geochemical and geophysical data such as:
  - Brine aquifers: fluid and gas composition plus pressures and temperatures of the Containment Systems in the proposed Geological Storage Complex in order to detect any changes due to CO_2 contamination from Migration/Seepage post-injection;
  - Wells: cement integrity logs, annulus pressure, wellhead pressure, bottomhole temperature and pressure, mineralogy, fluid analysis to support ongoing Modes of Operation analysis and well-bore integrity assessments during injection operations;
  - Gravity: gravimetric data to support time-lapse gravity surveys of the Geological Storage Complex;
  - Seismic: to support micro-seismic monitoring of Geological Storage Complex Features (faults, fissures etc.) for signs of reactivation. Fluid analysis from advanced seismic techniques. Other seismic data may be available from storage site characterisation activities;
  - Topography/relief: support time-lapse measurements of micro-changes in surface relief due to structural deformation effects of CO_2 injection operations. Satellite data of surface topography may be readily available without the need to collect specific data available. These data can provide proxy measures of CO_2 Migration;

(b) **Surface and near-surface:** data which can support warning signs for Seepage, support Seepage quantification, and provide a baseline for any remediation measures, such as:
  - Soil gas: to support repeat measurements of soil CO_2 flux rates, concentrations and geochemical compositions and fingerprints (isotopes). Base data necessary to calibrate against in the event of Seepage detection. Base-level measurements will need to be able to characterise natural diurnal, seasonal and annual variations in natural CO_2 fluxes from soil;
  - Potable aquifers: pH, elemental composition of the fluid and dissolved gases plus their isotopic signatures in order to detect any changes due to CO_2 contamination from Migration/Seepage post-injection;

(c) Surrounding domains:
  - Ecosystems: surveys may be required to provide base level data from which changes in certain ecosystems can be identified if Seepage occurs. The sensitivity of ecosystems

should be established during Geological Storage Complex risk assessment under site Selection & Characterisation (see Annex A, Section IV).

A range of other novel techniques may also require base level data to be collected (e.g. satellite hyperspectral imaging).

Base level survey activity should be documented in this section of the report where these are additional to data collected during *Geological Storage Complex Characterisation*. Data compiled should be documented in Table B.2 below. These data should correspond to the information compiled in Table B.1.

Table B.1 Base-level survey data collected

Base-level data type	**Date and time**	**Location**	**Reading(s)**	**Notes**
Data j	Insert dates and times of survey data collection, or start and end dates for surveys that require time series data.	Provide the grid reference for the location of the survey, and a description of the how the survey was carried out, and ambient conditions	Provide the results of the survey. Where graphical outputs are included, provide these in separate sections after the Table, and provide the clear cross-reference here.	
Data k				
Data l				
...Data z				

ANNEX C. MONITORING REPORTS

A. General Guidance for Geological Storage Complex Monitoring Reports

1. Subsurface Monitoring reports for a carbon dioxide capture and geological storage project activity should contain the results of the application of the techniques selected following guidance in Annex B, and used to support Sub-step 4b of the methodology document. This entails comparison of the results with predicted behaviour (history-matching), analysis of Features for signs of deviations from base-level conditions (which could indicate activation as a Seepage pathway), and ensuring appropriate Modes of Operation are adhered to. Results of this analysis should provide assurance that evaluations of storage performance and zero-Seepage assumptions derived from site selection and characterisation are valid (Annex A).

2. Monitoring results also provide indications of Significant Irregularities, including the detection and quantification of Seepage, as described below.

3. Even with the most rigorous data collection and Injection Formation design and analysis, some deviations from predicted CO_2 Migration behaviour post injection may occur. Moreover, commencement of injection operations and initial monitoring results will result in a rapid increase in understanding of the subsurface geology, storage performance and reservoir engineering assessments. As such, it is critical to adopt an adaptive learning process based around iterations of the procedure: model → predict → monitor → update → [repeat] etc. This is achieved through the process of history matching and updating of monitoring plans and model predictions.

4. To achieve its purposes, monitoring activities will need to be undertaken in all phases of the CCS CDM project activity (*i.e. development, operation, closure* and potentially *post closure*). The techniques, locations and frequency of monitoring will change over time as the both the understanding of the subsurface increases and the risk profile changes, both of which serve to modify the objectives of monitoring. This profile ranges from:

- **Early-operation phase:** intensive monitoring in the early operational phase (e.g. years 1-7 or so) to test the efficacy of certain techniques, test assumptions in *Performance Assessment*, recalibrate models and monitoring plan design, and incorporate any new data from injection wells;

- **Mid-operation phase to closure:** a move towards more routine monitoring (e.g. years 7-20+) when the reliability and effectiveness of certain techniques has been assured, and increasing convergence between observed and predicted behaviour is achieved;

- **Closure phase:** reducing risk as CO_2 Migration decreases and stabilisation of the CO_2 Plume occurs. Evidence of different CO_2 trapping mechanisms sought in order to make predictions on long-term containment security;

- **Post Closure phase:** cessation of regular monitoring and a move towards event based monitoring (i.e. initiation of monitoring linked to any events which could destabilise storage).

5. A Quality Assurance and Quality Control procedure is outlined at the end of the Annex which is designed to ensure that effective decision-making has been employed during the compilation and

analysis of monitoring results and updates to the monitoring plan. The procedures outlined there must be followed at each stage when preparing a Monitoring Report.

6. The analysis requirements outlined in this guidance document should only be implemented by specialist teams that include qualified geologists, geophysicists, geomechanics, geochemists and reservoir engineers. Verification of monitoring reports for the subsurface component of a carbon dioxide capture and geological storage can only be conducted by DOE’s accredited to a Sectoral Scope 16, Carbon Dioxide Capture and Geological Storage.

7. Monitoring reports shall contain the results of surface monitoring, as for other CDM project activities. No guidance is provided here on how these should be compiled.

B. Specific Guidance for Geological Storage Complex Monitoring Reports

I MONITORING RESULTS

A.1 History matching

Equations 13 to 18 in the methodology provide the basis for comparing monitoring results with predicted performance (history matching). The monitoring report should outline monitoring data which can support these requirements, based on the techniques selected following guidance in Annex B. These shall provide information on the following:

8. **CO_2 Migration (equations 13 and 14)**: images of the Geological Storage Complex which provide information regarding the behaviour of the injected CO_2 Plume so as to support reviews of the subsurface project boundaries post-commencement of injection operations;

9. **Geological Storage Complex Features (equations 15 and 16):** signs of significant irregularities within Features of the Geological Storage Complex as defined during Geological Storage Complex characterisation, including recognized Migration and Seepage pathways, and any other previously undetected Features; and;

10. **Modes of operation (equations 18 and 19)**: demonstrating that the Injection Formation has been operated within safe modes during the monitoring period;

Results should indicate whether the Geological Storage Complex is performing satisfactorily, or whether significant irregularities have occurred.

A.2 Significant Irregularities and Corrective Measures

Equations 14 and 16 of the methodology provide the basis for determining whether Significant Irregularities have occurred over the monitoring period. Where results of history matching indicate significant disagreement between predicted and observed results, a description and interpretation of the deviation should be provided in terms of:

11. **Lateral or vertical Migration**: reasons why CO_2 Migration beyond the subsurface boundaries could have occurred in way that wasn't predicted in the performance assessment, and measures to correct the irregularity.

12. **Activation of Features**: reasons why a feature could have been activated, and measures taken to correct the irregularity.

13. **Modes of operation**: reasons why pressure in the Injection Formation was exceeded and measures to correct the irregularity.

Information generated for all elements should be used to update the monitoring plan (Section II).

Where any Corrective Measures have been undertaken to remediate Seepage or potential Seepage through activation of emission pathways, these should also be documented in the Monitoring Report. This should include a description of the measures undertaken, the outcome, and the means of assessing the success of the measures undertaken.

A.3 Estimated Seepage

Indicate whether a Significant Irregularity included Seepage (yes/no). If yes, information regarding the following should be included in the monitoring report:

(a) **Emissions pathway**: details of the emissions pathway(s) by which Seepage occurred, including details of how this was established;

(b) **Flux rate**: estimated flux rate of the emissions pathway at the surface or into the hydrosphere (in $tCO_2/m^2/day$), and how the estimate was established;

(c) **Duration**: estimated duration of the Seepage (in days), and how this was established;

(d) **Area**: the areal extent of the identified Seepage zone (in m^2) associated with the emission pathway, and how this was established;

(e) **Uncertainty**: an overall estimate of the uncertainty of the result, including a description of the factors used to determine the accuracy and uncertainty of measurements undertaken.

The mass of CO_2 estimated to have seeped should be calculated following equation 19 of the methodology, and corrected by a conservative estimate of uncertainty for each parameter used to determine the final reported mass of seeped CO_2. A conservative estimate can involve expert judgement. It should be subject to verification by the DOE.

If the Seepage requires Compensation to be made, provide a description of the modalities for providing the Compensation to the UNFCCC CDM Registry account (dates on which Compensation will be made; from which account).

II UPDATES TO MONITORING PLANS

In order to account for improvement in understanding of the subsurface as a result of Subsurface Monitoring activities, and to accommodate the changing objectives of Subsurface Monitoring over time, the following analysis should be carried out through the project life-cycle:

(a) Data interpretation and re-appraisal of Performance Assessment;

(b) Re-assessment of risks;

(c) Review and update if necessary Geological Storage Complex Operating Plan Design

(d) Updating or re-design of the monitoring plan (where necessary).

These procedures must be carried out if a Significant Irregularity has occurred. New findings should be documented in addendums to the *Geological Storage Complex Selection & Characterisation Report* and the *Geological Storage Complex Monitoring Plan Report*, and submitted for verification in conjunction with a project's Monitoring Report.

Approval of updated monitoring plans should be carried out in accordance with the procedures agreed at the 26th Meeting of the CDM Executive Board, Annex 34.

B.1 Data Interpretation and Re-modelling

History-matching of observed and predicted CO_2 Migration behaviour allows for reinterpretation of the Containment System characteristics and engineering considerations (e.g. trap structure/geometry and dip; hydrogeology/flow; compartmentalisation; heterogeneity; Permeability; Features etc.). The new knowledge gained should be used to update data collected under Section III C.1 of the *Geological Storage Complex Selection & Characterisation Report*, and subsequently to re-appraise storage performance in terms of capacity estimates, CO_2 Migration analysis and Features analysis compiled in under Section III C.2 of the *Geological Storage Complex Selection & Characterisation Report.*

B.2 Re-assessment of Risks

Any new risk Features identified during monitoring activities should be documented and included as an update to the Initial Risk Register prepared in accordance with Table A.2.

B.3 Review and update Geological Storage Complex Operating Plan

Any new findings from *Performance* and *Risk Assessment* should be incorporated and included as an Addendum to the *Geological Storage Complex Selection & Characterisation Report.*

B.4 Update Monitoring Plan

New findings from Subsurface Monitoring and re-appraisal of *Performance Assessments* must be used to re-assess the efficacy of the Geological Storage Complex monitoring plan.

(a) **Knowledge gaps:** identifying and applying new or additional techniques/locations/frequencies which could any fill gaps apparent in information and understanding of the subsurface;

(b) **New Features:** identifying and applying new or additional techniques/locations/frequencies for certain monitoring techniques in relation to any new Features identified in the Geological Storage Complex;

(c) **Efficacy:** removing some techniques from the monitoring plan where they have proved ineffective or unnecessary;

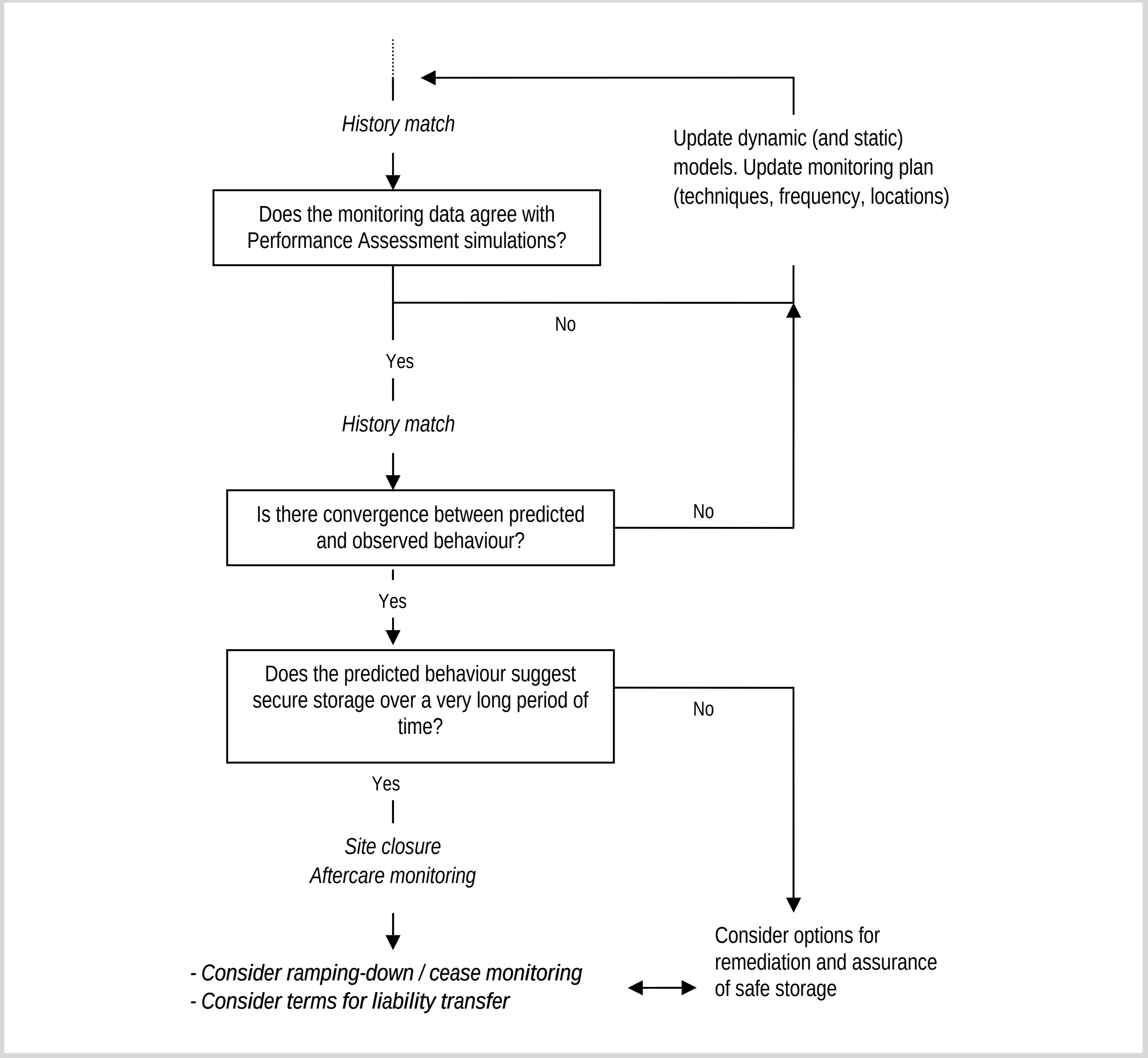
Where necessary, an addendum to the *Geological Storage Complex Monitoring Plan* should be prepared and submitted in conjunction with Monitoring Reports.

QUALITY ASSURANCE AND QUALITY CONTROL

The QA/QC outlined in Figure A.1 should be tested against the results of the monitoring plan.

For updates to the monitoring plan, the QA/QC considerations outlined in Figure B.1 should be applied. These procedures may be applied several times across the projects life-cycle to support liability considerations, including liability transfer.

Figure B.1 Additional QA/QC for Updates to Monitoring Plans



ANNEX D. COMPLEX CLOSURE REPORT

A. General Guidance for Complex Closure and Final Performance Assessment

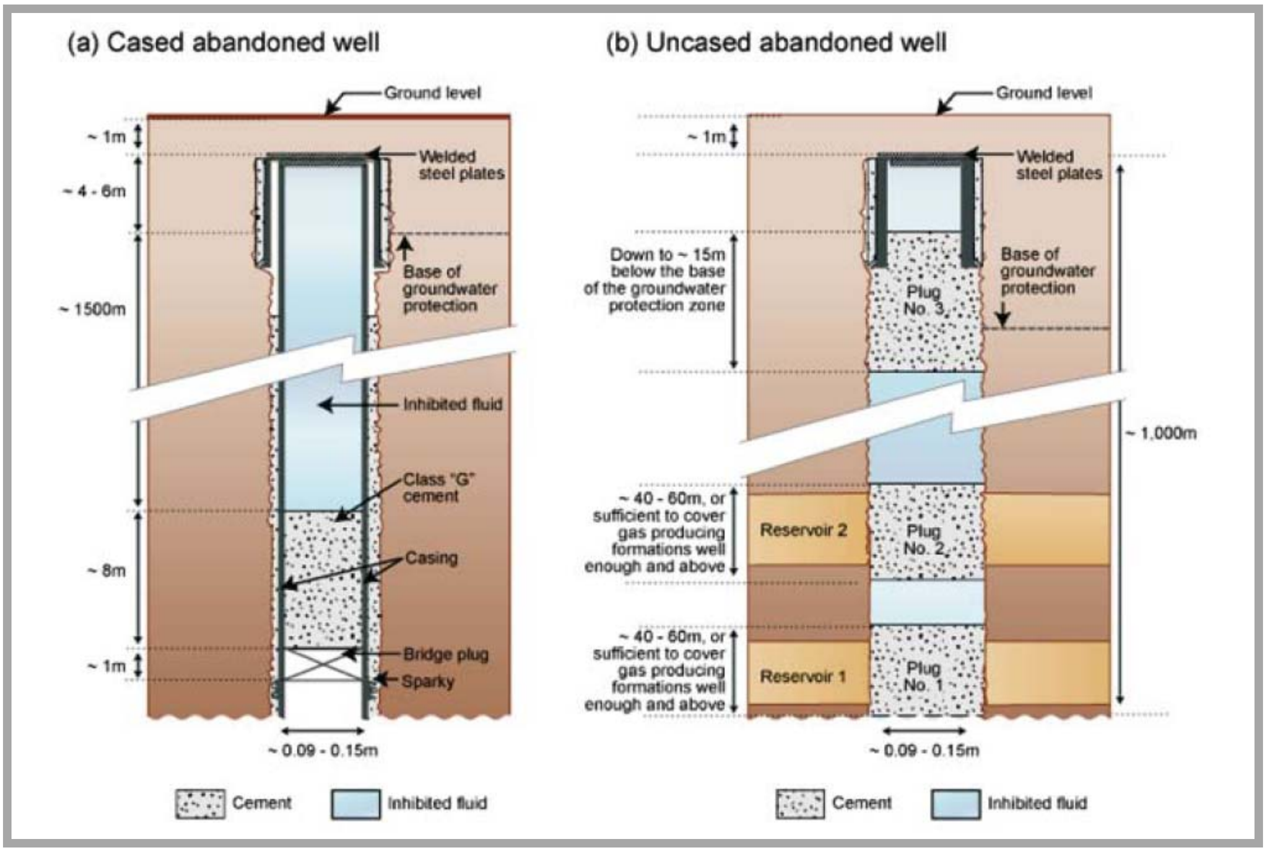
1. A Geological Storage Complex Closure Report should be prepared in advance of Stewardship transfer. In terms of site decommission, the Geological Storage Complex Closure Report should provide details on the following items:

- **Decommissioning and removal of surface equipment:** this should be done in accordance with local laws and regulations concerning similar activities (e.g. oil & gas exploration and production; mining activities). Details on decommissioning requirements may be included in the environmental impact assessment of the CDM project activity;

- **Well abandonment procedures:** abandoned wells are likely to pose the most significant Seepage risk for a Geological Storage Complex during Closure. Therefore it is imperative that wells are plugged and abandoned to a sufficient standard in order to form a vertical barrier to Seepage or Migration of CO_2. This is an area of ongoing research and development, and international best-practice from carbon dioxide storage, acid gas injection, oil & gas industry and geothermal wells should be sought and followed at the time of Closure. As a minimum, the procedure for well plug and abandonment includes: removal of the tubing and packer; sealing of the formation with a fluid to reduce its Permeability; placing plugs of cement or other material for isolation (Standard Portland Cement with fly-ash content is an example of one such material); testing of plugs; capping off the well at the surface; backfilling with soil; and accurately recording the well location. Figure D.1 provides an example of well-plugging activities.

- **Ongoing monitoring activities post-closure:** Subsurface Monitoring for the Closure phase should be designed following guidance outlined in Annex B and C. The objective of monitoring in the Closure phase should be to detect CO_2 Plume stabilisation and the effects of subsurface trapping mechanisms. Project participants should continue to prepare monitoring reports and updates in accordance with Annex C. History-matching and recalibration of subsurface models should continue in the Closure phase, and where observations and predictions of CO_2 Plume behaviour are converging, project participants should consider – depending on available evidence of storage performance and through dialogue with the host country DNA – moving towards a transfer of Stewardship for the Geological Storage Complex.

Figure D.1 Example of how cased and uncased wells are abandoned today



2. The risk posed by the Geological Storage Complex in terms of Seepage or unintended Migration decreases significantly after injection operations cease (during Closure). This is because pressure in the subsurface should decrease as the stress field produced by injection becomes attenuated in the subsurface. As this occurs, the CO_2 Plume should also stabilise as the motive forces induced by the pressure of injection decrease and various trapping mechanisms (in addition to physical trapping) should continue to take place in the Geological Storage Complex, serving to immobilise the injected CO_2.

3. In this context, the Geological Storage Complex Closure Report must also include an evaluation of the risk posed by the Geological Storage Complex in terms of Seepage or unintended Migration over the very long term. The focus of the risk assessment should be based on the results of Geological Storage Complex monitoring (established in both the operational and aftercare phases) and ongoing history-matching of observations with predictions. Where all available evidence suggests stabilisation of the CO_2 Plume and secure storage, then the terms for Stewardship transfer can be agreed.

4. The in terms of long term performance assessment, the Geological Storage Complex Closure Report should include:

- **Evidence of CO_2 Plume stabilisation**: a description and evidence base which demonstrates that the CO_2 Plume is stabilising and other trapping mechanisms are taking place in the subsurface;

- **Forward modelling of CO_2 Plume development**: the undertaking of long-term forecasts of CO_2 Plume Migration and stabilisation in order to demonstrate secure storage over a very long period of time (>1,000 years+);

- **Risk assessment**: a final risk assessment should be prepared following guidance provided in Annex A, Section IV;

- **Ongoing monitoring**: a description of potential ongoing monitoring activities that could be carried out in the Post-Closure phase in order to provide ongoing assurance of secure storage;

- **Financial mechanism**: a description of the modalities for transferring the financial mechanism from project participants to host country, where applicable.

5. The Geological Storage Complex Closure Report must be submitted to the host country DNA for approval. Upon approval by the DNA, the written approval and the reports should be validated by a DOE and submitted to the CDM Executive Board and any panels appointed there under for this purpose (e.g. a CCS Panel) and/or a CGSCoE for final approval.

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History of the document

Version	Date	Nature of revision(s)
03.1	20 May 2008	• Second bullet of formatting instructions changed to refer to Sections C and D, rather than Section B; • Change in numbering of paragraphs.
03	EB 38, Annex 6 14 March 2008	• Revision of the structure of the document to reflect the sections of a standard approved baseline methodology. • Section A. Recommendation by the Methodological Panel • Section B. Summary and applicability of the baseline and monitoring methodology • Section C. Proposed new baseline and monitoring methodology • Section D. Explanations / justifications to the proposed new baseline and monitoring methodology
02	EB 32, Annex 17 22 June 2007	• The form “CDM-NM” was merged with the recommendation form “F-CDM-NMmp”. The F-CDM-NMmp discontinued to be used. • The change was adopted in line with the revised “Procedures for submission and consideration of a proposed new methodology” in order to simplify and streamline the process of consideration of new methodologies.
01	EB 08, Annex 02 29 September 2006	Initial adoption