CATO-2 Deliverable WP 4.1-D03
Assessment of accuracy required by the Monitoring and Reporting Guidelines for CCS under the EU-Emission Trading System

Prepared by:	F.T. Blank	KEMA
	H. Spoelstra	KEMA
Reviewed by:	J.J. de Wolff	KEMA
	B.J.M. Stortelder	KEMA
Approved by:	J.Brouwer (CATO-2 Director)	

1 Executive Summary (restricted)

On 8 June 2010 the Commission Decision amending Decision 2007/589/EC as regards the inclusion of monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide (EU, 2010) entered into force. The monitoring and reporting guidelines have a large emphasis on the required uncertainty for the quantification of CO_2 emission. In these monitoring and reporting guidelines for CCS new emission sources from transfer, capture process, bypasses, fugitive, vented and leakage are required to be monitored. This requires the implementation of monitoring techniques which have been rarely or never used in the EU emission trading system. If the required uncertainties are not met the operator has to bear large costs for improvement of the monitoring systems or to surrender extra emission allowances to compensate a to large uncertainty.

This report provides an analysis of the uncertainty requirements and provides possible pathways and recommendations how to meet the requirements. The precise implementation of these rules is of great importance for permit holders, as it can ease uncertainty requirements for the monitoring, in particular when the emission sources are relatively small. This also applies for the process and bypass emissions, which are not handled in the CCS monitoring and reporting guidelines. For the uncertainty requirements of these streams the regular annexes of the monitoring and reporting guidelines apply.

The total emission of a capture installation and a transport network could in principle be monitored by the difference between input and output stream of CO_2. But it is shown that measurement of all the emission sources is the preferred option for reaching the lowest uncertainty. For a CO_2-concentration above 95% and an uncertainty in the flow measurement under 2%, it is sufficient to do four analyses a year for the CO_2-concentration.

The uncertainty requirements for the storage site are too strict in comparison with the capture installation and other installations in the EU-ETS system. It should be considered to base the categorisation of storage sites also on the “emission before transfer”. Then if the overall emission is under 2% of the emission before transfer and under 20 ktonnes, it is a de-minimis source. The operator may then apply approaches for monitoring and reporting using his own no-tier estimation method.

There are many advantages if the transport network plays an important role in the physical monitoring at the CO_2-transfer points of the capture installations and storage sites. Incorporation of the EU-ETS monitoring in the monitoring plan for the storage sites is a requirement. To ease validation and verification it is advised to make also a separate EU-ETS monitoring plan. This contains the limited measurement requirements from the monitoring guidelines for CCS.

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2 Introduction

2.1 Background and objectives

On 8 June 2010 the Commission Decision amending Decision 2007/589/EC as regards the inclusion of monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide (EU, 2010) entered into force. It amends Directive 2003/87/EC, so as to include the capture, transport and geological storage of carbon dioxide within the emission trading Community scheme from the year 2013 onwards.

These monitoring and reporting guidelines will probably be transposed into Dutch regulation by means of adaptation of the “Leidraad CO_2-monitoring” issued by the Dutch Emission Authority (NEa, 2007). The monitoring and reporting guidelines put a large emphasis on the required uncertainty for the quantification of CO_2. These guidelines describe a system with minimum required tiers depending on the size of source streams and installations. In the guidelines for CCS, new emission sources from capture, transfer, process, bypasses, fugitive, vented and leakage are required to be monitored. This requires the implementation of monitoring techniques which before were rarely or never used in the EU emission trading system.

The combination of new monitoring techniques and new source streams raises questions on how to meet the required uncertainties. The way in which these issues will be resolved can have an impact on the implementation of the monitoring of large scale CCS in the Netherlands. Not meeting the required uncertainties has large influence on the costs for monitoring systems. The emission permit will be issued if the requirements are met so the owner will need to invest in its metering equipment, to meet the required uncertainties. Medium sized capture plants and transport networks have an emission before transfer of more than 500 ktonnes CO_2 annually. For these installations (i.e. the ‘Category C installations’), a EU Member State shall notify to the Commission if the application of a combination of highest tier approaches for all major source streams does not take place. This report provides an analysis of the uncertainty requirements and provides possible pathways and recommendations on how to meet the requirements.

2.2 Research questions

The following specific research questions relating to the implementation of the EU Monitoring and Reporting guidelines for CCS were identified:

- How do the new MRG CCS relate to the already existing uncertainty requirements and procedures for monitoring CO_2 in the EU emission trading system?
- Will the uncertainty requirements be met for capture, transport and storage installations and what is the best approach to attain the requirements?

- How can a CEMS system for the determination of the CO_2 content of a gas stream be implemented?
- Is it really needed, and in proportion to other installations, to impose very tight uncertainty requirements on storage sites?
- How can the monitoring at the transfer points best be implemented to assure quality of the measurements, availability of data and cost effectiveness?

This report excludes:

- Practical guidance on technical monitoring under the Monitoring and Reporting Guidelines for CCS of the EU Emission Trading System. In that guidance document an overview is provided of the present technical status of monitoring equipment and best available technologies for monitoring. This will be the subject for $CATO_2$ deliverable 4.1.02 for year 1 (CATO-2 Deliverable WP 4.1-D4.1.02).

2.3 Reading guide

The report is structured in the following way:

- Chapter 3 provides an overview of existing monitoring requirements on uncertainty and the use of CEMS in the current monitoring and reporting guidelines.
- Chapter 4 provides an elaboration of the Dutch system for frequency of analysis and reasonable costs.
- Chapter 5 deals with the monitoring and its associated uncertainty of capture installations.
- Chapter 6 deals with the monitoring and its associated uncertainty of transport networks.
- Chapter 7 deals with the monitoring and its associated uncertainty of a storage sites.
- Chapter 8 provides an overview and analysis of the monitoring and the uncertainty of monitoring over the complete CCS-Chain.

3 Current EU Monitoring and Reporting Guidelines

3.1 Evolution of the Monitoring and Reporting Guidelines

Directive 2003/87/EC (EU, 2003) sets out the Scheme for Greenhouse Gas Emission Allowance Trading within the European Community. For implementation of the monitoring within the scheme in 2004 the “Monitoring and Reporting Guidelines (MRG) for greenhouse gas emissions were published (EU 2004). The Commission Decision containing the MRG is addressed to the Member States. Member States must ensure that the provisions of the monitoring guidelines are applied in the monitoring and annual reporting of greenhouse gas emissions of each of the installations covered by the EU greenhouse gas emission allowance trading scheme (referred to as the EU-ETS). The MRG thus provide the legally binding rules for the monitoring and reporting of greenhouse gas emissions within the EU-ETS. Member States must choose the appropriate modalities to ensure that these rules are applied by the operators of installations covered under the EU-ETS.

A revised version of the MRG has been accepted by the EU Climate Change Committee on 31 July 2006. Focus areas for the review included cost-effectiveness, harmonization and user-friendliness. The MRG 2007 (EU, 2007a) took effect from 1 January 2008. Member States, Competent Authorities, Operators and Verifiers had to comply with the requirements of the revised Commission Decision from 1 January 2008 onwards.

The MRG defines how an operator of an installation will carry out the monitoring and reporting of CO_2-emissions for that specific installation. This includes amongst other things the fuel and material streams to be monitored, the choice of tiers for all elements of the emission calculation, a description of metering devices (location, technology, uncertainty), a detailed description of emission measurement systems (if applicable) as well as QA/QC procedures for monitoring and reporting, e.g. for the processes of data collection and emission calculation. The approved documentation of the monitoring methodology (referred to as “monitoring plan” is part of or connected to the permit of an installation. Once approved, the installation has to implement and execute the monitoring of its greenhouse gas emissions in accordance to the approved “monitoring methodology”. This is checked by the verifier as part of the verification process each year.

3.2 The Tier system for uncertainty requirements

The tier system provides a set of building blocks to determine the appropriate monitoring methodology for each installation (EU, 2007b). The tier system defines a hierarchy of different ambition levels for activity data, emission factors and oxidation or conversion factors. The higher the number of the applied tier, the higher the level of accuracy. The operator must, in principle, apply the highest tier level, unless he can demonstrate to the competent authority that this is technically not feasible or would lead to unreasonably high costs. The categorisation of installations is based on the total emission of the installation before subtraction of transferred CO_2:

- 'category A installations' means installations with average reported annual emissions over the previous trading period equal to or less than 50 ktonnes of fossil CO_2 before subtraction of transferred CO_2,
- 'category B installations' means installations with average reported annual emissions over the previous trading period greater 50 ktonnes and equal to or less than 500 ktonnes of fossil CO_2 before subtraction of transferred CO_2,
- 'category C installations' means installations with average reported annual emissions over the previous trading period greater than 500 ktonnes of fossil CO_2 before subtraction of transferred CO_2

Transferred CO_2 has always been taken into account of the categorisation of the installations. Up till now the amount of transferred CO_2 has rarely been a substantial portion of the annual CO_2 emission of an installation. But for CCS it will be common practice that the annual emission, on which the category is based, is mainly transferred CO_2.

The requirement to apply the highest tiers is reinforced in the MRG 2007 in section 5.2 of Annex I for all major source streams of installations with emissions of more than 50 ktonnes of fossil CO_2 per year (i.e. category B and C installations). Subject to approval by the competent authority these installations may apply a next lower tier if the highest tier is technically not feasible or would lead to unreasonable costs down to the tier thresholds of Table 1 in the MRG 2007.

Except for small emitters (i.e. installations with a verified reported emissions of less than 25,000 tonnes of CO_2 per year during the previous trading period) it is required that Member States shall ensure that operators apply for all major source streams, as a minimum the tiers as set out in table 1 in the MRG 2007, unless this is technically not feasible. Approval of tier levels below the thresholds given in Table 1 in the MRG 2007 based solely on "unreasonable costs" is not acceptable for major source streams.

In cases where it is not technically feasible or would lead to unreasonable costs for the operator of an installation to reach even Tier 1 for at least one of the (non de-minimis) source streams, a fall-back approach can be applied: the operator is allowed to use a fully customized monitoring approach, but has to prove to the competent authority that by applying such an approach the overall specific uncertainty thresholds for the installation category (A, B or C) as laid down in the MRG are met.

3.3 The use of Continuous Emission Measurement Systems

3.3.1 Current situation for measurement of CO_2 with CEMS

The monitoring and reporting guidelines for CCS assume a large role for Continuous Emission Measurement systems (CEMS). This is based on the expectation that at all transfer points the composition of the CO_2 stream needs to be measured continuously. In the current monitoring and reporting guidelines - without CCS - continuous measurement of CO_2 plays a marginal role.

Paragraph 4.2 CALCULATION AND MEASUREMENT-BASED METHODOLOGIES in the MRG state:
"Annex IV to Directive 2003/87/EC permits a determination of emissions using either:
— a calculation-based methodology, determining emissions from source streams based on activity data obtained by means of measurement systems and additional parameters from laboratory analyses or standard factors;
— a measurement-based methodology, determining emissions from an emission source by means of continuous measurement of the concentration of the relevant greenhouse gas in the flue gas and of the flue gas flow.

The operator may propose to use a measurement based methodology if he can demonstrate that:
— it reliably results in a more accurate value of annual emissions of the installation than an alternative calculation based methodology, while avoiding unreasonable costs; and
— the comparison between measurement and calculation-based methodology is based on an identical set of emission sources and source streams.

The use of a measurement-based methodology shall be subject to the approval of the competent authority. For each reporting period the operator shall corroborate the measured emissions by means of calculation-based methodology in accordance with the provisions of Section 6.3(c).

The operator may, with the approval of the competent authority, combine measurement and calculation-based methodologies for different emission sources and source streams belonging to one installation. The operator shall ensure and demonstrate that neither gaps nor double counting concerning emissions occur."

The above requirements have made that CEMS is rarely used for monitoring CO_2 under EU-ETS.

- The obligation to corroborate it by a calculation based methodology is in practice not feasible. The prime reason not to use a calculation based methodology is, that it is impossible to perform or does not reach the required accuracy. For that reason the corroboration will probably give unsatisfactory results.
- The procedures in the corroborative approach must be described and reported being a major burden for implementation of CEMS. If the corroborative approach shows invalid results substitution values need to be established and used.
- It is not feasible for a CO_2-CEMS to attain a maximum uncertainty of 1.5% (Tier 4) which is the requirement for large source streams at category B or C combustion installations. The minimum uncertainty for the measurement in CO_2 in a flue gas stream will sooner be in the order of 5%.
- Besides concentration also the flue gas flow needs to be measured continuously. Different techniques exist to measure or calculate the flue gas flow. Typical uncertainties for flue gas flow measurement are in the range of 5-10% of the annual value. An uncertainty requirement of 1.5% will in practice be impossible.
- The uncertainty of the measurement of CO_2 and flue gas flow needs to be combined, giving the total uncertainty of the CO_2 stream. This only makes it even more improbable that the

required uncertainty of 1.5% will be attained. CEMS needs to achieve greater accuracy than the calculation of emissions using the most accurate tier approach (1.5%). In annex XII of the monitoring and reporting guidelines for each emission source measured by CEMS a total uncertainty of the overall emissions over the reporting period of less than ± 2,5% shall be achieved. The M&R guidelines are unclear what is leading for the uncertainty when using CEMS (1.5 or 2.5%).

- For justification of the measurement approach an uncertainty assessment needs to be made taking into account the EN 14181. The uncertainty calculations in the EN 14181 are based on hourly values. The procedures for recalculating hourly values to an annual uncertainty are ambiguous.

3.3.2 Implementation of N_2O measurement with CEMS in EU-ETS

In 2008 laughing gas (N_2O) is amended to the EU monitoring and reporting guidelines (EU, 2008). The quantification of this greenhouse gas can only be performed by continuous emissions measurement systems. This is probably the first time under the EU-ETS system that such large amounts of CO_2-equivalents are measured by CEMS and traded in the EU-ETS system. The amount of CO_2-equivalents from a single emission point could be around 250,000 tonnes, thus representing a value of about 3,750,000 Euro at an emission trading price of 15 Euro per ton.

The total uncertainty of the annual (average hourly) emissions for each emission source must not exceed the tier values as set out below. The highest tier approach shall be used by all operators. Only if it is shown to the satisfaction of the competent authority that the highest tier is not technically feasible or will lead to unreasonably high costs, may a next lower tier be used. For the reporting period 2008–12 as a minimum Tier 2 shall be applied unless technically not feasible.

- Tier 1: For each emission source a total uncertainty of annual average hourly emissions of less than ± 10 % shall be achieved.
- Tier 2: For each emission source a total uncertainty of annual average hourly emissions of less than ± 7,5 % shall be achieved.
- Tier 3: For each emission source a total uncertainty of annual average hourly emissions of less than ± 5 % shall be achieved.

In the uncertainty of 5% for the highest tier (tier 3) both the uncertainty of the measurement with CEMS and the uncertainty in the measurement/calculation of the flow are incorporated. If both uncertainties are of equal size, this implies that CEMS concentration measurement an uncertainty of the annual hourly emission of 3.5% ($5/\sqrt{2}$) is allowed. These measurement systems and their associated uncertainties are similar with CO_2-measurement in flue gasses. This supports the conclusion from paragraph 3.3.1, that a system using CEMS and flow measurements can not attain the same uncertainties as fuel-input based calculations.

To test whether this uncertainty requirement is fulfilled the European Standard EN 14181 “Quality Assurance of automated measurement systems” is prescribed. This standard tests the uncertainty of the hourly measurements values against the uncertainty requirements for emissions to air. Standard values for the hourly uncertainty requirements are maximum 20% (e.g. NO_x). The uncertainty requirements for an annual hourly emission of N_2O are not translated to an uncertainty limit for the hourly measurements. This reflects the ambiguity of the transformation from hourly to annual uncertainty.

4 EU Monitoring and Reporting Guidelines

CCS will be included in the EU ETS from Phase 3 (2013-2020 onwards) and can be opted-in by member states during Phase 2 (2008-2012). Under current proposals, CO_2 captured, transported and permanently stored will not be considered as emitted. However, any CO_2 leakage will have to be accounted for and surrendered under the Scheme. This essentially means that the CO_2 will have to be accurately monitored and reported throughout the whole CCS process.

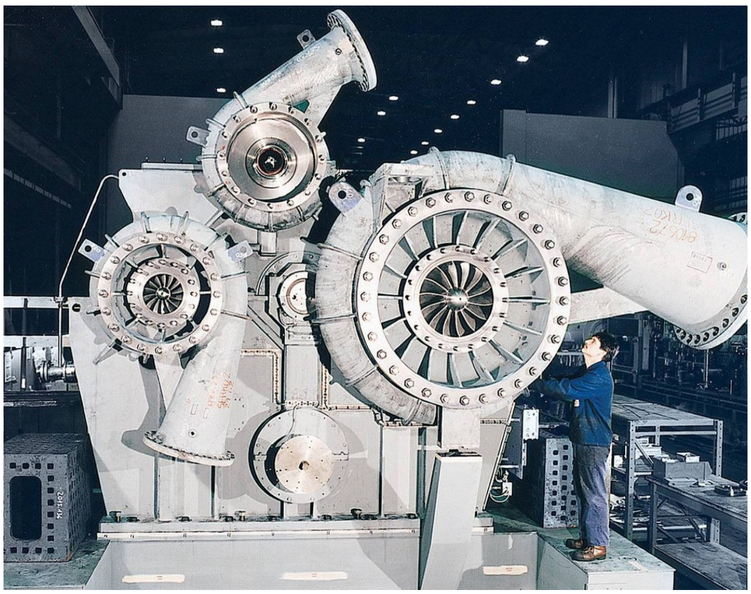

Figure 4.1 High capacity CO_2 compressor (source MAN Turbo)

The current monitoring and reporting guidelines are important for the technical implementation and investment costs for CCS monitoring. Continuous Emission Measurement is required for determination of the CO_2 content of transferred CO_2. It is demonstrated in this chapter that discontinuous measurement can also fulfil the uncertainty requirements. If the required uncertainties are not met an operator is required to invest in improvement of the measurement system. The mechanism of “reasonable cost” as it is implemented in the Netherlands is explained.

4.1 Frequency of analysis

The MRG in section 13.6 of Annex I specify the batch size by setting requirements regarding the analysis frequency. The sampling procedure and analysis frequency shall be designed to ensure that the emission factor, the net calorific value and the other parameters mentioned in section 13.6, exhibit an uncertainty of less than 1/3 of the approved uncertainty threshold for the annual mass flow of the respective source stream. In cases where operators are not able to meet this threshold or to demonstrate compliance, minimum analysis frequencies are to be applied.

In the MRG an indicative table with “minimum frequency of analyses” is given (table 5). Transferred CO_2 would in this table fall under: “Other input and output streams in the mass balance (not applicable for fuels or reducing agents)”. Here fore a measurement frequency of every 20.000 tonnes and at least once a month is given.

The MRG state the following general principles on determination of concentration parameters:
“The determination of the relevant emission factor, net calorific value, oxidation factor, conversion factor, carbon content, biomass fraction or composition data shall follow generally accepted practice for representative sampling. The operator shall provide evidence that the derived samples are representative and free of bias. The respective value shall be used only for the delivery period or batch of fuel or material for which it was intended to be representative.

The sampling procedure and frequency of analyses shall be designed to ensure that the annual average of the relevant parameter is determined with a maximum uncertainty of less than 1/3 of the maximum uncertainty which is required by the approved tier level for the activity data for the same source stream.

In all other cases the competent authority shall define the frequency of analyses. According to section 13.6, the operator shall provide evidence that the derived samples are representative and free of bias. The respective value shall be used only for the delivery period or batch for which it was intended to be representative.”

The MRG for CCS require the use of CEMS, for determination of the CO_2 content in the transferred CO_2. The same principles as for emission factor, net calorific value etc. can be applied to the frequency of continuous measurements. The variation in the CO_2 concentration is small with CO_2 concentrations near to 100% (DYNAMIS, 2007; Ecofys, 2008). In that case it is sufficient to sample and analyse with a relatively low frequency. The MRG state that uncertainty of other parameters needs to be smaller than 1/3 of the approved uncertainty of the annual mass flow.

The rules to calculate the minimum sample frequency are elaborated by the Dutch Emission Authority and incorporated in a spreadsheet calculation program (NEa, 2006). The procedure assumes that there is preliminary information on the variability of the CO_2 concentration. The standard deviation of the concentration can be calculated in two ways:

- from repeated analysis of the transferred CO_2 stream.
- calculated from the expected minimum and maximum CO_2 concentration in the stream. Then assuming it is a rectangular distribution for which the standard deviation is half width of the distribution, divided by $\sqrt{3}$:

  Standard deviation = (maximum concentration - minimum concentration) / 2 / $\sqrt{3}$

  As an example a CO_2-stream with a minimum concentration of 95% and a maximum concentration of 100%:

  Standard deviation = (100% - 95%) / 2 / $\sqrt{3}$ = 1.44%

The next step is to calculate the required number of samples (#samples) from the expected standard deviation and required uncertainty:

#samples = [(expected standard deviation x 2) / (required uncertainty /100 x concentration)]^2

Example:
the expected standard deviation is 1.44%, required uncertainty is 2.0% and the CO_2-concentration is 95%:

#samples = $[(1.44 \times 2) / (2.0 / 100 \times 95)]^2 = (2.88 / 1.90)^2 = 2.3$

Which is rounded to two samples per year. According to the guidelines of the Dutch Emission Authority the minimum number of samples should always be four per year.

For transferred CO_2 a total uncertainty of the overall emissions over the reporting period of less than 2.5 % shall be achieved. This total uncertainty is the combined uncertainty of flow and CO_2 concentration. The 1/3 rule does not apply in this case, but the required uncertainty of the CO_2 concentration depends on the attained uncertainty of the flow. Table 4.1 gives the required uncertainty of the CO_2 concentration calculated from the uncertainty of the flow. Both add up to 2.5% in every combination. The uncertainty of flow and CO_2 concentration are equal at 1.77%, at which the total uncertainty equals 2.5% ($\sqrt{(1.77^2 + 1.77^2)} = 2.5\%$).

In table 4.1 the required uncertainty for the measurement of the CO_2 concentration is calculated from the attained uncertainty of the flow determination. The expected standard deviation for the CO_2 concentration is calculated from the given expected CO_2 concentration and its maximum value (100% CO_2). With the formula given above, the minimum sampling frequency has been calculated.

Table 4.1 Calculation of the minimum sample frequency per year, depending on required uncertainty of the CO_2 concentration and the minimum CO_2 concentration

% Uncertainty		Minimum sampling frequency per year				
		Minimum CO2 concentration (%)				
Flow	CO_2 concentration	99	97.5	95	92.5	90
0.0	2.5	0	0	**1**	4	7
0.1	2.5	0	0	**1**	4	7
0.2	2.5	0	0	**1**	4	7
0.3	2.5	0	0	**1**	4	7
0.4	2.5	0	0	**2**	4	7
0.5	2.4	0	0	**2**	4	7
0.6	2.4	0	0	**2**	4	7
0.7	2.4	0	0	**2**	4	7
0.8	2.4	0	0	**2**	4	7
0.9	2.3	0	0	**2**	4	8
1.0	2.3	0	0	**2**	4	8
1.1	2.2	0	0	**2**	4	8
1.2	2.2	0	0	**2**	5	9
1.3	2.1	0	0	**2**	5	9
1.4	2.1	0	1	**2**	5	10
1.5	2.0	0	1	**2**	5	10
1.6	1.9	0	1	**3**	6	11
1.7	1.8	0	1	**3**	7	12
1.77	**1.77**	**0**	**1**	**3**	**7**	**13**
1.8	1.7	0	1	**3**	7	14
1.9	1.6	0	1	**3**	8	16
2.0	1.5	0	1	**4**	10	18
2.1	1.4	0	1	**5**	12	22
2.2	1.2	0	2	**7**	16	29
2.3	1.0	0	2	**10**	23	43
2.4	0.7	1	4	**19**	45	84
2.5	0.0	-	-	-	-	-

From table 4.1 it can be concluded that minimum sampling frequency per year can be four, if the expected composition is more than 95% CO_2 and uncertainty in the flow is less than 2%. This can substantially reduce the costs for monitoring the CO_2 concentration, if only four off-line analyses suffice, instead of continuous measurements.

In CATO2 deliverable 4.1.01 chapter five (CATO2 20101) the expected concentrations for three capture processes is given. For Post combustion Capture (amine absorption) the expected concentration is 99.5%, Pre combustion Capture (IGCC & physical absorption) 99.9% and for Oxyfuel (coal) 99.2% of CO_2. With these concentrations it would not be necessary to measure the CO_2 concentration continuously.

Conclusions:

The composition of a transferred CO_2 stream needs to be measured with a CEMS system. The required uncertainty for each measurement point of CO_2 flow of less than 2.5% shall be achieved. The combined uncertainty of flow and CO_2 concentration should than be less than 2.5%. A high uncertainty in either flow or compositions should be compensated in one of them. The transferred CO_2 would in most cases contain over 95% of CO_2. If the concentration is within such a narrow bandwidth, discrete sampling and subsequent analysis could suffice instead of using a CEMS. For a CO_2-concentration over 95% and an uncertainty in the flow measurement under 2%, doing four analyses a year would be sufficient. In that case one can refrain from using a CEMS for the CO_2-content. For a CEMS measurements in these pure CO_2-streams at high pressures the standard EN14181 is also not applicable.

4.2 Reasonable costs for investment in monitoring

In the MRG 2007 the following definition of "unreasonable costs" has been added: "*In respect to the choice of tier levels the benefit may correspond to the value of the allowances corresponding to an improvement of the level of accuracy. For measures increasing the quality of reported emissions but not having a direct impact on accuracy, the benefit may correspond to a fraction exceeding an indicative threshold of 1% of the average value of the allowances allocated to the installation for the previous trading period. For installations without this history, data from representative installations carrying out the same or comparable activities can be used as reference and scaled according to their capacity*."

This definition addresses the cost-benefit relation of a measure. The costs are incurred by the individual operator while benefits are harvested by all market participants. The definition is indicative as it is not clear how individual costs and societal benefits are to be balanced for each specific case. Therefore the ultimate responsibility for this decision rests with the competent authority. There are no agreed rules on how to calculate costs. Because of the indicative nature of these calculations it is recommended to keep the approach simple and divide investment costs over the full length of a trading period (i.e. 5 years) with an interest rate of zero.

In the Dutch guidance document for monitoring CO_2 under EU-ETS the calculation of reasonable costs is further elaborated (NEa, 2007). The NEa has developed two formulas to determine the unreasonable costs involved in meeting the uncertainty requirements for determining quantities of fuels or materials and other determination.

Formula one:
Unreasonable costs = (achieved uncertainty – required uncertainty) x annual CO_2 emissions x depreciation period x financial value of CO_2 emission allowance

With:

- achieved uncertainty : the actual uncertainty of the source stream concerned [%]
- required uncertainty : the required uncertainty for the source stream concerned [%]
- annual CO_2 emissions : the annual CO_2 emissions from the source stream concerned either determined or estimated [tonnes]
- depreciation period : a fixed depreciation period of five years [-]
- financial value of CO_2 emission allowance : established and published by the NEa [€]

The formula for calculating the investment which has to be made to achieve the required uncertainty is: cost of the meter x 2. The hardware costs must be substantiated, e.g. with a quote from a meter supplier. The factor 2 is intended to include the costs involved in installing a meter.

Example of calculation of unreasonable costs of a meter

Let us suppose that a source stream produces 100,000 tonnes of CO_2 per year. The amount is monitored with an uncertainty of 2.3%, although an uncertainty of 1.5% is required. A new metering device which would ensure that the uncertainty of the source stream meets the required uncertainty costs EUR 20,000.

Unreasonable costs for an investment in this source stream are: (2.3 – 1.5)% x 100,000 tonnes x 5 years x EUR15 per tonne = EUR 60.000. Improving the measurement uncertainty may therefore cost EUR 60,000. The actual costs are EUR 20,000 x 2 = EUR 40,000. Because EUR 40,000 < EUR 60,000, the cost of reducing the measurement uncertainty is not unreasonable in this example. The source stream concerned must therefore comply with the required tier.

This system should also be used when deviating from the required tier for continuous measurement of CO_2 emissions. The examples given in the individual chapters this approach are used to quantify reasonable costs for the metering of CO_2 according to the MRG-CCS guidelines.

Other unreasonable costs

The following formula is used to determine unreasonable costs involved in the other determinations (all determinations except for measurement uncertainties in quantity determinations and continuous CO_2 measurements):

Formula two:
Unreasonable costs = annual CO_2 emissions x financial value of CO_2 emission allowance x 1%

With:

- annual CO_2 emissions : determined or estimated [tonnes]
- financial value of CO_2 Allowance : established and published by the NEa [EUR]
- fixed factor : 1 [%]

Example of other unreasonable costs
Let us suppose a source stream being 1.5 Mtonnes of CO_2 emissions per annum. The analysis of the specific emission factor by an accredited laboratory costs EUR 22,000 a year.

Unreasonable costs for the analysis of the activity-specific emission factor are:

1% x 1,500,000 x EUR 15 = EUR 225.000.

Because the actual costs are lower than the unreasonable costs, the determination of the emission factor must comply with the required tier.

5 Uncertainty assessment of Capture Installations

5.1 Monitoring of capture under the MRG for CCS

The following cursive text is cited from the monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide (EU, 2010):

"Emissions are calculated using a complete mass-balance, taking into account the potential CO_2 emissions from all emission relevant processes at the installation as well as the amount of CO_2 captured and transferred to the transport network.

The emissions of the installation shall be calculated using the following formula:

$$E_{capture\ installation} = T_{input} + E_{without\ capture} - T_{for\ storage}$$

With:

$E_{capture\ installation}$ = Total greenhouse gas emissions of the capture installation

T_{input} = Amount of CO_2 transferred to the capture installation, determined in accordance with Annex XII and Section 5.7 of Annex I; If the operator can demonstrate to the satisfaction of the competent authority that the total CO_2 emissions of the emitting installation are transferred to the capture installation, the competent authority may allow the operator to use the emissions of the emitting installation determined pursuant to Annexes I to XII instead of using CEMS.

$E_{without\ capture}$ = Emissions of the installation if the CO_2 were not captured, i.e. the sum of the emissions from all other activities at the installation, monitored in accordance with the respective Annexes;

$T_{for\ storage}$ = Amount of CO_2 transferred to a transport network or a storage site, determined in accordance with Annex XII and section 5.7 of Annex I.

In cases, in which CO_2 capture is carried out by the same installation as the one from which the captured CO_2 originates, T_{input} is zero.

In cases of stand-alone capture installations, $E_{without\ capture}$ represents the amount of emissions that occur from other sources than the CO_2 transferred to the installation for capture, such as combustion emissions from turbines, compressors, heaters. These emissions can be determined by calculation or measurement in accordance with the appropriate activity specific Annex.

In the case of stand-alone capture installations, the installation transferring CO_2 to the capture installation shall deduct the amount T_{input} from its own emissions.

DETERMINATION OF TRANSFERRED CO_2
The amount of CO_2 transferred from and to the capture installation shall be determined in accordance with Section 5.7 of Annex I by means of CEMS carried out in accordance with Annex XII. As a minimum, Tier 4 as defined in Annex XII shall be applied. Only if it is shown to the satisfaction of the competent authority that this tier approach is technically not feasible, may a next lower tier be used for the relevant emission source.”

5.2 Capture example calculations

The CCS monitoring and reporting guidelines are comprehensive in their description of the calculation procedures. The CCS MRG are an amendment on the existing MRG, this implies that the rules that exist for the regular EU-ETS installations also apply for CCS installations. To show how these rules are interconnected and what they mean in practice for the required uncertainty of the monitoring an example CCS chain is made. This chain includes all steps from generation, capture, transport and storage. All calculation options for emissions and transfer are incorporated and the uncertainty calculations are explained.

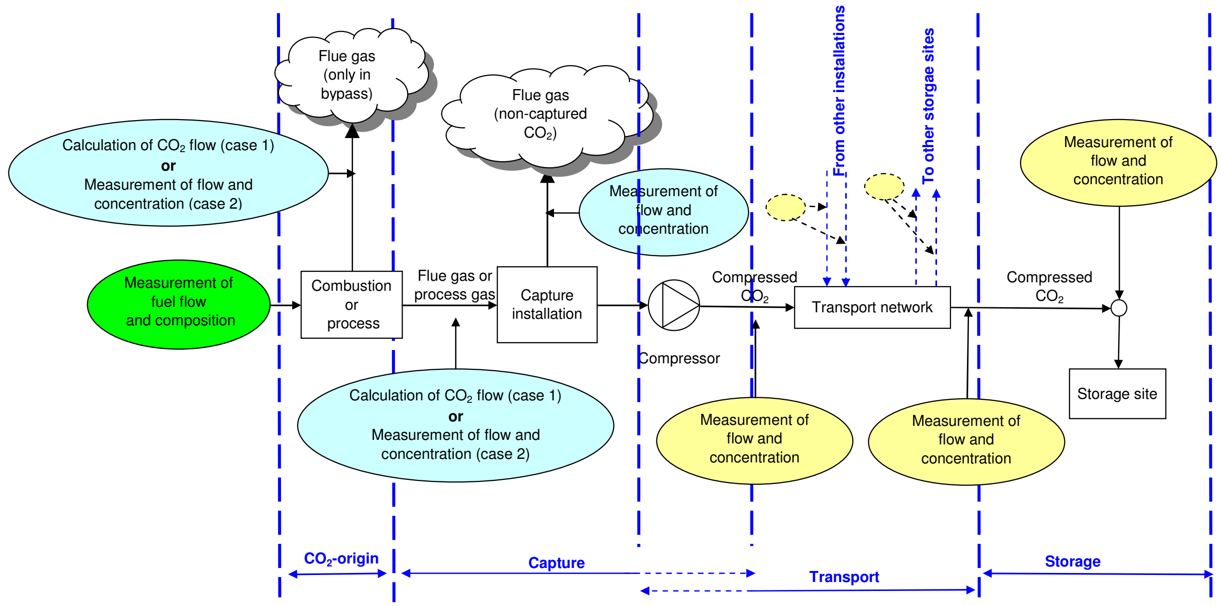

Figure 5.1 Overview of the monitoring over the CCS Chain

5.2.1 Stand alone capture installation

To illustrate the emission and uncertainty calculations an example is created. A fossil fuelled power plant with post-capture operation having a total CO_2 input from fuel of 2040 ktonnes CO_2.

At first it is assumed that the power plant partially transfers its CO_2 to a capture installation having an individual emission permit.

All installations under EU-ETS fall under a certain category (A, B or C), depending on the total emission of the installation <u>before transfer of CO_2</u>. The emission to base the installation category on is the sum of emissions to the atmosphere plus the transferred CO_2:

Emission before transfer = Emission (bypass) + Transferred CO_2
= 60 + 1980 = 2040 ktonnes

As this amount is larger than 500 ktonnes this installation will also be of category C. A category C installation has to attain the highest tiers of uncertainty for all its major sources.

Table 5.1. Example of the application of the MRG CCS for a combustion installation

	Emission			Source stream			Uncertainty		Reason-able costs
Installation (post combustion)	source kton	before transfer	relative	size	tier	max. un-certainty	kton	relative	
Total CO2 (from fuel)	2040	2040				1.5%			
Transferred CO2	**1980**				4	2.5%		7.0%	€ 6,682,500
				complete transfer:		2.5%		1.5%	€ 0
Emission (bypass)	60	Cat.C	2.9%	minor	1	7.5%	58.2	97%	€ 4,027,094
				measurement:			4.5	7.5%	

Total CO_2 = transferred CO_2
If the installation is able to transfer all its CO_2 input, the amount of transferred CO_2 is equal to the input of CO_2. The regular requirements for the uncertainty of the input would than be 1.5% (or 2.5% in case of a coal-fired power plant). The same uncertainty will than be assigned to the transferred CO_2 (1.5%) .

Transferred CO_2 = measured by CEMS
Transferred CO_2 involves measurement of flow and composition in the flue gas flow stream. The combined uncertainty of flow and composition should be no more than 2.5%. Continuous emission measurement systems for NO_x and SO_2 in flue gasses have a maximum allowed hourly uncertainty of 20%. Recalculated to an annual uncertainty this value halves to around 10%. CO_2 is present in high concentration, which makes it relatively easier to measure. But without additional measures and when calibrated according to EN 14181 it can not be expected to have a better uncertainty then 5%. For standard flow measurements the same maximum uncertainty 5% must be regarded taking into account the large ducts and inhomogenity in them. The combined uncertainty of flow and composition would at best be:

$$= \sqrt{(5^2 + 5^2)} = 7.0\%$$

This does not fulfil the criteria of 2.5% and would require an investment to improve it. The maximum amount can be calculated with the formula given in chapter four:

Unreasonable costs = (achieved uncertainty – required uncertainty) x annual CO_2 emissions x depreciation period x financial value of CO_2 emission allowance

= (7.0% - 2.5%) x 1980 ktonnes x 1000 x 5 year x 15 (€/ton) = €6,682,500

Emission (bypass)
A typical source of emission at a combustion installation, delivering its flue gas to a capture installation, can be the bypass emission. These situations can occur when:

- The capture installation is (partially) shut down, for example during maintenance, disturbances etc. Bypass emissions can be a substantial part. At partial shut down the amount of flue gasses to the capture installation and to the atmosphere have to be measured separately. At a complete shutdown of the capture installation the emission to the atmosphere can be monitored from the fuel input.
- During start-up or load variation of the combustion installation the capture installation is not able to process all emissions. In this case the emission to the atmosphere and transferred CO_2 have to be measured separately.
- The capture installation is not large enough to process all flue gasses. The distribution between combustion installation and capture plant both have to be measured continuously.
- The capture installation is (partially) shut down to increase the electric output of the combustion installation.

If the installation has other sources of CO_2, this source must be monitored as if it is a source of a regular combustion installation. In our example the size of the source 2.9% of the total emission, this implies it is a minor source. The total set of sources with combined emission of less than 10% of the total emission before transfer are minor sources. A minor source is allowed to be monitored with the lowest tier, in this case 7.5%. For the measurement of the (bypass) emission there are two options. Either as the difference between input and output or the emission source is measured directly.

The first option (2040 -1980 = 60) gives an extremely high uncertainty, as it is the difference of two large streams. The maximum uncertainty is calculated from the input and output uncertainty:

$$= \sqrt{((1.5\% \times 2040)^2 + (2.5\% \times 1980)^2)} = \sqrt{(30.6^2 + 49.5^2)} = 58.2 \text{ ktonnes}$$

On the total emission of this example this is 58.2 / 60 x 100% = 97%. This is much larger than the maximum allowed uncertainty of 7.5%. The reasonable cost for improvement to 7.5% is calculated according the equation of chapter four in this report:

= (97% - 7.5%) x 60 ktonnes x 1000 x 5 year x 15 (€/ton) = €4,027,094

If the cost of improvement in metering exceeds this amount, the cost can be considered unreasonable. If allowed by the competent authority, improvement in metering can be discarded. With this difference calculation the amount of unreasonable cost is more or less independent of the size of the emission source. If the source halves in size the relative precision nearly doubles. An example calculation on the bypass emission being 30 ktonnes instead of 60 ktonnes:

$$= \sqrt{((1.5\% \times 2040)^2 + (2.5\% \times 2010)^2)} = \sqrt{(30.6^2 + 50.3^2)} = 58.8 \text{ ktonnes}$$

On the total emission of this example this is 58.8 / 30 x 100% = 196%. Giving an almost equal value in the calculation for unreasonable cost:

= (196% - 7.5%) x 60 ktonnes x 1000 x 5 year x 15 (€/ton) = €4,241,250

The second option is to measure the flow and composition of the bypass stream directly. The uncertainty of measuring CO_2 in flue gas streams is already discussed above. If the stream is minor the required uncertainty is 7.5%, which is the minimum required tier (2) for CEMS in the Annex XII in the MRG for the reporting period 2008-2012. In a flue gas stream this uncertainty will be met. If the stream is major the required uncertainty will be 2.5%, which is now technically not feasible.

An option to improve the uncertainty is to measure the outgoing flow to the capture installation and to the atmosphere. The concentration of CO_2 in these output streams will be equal. The total input stream of CO_2 is calculated from the fuel input. This total input stream can then be divided by the ratio of both flow measurements. The CO_2 output concentration does not need to be measured and the uncertainty of the input CO_2 is relatively low.

5.2.2 Stand alone capture installation

An amount of 1980 ktonnes of CO_2 in the flue gas is received by the capture installation. The capture installation can have its own emission sources ($E_{without\ capture}$) and emissions because CO_2 will not be captured completely.

Table 5.2 Example of the application of the MRG CCS for a stand-alone capture installation

	Emission			**Source stream**			**Uncertainty**		**Reason-able costs**
Capture installation	**source kton**	**before transfer**	**relative**	**size**	**tier**	**max. un-certainty**	**kton**	**relative**	
Received CO2 (T_{input})	**1980**	2005							
Combustion ($E_{without\ capture}$)	25		1.2%	de minimis	-		1.9	7.5%	
Emission of process	99		4.9%	minor	1	7.5%	6.9	7.0%	
					mass balance:		68.3	55%	€ 3,531,421
Transferred CO2 (($T_{for\ storage}$)	**1881**				4	2.5%			
Emission ($E_{capture\ installation}$)	124	Cat.C							

The emission to base the installation category on is the sum of emissions to the atmosphere plus the transferred CO_2 to the transport network:

$$\text{Emission before transfer} = E_{without\ capture} + \text{Emission of process} + T_{for\ storage} = 25 + 99 + 1881 = 2005 \text{ ktonnes}$$

As this amount is larger than 500 ktonnes this installation will also be of category C.

Combustion
The combustion example of 25 ktonnes belongs to the sources with a combined emission of less than 2% of 2005 ktonnes. These are “de minimis” sources for which it is not required to achieve a defined tier. For a standard combustion emission it should also attain at least tier 1 = 7.5%.

Emission of process
The process emission of 99 ktonnes is a minor source. The first option to measure this emission is by direct measurement. Since it is a minor source stream the required uncertainty would be 7.5%. The composition of the process emission is largely dependent on the type of capture process. For example a post capture process would involve the normal flue gas flow stream with a concentration of CO_2 of about 1%. The flow monitoring of these streams is comparable to the monitoring of the transferred CO_2 in the flue gas stream to the capture plant.

The concentration measurement would however be more difficult at lower concentrations. The monitoring of N_2O with CEMS is of comparable difficulty, up till 2012 the required tier is 3, which corresponds to an maximum uncertainty of 5%. Considering this the combined uncertainty of flow and composition will also be no better than 7%. This is within the range of the maximum uncertainty.

The second option for quantification of the process emission is by a mass balance approach. The process emission is the difference of received CO_2 minus transferred CO_2.

$$\text{Process emission} = T_{input} - T_{for\ storage} = 1980 - 1881 = 99 \text{ ktonnes}$$

The maximum uncertainty calculated from the uncertainty of the input parameters than is:

$$= \sqrt{((2.5\% \times 1980)^2 + (2.5\% \times 1881)^2)} = \sqrt{(49.5^2 + 47.0^2)} = 68.3 \text{ ktonnes}$$

equals

$$= 68.3 / 99 \times 100\% = 55\% \text{ uncertainty}$$

The calculation of unreasonable cost gives:

$$(55.0\% - 2.5\%) \times 99 \text{ ktonnes} \times 1000 \times 5 \text{ years} \times 15 \text{ (€/ton)} = €3,531,421$$

It is obvious that in this case direct measurement is the preferred option.

If the process emissions are larger than 10% of total emission before transfer, it would be a major source stream for the installation. In that case it should attain the highest required tier. It is unclear from what type of process the tiers need to be chosen. The MRG CCS do not mention the process stream from capture installations as a possible source of emission. The most applicable will be the combustion of coal for which applies tier 3 which is associated with a maximum uncertainty of 2.5%. It can not be expected that a low uncertainty will be attained for the process emission.

5.2.3 Integrated capture installation

Instead of the previous example, another configuration will be an integrated combustion and capture plant with one emission permit. With the same figures the balance of the integrated plant will be:

Table 5.3 Example of the application of the MRG CCS for an integrated capture installation

Capture installation (integrated)	Emission			Source stream			Uncertainty		Reason-able costs
	source kton	before transfer	relative	size	tier	max. un-certainty	kton	relative	
Total CO2 (from fuel)	2040	2065				1.5%			
Combustion ($E_{without\ capture}$)	25		1.2%	de minimis	-		1.9	7.5%	
Emission (bypass)	60		2.9%	minor	1	7.5%	4.5	7.5%	
Emission of process	99		4.8%	minor	1	7.5%	6.9	7.0%	
					mass balance:	7.5%	56.1	35.3%	€ 2,064,560
Transferred CO2 (($T_{for\ storage}$)	**1881**				4	2.5%			
					complete transfer:	2.5%		1.5%	
Emission ($E_{installation}$)	184	Cat.C							

In principle there is not much difference between an integrated capture plant and separate plants. The same principles apply as the stand alone combustion and capture plant.

The emission to base the installation category on is the sum of emissions to the atmosphere plus the transferred CO_2 to the transport network:

$$\text{Emission before transfer} = E_{without\ capture} + \text{Emission (bypass)} + \text{Emission of process} + T_{for\ storage} = 25 + 60 + 99 + 1881 = 2065 \text{ ktonnes}$$

As this amount is larger than 500 ktonnes this installation will also be of category C.

Emission of process

The process emissions measured by a mass balance is relatively better because it is assumed that also the bypass emission is calculated from the mass balance.

$$= \sqrt{((1.5\% \times 2040)^2 + (7.5\% \times 25)^2 + (2.5\% \times 1881)^2)} = \sqrt{(30.6^2 + 4.5^{\wedge 2} + 47.0^2)} = 56.1 \text{ ktonnes}$$

equals

$$= 56.1 / 159 \times 100\% = 35.3\% \text{ uncertainty}$$

If the bypass emission or process emission would become a major emission at the installation, it needs to be measured with the highest tiers. For combustion installations this would be either tier 3 for coal or tier 4 for gas fired installations. For coal this means an uncertainty of maximum 2.5% and 1.5% for gaseous fuels. Installations have the opportunity to choose which sources fall under minor sources, as long as the combined emission of these sources is smaller than 10% of the total emission.

If the bypass emission is fluctuating in time, because of the capacity of the capture installation, the flow and composition need to be monitored continuously. As reasoned above for the separate installation it can not be expected that streams of flue gas can be measured with an uncertainty less than 1.5 or 2.5%.

Figure 5.2 Vattenfall Schwarze Pumpe CCS Oxyfuel demo plant

From the two examples for carbon capture a set of conclusions and recommendations can be drawn on the approach to attain the required measurement uncertainty of the MRG for CCS.

Conclusions:

Depending on the process at the capture installation and its physical operation two distinct CO_2 emission sources can be present, which are not mentioned in the CCS monitoring and reporting guidelines. A gas stream to the atmosphere containing the fraction of CO_2 that is not captured. And a flue gas stream to the atmosphere, when only a partial fraction of the flue gas goes to the capture or the capture plant is (partially) out of operation. The size of these streams can vary from nil up to being the largest emission of the capture plant. If these sources contribute together less than 10% of the emission, they are minor sources. When applying the tiers for combustion systems, would in that case mean that the required uncertainty could quite easily be met. When they are major sources it will be an unlikely to attain the highest tier levels.

The total emission of the capture installation could in principle be monitored by the difference between input and output stream of CO_2. Input stream would be the carbon content of the fuels, output the flow and concentration of the captured CO_2. This balance approach subtracts two large quantities with relatively small uncertainty, giving high uncertainty in the end result (tens of percent). This is not acceptable within the context of the monitoring and reporting guidelines for EU-ETS. The solution is to measure all individual emission to the atmosphere and transferred emission separately.

6 Uncertainty assessment of Transport Networks

6.1 Monitoring of transport under the MRG for CCS

The following cursive text is cited from the monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide (EU, 2010):

"Operators of transport networks may choose one of the following approaches:

METHOD A
The emissions of the transport network are determined using a mass balance according to the following formula:

$$Emissions\ [tCO_2] = E_{ownactivity} + \sum T_{IN,i} + \sum T_{OUT;j}$$

With:
Emissions = Total CO_2 emissions of the transport network [t CO_2];

$E_{own\ activity}$ = Emissions from the transport network's own activity (i.e. not stemming from CO_2 transported), like from fuel use in booster stations, monitored in accordance with the respective Annexes of these Guidelines;

$T_{IN,i}$ = Amount of CO_2 transferred to the transport network at entry point i, determined in accordance with Annex XII and Section 5.7 of Annex I;

$T_{OUT,j}$ = Amount of CO_2 transferred out of the transport network at exit point j, determined in accordance with Annex XII and Section 5.7 of Annex I.

METHOD B
Emissions shall be calculated taking into account the potential CO_2 emissions from all emission relevant processes at the installation as well as the amount of CO_2-captured and transferred to the transport facility, using the following formula:

$$Emissions\ [tCO_2] = CO_{2\ fugitive} + CO_{2\ vented} + CO_{2\ leakage\ events} + CO_{2\ installations}$$

With:
Emissions = Total CO_2 emissions of the transport network [tCO_2];

$CO_{2\ fugitive}$ = Amount of fugitive emissions [tCO_2] from CO_2 transported in the transport network, including from seals, valves, intermediate compressor stations and intermediate storage facilities;

$CO_{2\ vented}$ = Amount of vented emissions [tCO_2] from CO_2 transported in the transport network;

$CO_{2\ leakage\ events}$ = Amount of CO_2 [tCO_2] transported in the transport network, which is emitted as the result of failure of one or more components of the transport network;

$CO_{2\ installations}$ = Amount of CO_2 [tCO_2] being emitted from combustion or other processes functionally connected to the pipeline transport in the transport network, monitored in accordance with the respective Annexes of these Guidelines.

In choosing either Method A or Method B, the operator has to demonstrate to the competent authority that the chosen methodology will lead to more reliable results with lower uncertainty of the overall emissions, using best available technology and knowledge at the time of application for the greenhouse gas emissions permit, without leading to unreasonable costs. If Method B is chosen the operator shall demonstrate to the satisfaction of the competent authority that the overall uncertainty for the annual level of greenhouse gas emissions for the operator's transport network does not exceed 7.5 %.

Given that monitoring of CO_2 transferred to and from the transport network will in any case be carried out for commercial reasons, the operator of a transport network shall use Method A for validation of the results of Method B at least once annually. In this regard, for measurement of transferred CO_2 lower tiers defined in Annex XII may be used."

6.2 Transport example calculation

From the example of the capture installation the same data for the CO_2 stream going out of the capture installation (1881 ktonnes) is used as an example in a transport network. Later in this report the uncertainty for the whole measurement chain in CCS will be elaborated.

Table 6.1 Example of the application of the MRG CCS for a transport network

	Emission			Source stream			Uncertainty		Reason-able costs
Transport network	**source kton**	**before transfer**	**relative**	**size**	**tier**	**max. un-certainty**	**kton**	**relative**	
Received CO2 ($\Sigma T_{IN,i}$)	**1881**	1891							
Combustion	10		0.5%		-		0.8	7.5%	
Fugitive emissions	2		0.1%		-		0.6	30.0%	
Vented emissions	5		0.3%		-		0.3	5.0%	
Leakage emissions	3		0.2%		-		1.5	50.0%	
Method B			1.1%	de minimis	-	7.5%	1.8	9.0%	
Transferred CO2 ($\Sigma T_{OUT,j}$)	**1871**				4	2.5%			
Emission Method A	20	Cat.C		de minimis	-		66.3	332%	

The emission to base the installation category on is the sum of emissions to the atmosphere plus the transferred CO_2 to the storage site:

Emission before transfer = Combustion + Fugitive emissions + Vented emissions + Leakage emissions $\sum T_{OUT,j}$
= 10 + 2 + 5 + 3 = 1891 ktonnes

As this amount is larger than 500 ktonnes this installation will also be of category C.

Method B

The maximum allowed uncertainty for the sum of emission sources is 7.5% as stated in the MRG for CCS. Because the total emission of all sources is 20 ktonnes (= 1.1% of 1891 ktonnes) This means that one may apply approaches for monitoring and reporting using own no-tier estimation method for de minimis source streams (sources up to 2% of the emission before transfer and up to a total maximum contribution of 20 ktonnes CO_2).

Combustion

Combustion emission will fulfil the criteria for tier 1 easily; therefore an uncertainty is stated of 7.5% for a tier 1 emission source.

Vented emissions

Vented emission can be calculated if the volume, temperature and pressure of the transport system are available. Or if the amount of CO_2 is measured by flow measurement devices. In both cases the amount of CO_2 vented can be quantified with a relatively low uncertainty. In the example a value of 5% was chosen.

Fugitive or leakage emissions

These types of emissions are hard to quantify and even uncertainties are mostly unknown. The uncertainty of the fugitive emissions is mainly influenced by the largest emission sources. For a gas transport network the largest contributor will be at the compression stations, followed by seals and valves and the steel piping (e.g. flanges) of the network.

The MRG CCS state that the combined uncertainty of all sources must be smaller than 7.5%. As only one Tier is given it would also be the minimum required tier if it was a minor source. For the example the maximum uncertainty of a combustion emission (7.5%) is used. For fugitive and leakage emissions arbitrary values of 30% and 50% are chosen. In this example the combined calculated uncertainty is:

$$= \sqrt{((7.5\% \times 10)^2 + (30\% \times 2)^2 + (5\% \times 5)^2 + (50\% \times 3)^2)} = \sqrt{(3.2)} = 1.8 \text{ ktonnes}$$
$$= 1.8 \text{ ktonnes} / 20 \times 100\% = 9\%$$

As it does not fulfil the criterion of 7.5% one can use the rules on “de minimis” sources and use a no-tier approach.

The calculated uncertainty is the combined uncertainty of all emissions. When it is needed to reduce uncertainty the operator of the network needs to make a balanced decision which of the emission sources of the network to improve. This does not necessarily have to be the largest emission source or the one with highest uncertainty. In this example halving the uncertainty of the leakage emission from 50% to 25% brings the combined uncertainty from 9.0% to 6.2%.

Method A

When method A is applied the uncertainty of the emission of the transport network is based on a "mass balance". In that case the emission is calculated with:

$$\text{Emissions } [tCO_2] = E_{ownactivity} + \sum T_{IN,i} + \sum T_{OUT;j}$$

$$\text{Emissions } [tCO_2] = 10 + 1881 - 1871 = 20 \text{ ktonnes}$$

The calculated uncertainty of the transport network is maximum:

$$= \sqrt{((7.5\% \times 10)^2 + (2.5\% \times 1881)^2 + (2.5\% \times 1871)^2)} = 66.3 \text{ ktonnes}$$
$$= 66.3 \text{ ktonnes} / 20 \times 100\% = 332\%$$

The total emission is relatively small and because of the subtraction of two large numbers the relative uncertainty is enormous. The MRG CCS only state a required uncertainty on the method A calculation procedure for the amount of CO_2 transferred from and to the transport network. The requirements for this in- and output stream are 2.5%. These are separate requirements and probably met (TUVNEL, 2009). In this case it is also a de-minimis source, for which a no tier approach can be used. An additional problem is that because of the large uncertainty negative emissions could also be calculated. In that case the MRG for CCS do not give an approach for handling negative emissions.

The only requirement for choosing either method A or method B is that the operator has to demonstrate to the competent authority that the chosen methodology will lead to more reliable results with lower uncertainty of the overall emissions. Only in rare cases will method A delivers a more reliable result than method B. For example when the emission of the transport network is very large.

Method B will be the obvious choose. The operator of a transport network shall use Method A for validation of the results of Method B at least once annually. In this regard, for measurement of transferred CO_2 lower tiers defined in Annex XII may be used. This validation will not deliver a meaningful result as one compares the low absolute uncertainty of method B with the high uncertainty of method A. This will even be more the case if for the comparison lower tiers for method A are allowed.

Conclusions:

It is an option to measure the total emission of a transport network by the difference between input and output stream of CO_2. Input stream would be the CO_2 transferred to the network and output the CO_2 transferred to storage sites. This balance approach, given under “method A” in the MRG approach, subtracts two large quantities with relatively small uncertainty, possibly giving high uncertainty in the end result (hundreds of percent). This is not acceptable within the context of the monitoring and reporting guidelines for CCS, because one has to choose the method giving the lowest uncertainty. In case of the transport network this would most probably be “method B”, which involves measurement of all emissions from the transport network. Using method B would require to compare annually with method A, which is because of the extremely high uncertainty of “method A” an insignificant procedure. The overall uncertainty of all emission sources should not exceed 7.5%, being the required tier level. If the overall emission is under 2% of the emission before transfer and under 20 ktonnes it is a de-minimis source. The operator may apply approaches for monitoring and reporting using his own no-tier estimation method.

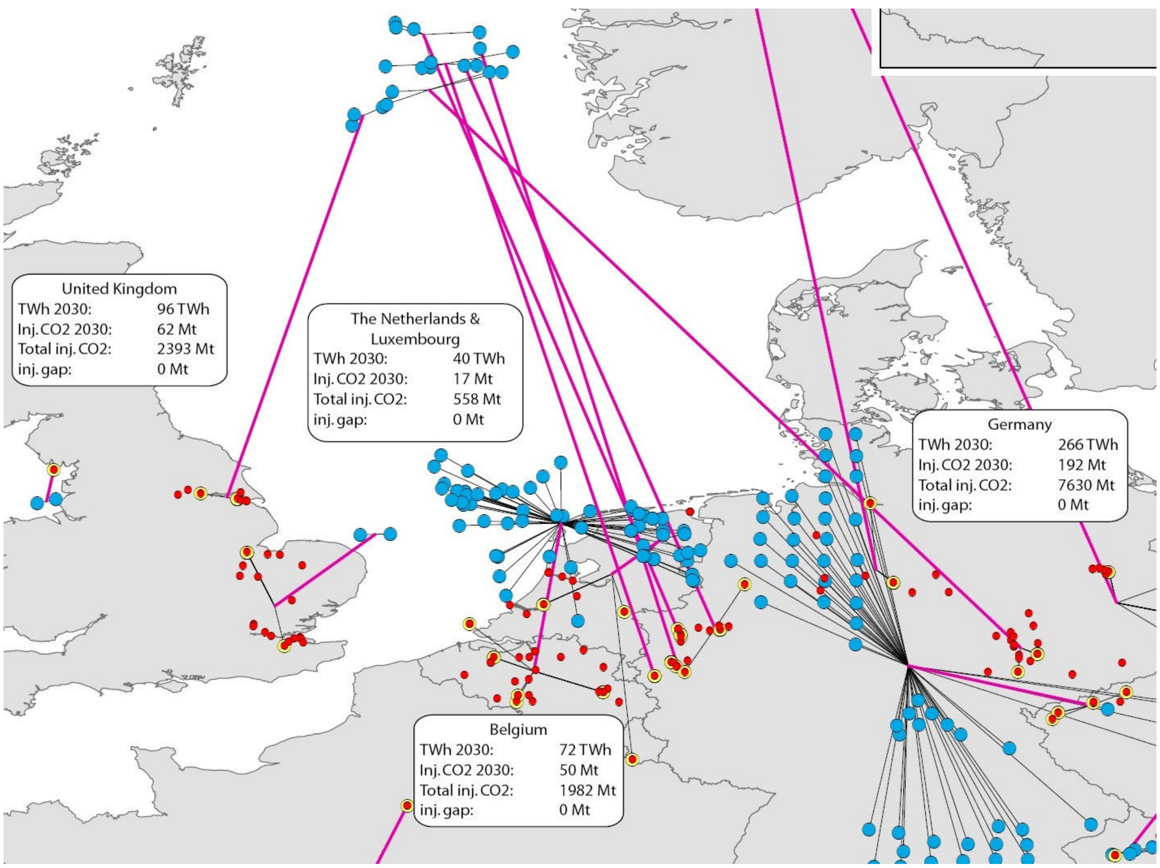

Figure 7.1 Example of a pipeline configuration in North-West Europe (from EU commission)

7 Uncertainty assessment of Storage Sites

7.1 Monitoring of storage under the MRG for CCS

The following cursive text is cited from the monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide (EU, 2010):

"Potential emissions sources for CO_2 emissions from the geological storage of CO_2 include:

- Fuel use at booster stations and other combustion activities such as on-site power plants. Combustion emissions from above ground activities shall be determined in accordance with Annex II of the MRG

- venting at injection or at enhanced hydrocarbon recovery operations,
- fugitive emissions at injection,
Emissions from venting and fugitive emissions shall be determined as follows:

$$CO_2 \text{ emitted } [tCO_2] = V\ CO_2\ [tCO_2] + F\ CO_2\ [tCO_2]$$

With

$V\ CO_2$ *= amount of* CO_2 *vented*

$V\ CO_2$ shall be determined by using CEMS according to Annex XII of these Guidelines. If the application of CEMS would lead to unreasonable costs, the operator may include in the monitoring plan an appropriate methodology based on industry best practice, subject to approval by the competent authority.

$F\ CO_2$ *= amount of* CO_2 *from fugitive emissions*

$F\ CO_2$ shall be considered as one source, meaning that the uncertainty requirements of Annex XII and Section 6.2 of Annex I apply to the total value and not to the individual emission points. The operator shall provide in the monitoring plan an analysis regarding potential sources of fugitive emissions, and provide a suitable documented methodology to calculate or measure the amount of $F\ CO_2$, based on industry best practice guidelines. For the determination of $F\ CO_2$ data collected pursuant to Article 13 and Annex II 1.1 (e) – (h) of Directive 2009/31/EC for the injection facility can be used, where they comply with the requirements of these Guidelines.

- breakthrough CO_2 from enhanced hydrocarbon recovery operations,
The combination of enhanced hydrocarbon recovery (EHR) with geological storage of CO_2 is likely to provide an additional source stream of emissions, namely the breakthrough of CO_2 with the produced hydrocarbons. Additional emission sources from EHR operations include:
- the oil-gas separation units and gas recycling plant, where fugitive emissions of CO_2 could occur,

- the flare stack, where emissions might occur due to the application of continuous positive purge systems and during depressurisation of the hydrocarbon production installation,
- the CO_2 purge system, to avoid that high concentrations of CO_2 extinguish the flare.

Any fugitive emissions occurring will usually be rerouted in a gas containment system, to the flare or CO_2 purge system. Any such fugitive emissions or CO_2 vented e.g. from the CO_2 purge system shall be determined in accordance to Section 2.2 of this Annex.

Emissions from the flare stack shall be determined in accordance with Annex II, taking into account potential inherent CO_2 in the flare gas

- leakage.
Monitoring shall start in the case that any leakage results in emissions or release to the water column. Emissions resulting from a release of CO_2 into the water column shall be deemed to be equal to the amount released to the water column.

Monitoring of emissions or of release into the water column from a leakage shall continue until corrective measures pursuant to Article 16 of Directive 2009/31/EC have been taken and emissions or release into the water column can no longer be detected.

Emissions and release to the water column shall be quantified as follows:

$$CO_{2\ emitted}\ [tCO_2] = \sum L\ CO_2\ [tCO_2 / d]$$

With

$L\ CO_2$ = mass of CO_2 emitted or released per calendar day due to the leakage. For each calendar day for which leakage is monitored it shall be calculated as the average of the mass leaked per hour [tCO_2/h] multiplied by 24. The mass leaked per hour shall be determined according to the provisions in the approved monitoring plan for the storage site and the leakage. For each calendar day prior to commencement of monitoring, the mass leaked per day shall be taken to equal the mass leaked per day for the first day of monitoring.

T_{start} = the latest of:
(a) the last date when no emissions or release to the water column from the source under consideration were reported;
(b) the date the CO 2 injection started;
(c) another date such that there is evidence demonstrating to the satisfaction of the competent authority that the emission or release to the water column cannot have started before that date.

T_{end} = the date by which corrective measures pursuant to Article 16 of Directive 2009/31/EC have been taken and emissions or release to the water column can no longer be detected.

Other methods for quantification of emissions or release into the water column from leakages can be applied if approved by the competent authority on the basis of providing a higher accuracy than the above approach.

The amount of emissions leaked from the storage complex shall be quantified for each of the leakage events with a maximum overall uncertainty over the reporting period of ± 7,5 %. In case the overall uncertainty of the applied quantification approach exceeds ± 7,5 %, an adjustment shall be applied, as follows:

$$CO_{2,\,Reported}\,[tCO_2] = CO_{2,\,Quantified}\,[tCO_2] \times (1 + (Uncertainty_{System}\,[\%]/100) - 0.075)$$

With
$CO_{2,\,Reported}$: Amount of CO_2 to be included into the annual emission report with regards to the leakage event in question;

$CO_{2,\,Quantified}$: Amount of CO_2 determined through the used quantification approach for the leakage event in question;

$Uncertainty_{System}$: The level of uncertainty which is associated to the quantification approach used for the leakage event in question, determined according to section 7 of Annex I to these guidelines.'EN 22.6.2010 Official Journal of the European Union L 155/47

7.2 Storage example calculation

For an example of a transport network the value for the CO_2 stream going out of the network (1871 ktonnes) is used. Later in this report the uncertainty for the whole measurement chain in CCS will be elaborated.

The annual emission of a storage complex will be relatively low (NETL, 2009). If there is no combustion or breakthrough emissions, negligible fugitive emission and if no venting or leakage occurs, the total emission will be negligible. For showing the implications when these streams do exist some were assigned a arbitrary emission.

In the example the total emission is 17 ktonnes which makes the storage site a category A installation. Because the emission of the installation is even smaller than 25 ktonnes, it can be monitored as an installation with a low emission. In that case the operator can use a simpler monitoring plan and estimate uncertainties from supplier information.

Table 7.1 Example of the application of the MRG CCS for a storage site

Storage site	Emission			Source stream			Uncertainty		Reason-able costs
	source kton	before transfer	relative	size	tier	max. un-certainty	kton	relative	
Received CO2	**1871**	17							
Combustion	5		29.4%	major	2	5.0%	0.3	5%	€ 0
Fugitive emissions (F CO2)	2		11.8%	major	-	2.5%	0.3	15%	€ 18,750
Vented emissions (V CO2)	0		0.0%	-	-	2.5%	0.0	5%	€ 0
Breakthrough emissions	0		0.0%	-	-	2.5%	0.0	10%	€ 0
Leakage emissions	10		58.8%	major	-	7.5%	5.0	50%	€ 318,750
To storage complex	1859								
Emission	17	Cat.A-					5.0	29.5%	

Combustion emissions

A combustion emission at a category A installation has to attain tier 2. This is a maximum uncertainty of 5%, what in general is not a problem to attain for the (fuel) measurement system of a combustion installation.

Fugitive emissions

The maximum allowed uncertainty for the determination of the total amount of fugitive emissions is 2.5%. It is not expected that such a low figure can be attained for diffuse emissions. It can well be that the number of places where fugitive emissions can occur are minimal. For example if the measurement point from the network to the storage site is at the storage site and no further compression is needed, fugitive emission will be minimal.

Vented emissions

Two types of vented emission could be distinguished:
A relatively small stream if compressors or piping needs to be vented. These are well controlled sources with known volumes, thus having a relatively low uncertainty. The other type of vented emission would involve venting of the storage site. Venting the storage would be an exceptional situation, done only in emergency circumstances. The CO_2 stream will than be substantial and the question is whether any meter will be installed to measure flow and composition, being able to measure this large stream.

The composition will be of major importance in this case, because the CO_2 will contain water, non condensable gasses and methane. Methane can be an important greenhouse gas, especially if depleted gas fields are used as storage site. The requirement to monitor methane is not stated in the MRG for CCS. If the stream is constant in its composition discontinuous sampling is an option for the composition.

Leakage emissions

Two types of leakage emission can be distinguished:

- gradual leakage, through undetected faults, fractures or wells, either through the water column and at land. Due to the vast area where these leakage emissions can occur it is absolutely not expected that the uncertainty of leakage emissions will be smaller than 7.5%

- abrupt leakage emissions occurs abrupt, through injection well failure or leakage up an abandoned well, injection points (blow-out), in high quantities accurate determinations of flow and composition are not possible

In the example a leakage emission of 10 ktonnes with an uncertainty of 50% is assumed. Using the Dutch method for reasonable cost calculation there needs to be spend:

= (50% - 7.5%) x 10 ktonnes x 1000 x 5 year x 15 (€/ton) = €318,750

at maximum for improvement of the metering system.

With the adjustment calculation for leakage in the MRG for CCS, the emission has to be raised with:

= (50% - 7.5%) x 10 ktonnes x 1000 = 4,350 ktonnes

With the previously assumed price of 15 (€/ton) gives an extra cost of €63,750

In this example the combined calculated uncertainty of all emissions is:

$= \sqrt{((5\% \times 5)^2 + (15\% \times 2)^2 + (50\% \times 10)^2)} = \sqrt{(25.2)} = 5$ ktonnes
= 5 ktonnes / 17 x 100% = 29.5%

At the beginning of this example, it was assumed that the installation is of category A. During the operation the CO_2 is not transferred to any other emission permit holder. Twenty years after closure of the storage site the responsibility and liability of the storage site can be surrendered to the state. This is including the emission permit. At that point it could be argued that all CO_2 is transferred. Following this line one could state that upon placement of the CO_2 in the storage complex, it is transferred to the state. Having an emission before transfer larger than 500 ktonnes, the storage site would then be a category C installation. Which is the same category as the capture installation and the transport network.

In the MRG for CCS only one tier level is given for the individual emission sources. For minor sources this tier would also be the lowest tier, being allowed for minor sources. De-minimis sources could be allowed to monitor without a given tier and any uncertainty of the monitoring system. This is beneficial for the monitoring, because otherwise relatively small sources need to be monitored with a disproportional low uncertainty.

Allowing the standard de-minimis approach of the MRG emission sources, automatically gives a graduated approach for the required uncertainty. In line with the system of major, minor and de-minimis of the MRG the following steps are proposed:

≤20 ktonnes: no tier and no maximum uncertainty
> 20 ktonnes and ≤100 ktonnes: maximum uncertainty 15%
>100 ktonnes: maximum uncertainty 7.5%

After closure of the storage site, monitoring can still occur, but the "emission before transfer" is zero. In that case it is advised to apply the same uncertainty requirements as before closure of the storage site.

The literature on storage sites mentions fluctuating quantities on leakage from storage sites (Damen, 2007). That analysis indicates an average cumulative CO_2 release to the biosphere of 0.2% of the initial stored CO_2 during 5000 years. Assuming a storage site with a storage capability of 50 million tonnes CO_2 will give an annual release of:

$$50 \times 10^6 \times 0.2\% / 5000 \text{ years} = 20 \text{ tonnes / year}$$

With regard to global risks, based on observations and analysis of current CO2 storage sites, natural systems, engineering systems and models, the fraction retained in appropriately selected and managed reservoirs is very likely to exceed 99% over 100 years, and is likely to exceed 99% over 1000 years. A reservoir size with 50 million tonnes of CO_2 would then give a leakage of:

$$50 \times 10^6 \times 1\% / 1000 \text{ years} = 500 \text{ tonnes / year}$$

Conclusions:

The storage site will probably always be a category A installation since it has no "emissions before transfer". Therefore the emission sources will be qualified as major and need to fulfil the most stringent uncertainty requirements. For fugitive, vented and breakthrough emission it is not expected that these will comply with the maximum uncertainty of 2.5%. Any leakage event shall be quantified with a maximum uncertainty of 7.5%. There is no threshold on the emission quantity from which this uncertainty needs to be attained. It should be considered to base the categorisation of storage sites also on the "emission before transfer". The system of de-minimis and minor sources can than be meaningful applied. The operator may then also apply approaches for monitoring and reporting using his own no-tier estimation method, as is allowed at the capture installation and storage network also.

The examples given for the different installation give a good insight how the calculations and uncertainty requirements would work out in a real situation. The subsequent calculation of the reasonable costs, if the required uncertainty is not attained, gives an indication on what would be the maximum required investment for improvement of the uncertainty.

8 Integral approach over the CCS chain

8.1 Analysis of uncertainty over the CCS chain

The 2007 version of the monitoring and reporting guidelines of the EU were mainly based on calculation of the emissions from the input sources. These inputs are mainly standard fuels being accurately metered and with relatively constant composition. The required uncertainty is stated by a tier system, in which the requirements depend on the average annual emission of the installation and the size of the sources within the installation. This system safeguards that the monitoring requirements for every source at an installation are neither too high nor too low. As such it prevents the operator to invest on monitoring systems that do not bring much extra on the uncertainty of the emission. On the other hand relevant sources are measured with the required uncertainty

In Europe the use of CEMS for monitoring CO_2 emission is rare. The combination of measuring the flue gas flow and its composition does not give the same uncertainty as measurement of the fuel input. In practice CEMS is only used if it is not possible to quantify the CO_2 stream through fuel or process inputs. The obligation to use EN14181 for the CEMS system makes the implementation of CEMS even more confusing. This is also experienced during the implementation of CEMS for the opt-in of N_2O in the EU-ETS. All requirements for CEMS under EN14181 are based on hourly values and requirements of the MRG based on the annual load.

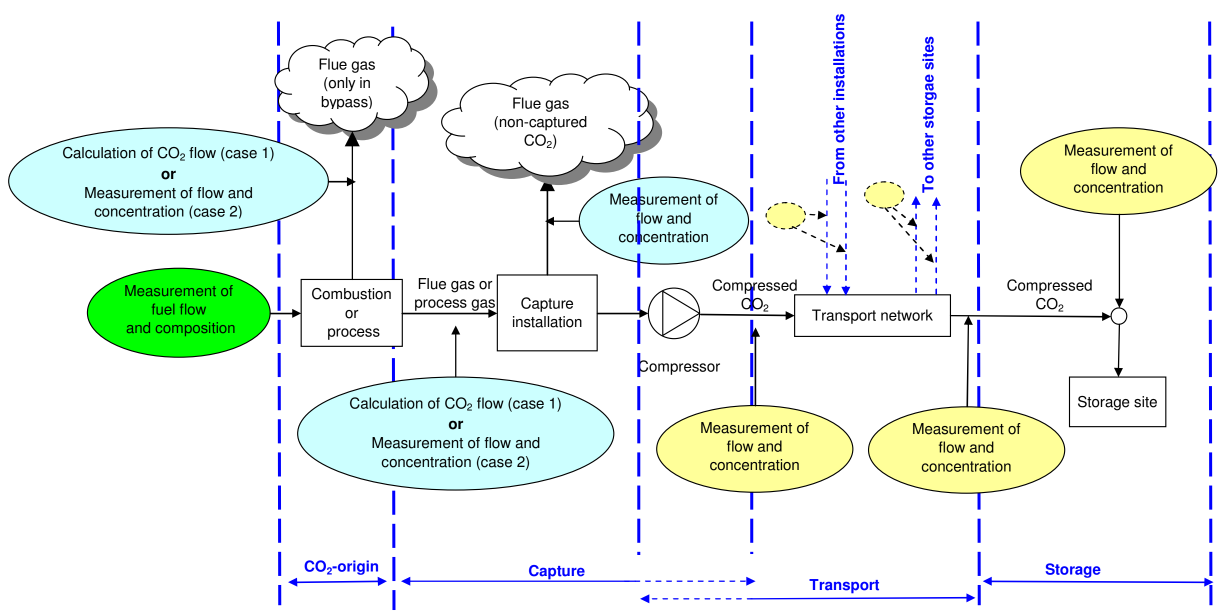

Figure 8.1 Overview of the monitoring over the CCS Chain

To analyse the balance in requirements for the emissions of capture, transport and storage the same example is used as for the individual cases. The requirements for the emission sources are compared to a situation as capture would not have occurred.

Table 8.1 Example of the application of the MRG CCS for the CCS-Chain

	Emission			Source stream			Uncertainty		Reason-able costs
Total Chain	**source kton**	**before transfer**	**relative**	**size**	**tier**	**max. un-certainty**	**kton**	**relative**	
Emission measurements	221				Fall-Back	5.0%	10.0	4.5%	
Emission balance	221	Cat.B			Fall-Back	5.0%	56.2	25.4%	€ 3,382,947
To storage	1859				4	2.5%	47.0	2.5%	
To storage (input + meas..)	1859	Cat.C			4	2.5%	32.3	1.7%	
Without capture	2040				4	1.5%	30.6	1.5%	

The total emission of the CCS chain can be measured from the sum of all emissions or as a balance between input and output plus the extra combustion emissions:

$$= \sum \text{capture emissions} + \sum \text{transport emissions} + \sum \text{storage emissions}$$
$$= 25 + 60 + 90 + 20 + 17 = 221 \text{ ktonnes}$$

With a calculated uncertainty of :

$$= \sqrt{((\text{uncertainty capture emissions})^2 + (\text{uncertainty transport emissons})^2 + (\text{uncertainty storage emissions})^2)}$$
$$= \sqrt{(1.9^2 + 4.5^2 + 6.9^2 + 1.8^2 + 5.0^2)} = 10.0 \text{ ktonnes}$$
$$= 10.0 / 221 \times 100\% = 4.5\%$$

Or:

$$= (\text{Total input - transferred to storage site}) + \text{combustion emission capture} + \text{combustion emission transport} + \text{emission of storage site}$$
$$= (2040 - 1871) + 25 + 10 + 17 = 221 \text{ ktonnes}$$

With a calculated uncertainty of:

$$= \sqrt{((2040 \times 1.5\%)^2 + (1871 \times 2.5\%)^2 + 1.9^2 + 0.8^2 + 5.0^2)} = 56.2 \text{ ktonnes}$$
$$= 56.2 / 221 \times 100\% = 25.4\%$$

It is obvious that in this example the total emission of the CCS chain can best be quantified by actual measurement of all the emission sources. Quantification by a mass balance in any place in the chain immediately gives very high uncertainties in this case. This does not hold true in any case, if the bypass emission of the integrated capture plant is about halve or more than the emission before transfer a mass balance approach gives satisfactory uncertainties.

The MRG give the so called fall back approach, if it is technically not possible or would lead to unreasonably high costs to apply tier 1. The uncertainty threshold for a Category B installation (50

- 500 ktonnes) is 5.0%. In the example this is attained by emission measurements but not at all for the balance approach.

The uncertainty of the transfer to the storage site can also be calculated in two different ways. From the uncertainty of the transfer to the storage site minus the emissions after that transfer or from the total input of fuels minus all the emissions in the CCS chain. In the first case the uncertainty is roughly equivalent to the meter uncertainty (2.5%). From the input side has an uncertainty that is slightly larger than the 1.5% on the uncertainty of the input side (1.7%).

In all steps of the CCS chain there are uncertainty requirements which are difficult to attain. Especially for the leakage emissions at the storage site, for which it is also expected that they are small and rarely happen. Not reaching the uncertainty thresholds for leakage at the storage site also gives an extra uncertainty penalty on the leakage emissions. In the next table a summary of all emissions in the example are given and compared with the uncertainty if capture would not have occurred.

Table 8.2 Example of the application of the MRG CCS over the complete CCS Chain

	Emission			Source stream			Uncertainty		Reason-able costs
Total Chain of Emission measurements	**source kton**		**relative**	**size**	**tier**	**max. un-certainty**	**kton**	**relative**	
Without capture	2040		100%		4	1.5%	30.6	1.5%	
Capture Emission	25		1.2%	major	4	2.5%	1.9	7.5%	
Bypass	60		2.9%	minor	1	7.5%	4.5	7.5%	
Process	99		4.9%	minor	1	7.5%	6.9	7.0%	
Transport	20		1.0%	de minimis	-	-	1.5	7.5%	
Storage	17		0.8%	de minimis	-	-	5.0	29.5%	
Total Chain	221		10.8%				10.0	0.5%	-€ 1,544,333

If capture would not have occurred the required uncertainty of the emission of the power plant would have been 1.5%. Note that the maximum uncertainty for a coal fired power plant would have been 2.5% (tier 3 for consumed fuel). At the capture installation the largest emissions will take place. Because of their size the uncertainty of these emissions have a large impact on the uncertainty of the total chain. In the example the total uncertainty of the emission of the storage site was 29.5%. Despite this high value total impact on the uncertainty of the measurement chain is minor.

In this example when capture would not have occurred the uncertainty of the emission would have been 30.6 ktonnes. With capture the total uncertainty of the emission would be 10.0 ktonnes = 0.5% of the emission of 2040 ktonnes. The uncertainty of the emissions has improved considerably by implementation of the CCS chain. For an uncertainty improvement of this size the reasonable costs would amount over EUR1.5 million.

Unreasonable costs = (achieved uncertainty – required uncertainty) x annual CO_2 emissions x depreciation period x financial value of CO_2 emission allowance

= (0.5% - 2.5%) x 2040 ktonnes x 1000 x 5 year x 15 (EUR/ton) = -EUR1,544,333

Conclusions:

The example shows that the overall uncertainty over the whole CCS-chain is considerably lower than it would have been if capture did not take place. The fact that the absolute uncertainty of the remaining emission to the atmosphere is much lower does not reflect in the requirements for the individual emissions at the CCS installations. Especially uncertainty criteria for the capture installation are extremely tight in relation to the capture installation and towards the criterion what would apply if the capture would not have taken place at all. As such the uncertainty requirements for the storage site are unbalanced in comparison with any other installation in the EU-ETS system. This is an extra reason to allow the storage site to use approaches for monitoring and reporting using his own no-tier estimation method.

8.2 The network as the spider in the monitoring web

At the beginning of the transport network the amount of transferred CO_2 is measured. The MRG for CCS do not state who has to perform the measurements at the transfer point. It could be the capture installation, transport network, both or even an external organisation. It is sufficient that one party performs the measurements and makes them available to the capture installation and the transport network. The same situation applies to the transfer point from the transport network to the storage site. All the permit holders involved have the need for timely information of the CO_2 transferred.

The network operator could also be the organisation who performs the metering at the capture and storage site. This would in fact be a similar situation as for the natural gas transport network in the Netherlands operated by Gas Transport Services. This network also operates the gas metering at point of transition to the user. This metering of natural gas has to meet the requirements of the so called “meetcode gas”. This "meetcode" stated maximum uncertainties for the flow and composition, dependent on the operating range and capacity of the flow meter.

At this moment a number of advantages can be seen when the operation of a CO_2 network would go in a similar way:

- The measurement at the transfer points takes places with a predefined and guaranteed quality of the metering systems for flow and composition. In the monitoring plans for CO_2 in the Netherlands there can always be referred to the “meetcode gas” to account for the measurement uncertainty of the natural gas supply. So on this point the effort is nil for the permit holders. Transparency of the metering systems will also ease the third party access to the transport network and data.
- The quality assurance and control of the metering system at the capture installation and storage site is not the responsibility of the permit holder. Because of their important role in the financial transactions the measurement systems will probably be implemented redundantly (double meters). Measurement values from the metering system are nearly always available and if not procedures for data restoration are in place. This also simplifies the content of the

monitoring plan and independent verification of the annual emission report of the capture installation and storage site. Calibration, maintenance and testing of the metering systems can be optimized and standardized.

- The monitoring of composition could be limited to the transfer points from capture installation to the network. From these input concentrations and the distribution in the network the output concentration can be calculated. The same holds for the concentration of polluting (or corrosive) components and the amount of CO_2 originating from biomass. The network operator has to safeguard that no pollutants are added in the network. From the window of concentrations, of all capture installations feeding in the network, the integrity of the CO_2 streams to the storage sites can be controlled. The physical properties can also be calculated to provide the necessary data for handling and transporting the CO_2 throughout the different parts of the CCS network and for flow measurement purposes.
- The information stream on flow and concentrations can be supplied to all installations at the transfer points continuously (e.g. on a five minute basis). This also delivers the necessary data to determine and calculate the physical properties and phase envelope at various points. Concentrations of interfering components of which the concentration needs to stay below certain limits (water, sulphur etc.) can be optimised.
- The network organisation would be a neutral organisation; it has no interest in deliberately measuring to low or high values. Double metering at a transfer point, its averaging and explanation of differences can be avoided.

Conclusions:

There are many arguments that plead for the transport network to play an important role in the monitoring at the transfer points. The main advantages lie in the fulfilment of the required uncertainty, the continuous availability of measurement data, Quality assurance of the metering systems, safeguarding and control of the composition of the CO_2-streams and the neutrality of the organisation.

8.3 Overlap of the MRG CCS with the CCS directive

Several areas of overlap between monitoring under the Storage Directive (EU, 2009) and the ETS Directive exist. Emissions from injection have to be quantified under both Directives (FENCO-ERA, 2009). Art. 13.2 of the Storage Directive also requires that the monitoring under the ETS Directive be included in the monitoring plan. For quantification approaches for leakage from the storage reservoir a standard format does not yet exist. As there is no experience with leakage events at storage sites so far and the approaches to be used are not yet clear, it seems advisable, to leave flexibility in setting up this format.

In the paragraph above it is argued that the network organisation who performs a central role in the monitoring of the input in the network can be of great benefit to the capture installation and even more to the storage site. The citations from the Storage directive are in *Italic and the* *important monitoring requirements underlined*. In between the text from the storage directive is indicated how and whether the criterion is fulfilled.

Window of concentration
"(27) It is necessary to impose on the composition of the CO_2 stream constraints that are consistent with the primary purpose of geological storage, which is to isolate CO_2 emissions from the atmosphere, and that are based on the risks that contamination may pose to the safety and security of the transport and storage network and to the environment and human health. To this end, the composition of the CO_2 stream should be verified prior to injection and storage. The composition of the CO_2 stream is the result of the processes at the capture installations.

If the window of concentrations at the capture installations is known to the transport network, it can calculate with what concentrations the CO_2 stream arrives at the storage site. If the input concentrations are known at any given moment or the maximum concentration of components can be safeguarded it can be prevented that at any moment the concentrations do not fulfil the criteria of the storage site

Monitoring for acceptance
Following inclusion of capture installations in Directive 85/337/EEC, an environmental impact assessment has to be carried out in the capture permit process. Inclusion of capture installations in Directive 2008/1/EC further ensures that best available techniques to improve the composition of the CO_2 stream have to be established and applied. In addition, in accordance with this Directive, the operator of the storage site should only accept and inject CO_2 streams if an analysis of the composition, including corrosive substances, of the streams, and a risk assessment have been carried out, and if the risk assessment has shown that the contamination levels of the CO_2 stream are in line with the composition criteria referred to in this Directive.

Article 7.4 the total quantity of CO_2 to be injected and stored, as well as the prospective sources and transport methods, the composition of CO_2 streams, the injection rates and pressures, and the location of injection facilities

Article 9 The permit shall contain at least the following: the requirements for the composition of the CO_2 stream and the CO_2 stream acceptance procedure pursuant to Article 12, and, if necessary, further requirements for injection and storage in particular to prevent significant irregularities;

Article 12-3: Member States shall ensure that the operator:
(a) accepts and injects CO_2 streams only if an analysis of the composition, including corrosive substances, of the streams and a risk assessment have been carried out, and if the risk assessment has shown that the contamination levels are inline with the conditions referred to in paragraph 1;
(b) keeps a register of the quantities and properties of the CO_2 streams delivered and injected, including the composition of those streams.

The three points underlined above can also be fulfilled if the network operator has the ability to predict what the concentration at the storage site will be at any given (future time). Composition is known from the measurements at the input side, or specifications provided by the storage site and the mixing and flows in the network. Total quantities are known to the network anyhow and the requirements for acceptance of the CO_2 stream can be checked to the acceptance criteria on a continuous basis.

Reporting to the authorities

Article 13.2: The monitoring shall be based on a monitoring plan designed by the operator pursuant to the requirements laid down in Annex II, including details on the monitoring in accordance with the guidelines established pursuant to Article 14 and Article 23(2) of Directive 2003/87/EC, submitted to and approved by the competent authority pursuant to Article 7(6) and Article 9(5) of this Directive. The plan shall be updated pursuant to the requirements laid down in Annex II and in any case every five years to take account of changes to the assessed risk of leakage, changes to the assessed risks to the environment and human health, new scientific knowledge, and improvements in best available technology. Updated plans shall be re-submitted for approval to the competent authority.

Article 14.2 At a frequency to be determined by the competent authority, and in any event at least once a year, the operator shall submit to the competent authority:
2. the quantities and properties of the CO_2 streams delivered and injected, including composition of those streams, in the reporting period, registered pursuant to Article 12(3)(b);

Annex II 1.1: The parameters to be monitored are identified so as to fulfil the purposes of monitoring. However, the plan shall in any case include continuous or intermittent monitoring of the following items:
(e) fugitive emissions of CO_2 at the injection facility;
(f) CO_2 volumetric flow at injection wellheads;
(g) CO_2 pressure and temperature at injection wellheads (to determine mass flow);
(h) chemical analysis of the injected material;
(i) reservoir temperature and pressure (to determine CO_2 phase behaviour and state).

The above can be provided by the network operator(s) who supplies to the storage site. The monitoring of leakage (if occurring) and fugitive emissions is the responsibility of the storage site permit holder. The need for measurement of pressure and temperature is dependent on the type of metering system. Chemical analysis can come from the input and calculations of the network monitoring system. For checks the injected material can be analysed by discrete sampling and off-line analysis.

EU-ETS monitoring in the storage monitoring plan

Leakage detection takes place under the monitoring for the Storage Directive. Where leakage is detected or where significant irregularities occur, which might lead to leakage, the storage site operator has to inform the competent authority under the Storage Directive as well as the competent authority responsible under the ETS Directive. In case leakage has occurred, the latter includes the leakage event as new emission source in the ETS permit of the storage site.

The Storage directive requires to include the details of monitoring for the MRG to be included in the monitoring plan for the storage directive. The monitoring plan for the Storage directive will be extensive with many different methodologies and conclusions on it (North Sea Basin Task Force, 2009). The monitoring for EU-ETS of the storage site will be minor. Leakage will be probably not be suspected, enhanced oil recovery is rare in Western Europe and combustion emissions do not necessarily occur. Depending on the type of storage only a reduction in pressure is done, in which case also the fugitive emission is nil.

Remains the total amount of injected CO_2. The validated figures could be delivered by the transport network on a monthly basis. Probably the network organisation has calculated them already to tonnes of pure CO_2. The main requirements for the storage site is to sum the monthly transferred tonnes of CO_2 to an annual amount of transferred CO_2, validate this figure and report it to the emission authority. It is questionable whether this relatively simple procedure should be incorporated in the monitoring plan for the storage directive. Common procedure for monitoring plans for EU-ETS is that they are approved by the emission authority. When there are a lot of information and procedures not relevant to the EU-ETS monitoring plan, this will jeopardize the approval by the emission authorities.

The Storage directive requires that the monitoring for EU-ETS is incorporated in the monitoring plan for the Storage directive. In the supply of information the network operator can also play a major role. In many cases the monitoring and reporting effort for EU-ETS at the storage site would be minimal. It is advisable that the emission authority only receives the part that handles on the EU-ETS monitoring. Otherwise it will bother any verifier and the emission authority with unnecessary information and procedures.

9 Conclusions and recommendations

In the introduction to the Monitoring and Reporting guidelines for the EU-ETS system the system for major, minor and de-minimis sources, fall back approach and category of installation is introduced. The applicability of these rules is shown for the measurement system at capture, transport and storage installations. The precise implementation of these rules is of great importance for such installations as it can ease uncertainty requirements for the monitoring, especially at minor and de-minimis sources.

Depending on the process at the capture installation and its physical operation it can have two distinct CO_2 emission sources. A gas stream to the atmosphere containing the fraction of CO_2 that is not captured. A flue gas stream to the atmosphere, when only a partial fraction of the flue gas goes to the capture or the capture plant is (partially) out of operation. The size of these streams can vary from nil up to being the largest emission of the capture plant. If these sources contribute together less than 10% of the emission, they are minor sources. When applying the tiers for combustion systems on them would in that case mean that the required uncertainty could quite easily be met. When they are major sources it will be a hard case to attain the highest tier levels.

The total emission of the capture installation could in principle be monitored as the difference between input and output stream of CO_2. Input stream would be the carbon content of the fuels, output the flow and concentration of the captured CO_2. This balance approach subtracts two large quantities with relatively small uncertainty, giving high uncertainty in the end result (tens of percent). This is not acceptable within the context of the monitoring and reporting guidelines for EU-ETS. The solution is to measure all individual emission to the atmosphere and transferred emission separately.

The composition of a transferred CO_2 stream needs to be measured with a CEMS system. The required uncertainty for each measurement point of CO_2 flow of less than 2.5% shall be achieved. The combined uncertainty of flow and composition should than be less than 2.5%. A high uncertainty in either flow or compositions should be compensated in one of them. The transferred CO_2 would in most cases contain over 95% of CO_2. Within a so narrow bandwidth, discrete sampling and subsequent analysis could suffice instead of using a CEMS. For a CO_2-concentration over 95% and an uncertainty in the flow measurement under 2%, four analyses a year would be sufficient. In that case one can refrain from using a CEMS for the CO_2-content. For CEMS measurements in these pure CO_2-streams at high pressures the standard EN14181 is not applicable as it is applicable for flue gasses.

It is an option to measure the total emission of a transport network as the difference between input and output stream of CO_2. Input stream would be the CO_2 transferred to the network and output the CO_2 transferred to storage sites. This balance approach, given under “method A” in the MRG approach subtracts two large quantities with relatively small uncertainty, giving high uncertainty in the end result (hundreds of percent). This is not acceptable within the context of the monitoring and reporting guidelines for CCS, because one has to choose the method giving the lowest uncertainty. In case of the transport network this would be “method B”, which involves measurement of all emissions from the transport network. Using method B would require to compare annually with method A, which is because of the extreme high uncertainty of “method A” an obsolete procedure. The overall uncertainty of all emission sources should not exceed 7.5%, being the required tier level. If the overall emission is under 2% of the emission before transfer and under 20 ktonnes it is a de-minimis source. The operator may apply approaches for monitoring and reporting using his own no-tier estimation method.

The storage site will probably always be a category A installation since it has no “emissions before transfer”. Therefore the emission sources will be qualified as major and need to fulfil the highest tier level. For fugitive, vented and breakthrough emission it is not expected that these will comply with the maximum uncertainty of 2.5%. Any leakage event shall be quantified with a maximum uncertainty of 7.5%. There is no threshold on the emission from which this uncertainty needs to be attained. It should be considered to base the categorisation of storage sites also on the “emission before transfer”. The system of de-minimis and minor sources can than be meaningful applied. The operator may then also apply approaches for monitoring and reporting using his own no-tier estimation method, as is allowed at the capture installation and storage network also.

The examples given for the different installation give a good insight how the calculations and uncertainty requirements would work out in a live situation. The subsequent calculation of the reasonable costs, if the required uncertainty is not attained, gives an indication on what would be the required investment for improvement of the uncertainty.

It is shown that measurement of all sources is the preferred option in most cases for reaching the lowest uncertainty. If the Fall-Back approach of the monitoring and reporting guidelines would be used for all emissions in the CCS-chain the maximum uncertainty for a category B installation would be attained with measurements. This is not the case if a balance approach is used at any step in the CCS-chain.

With CCS the absolute uncertainty of the remaining emission to the atmosphere is much lower, but this does not reflect in the requirements for the individual emissions at the CCS installations. Especially uncertainty criteria for the capture installation are extremely tight in relation to the capture installation and towards the criterion what would apply if the capture would not have taken place at all. As such the uncertainty requirements for the storage site are unbalanced in comparison with any other installation in the EU-ETS system. This is an extra reason to allow the storage site to use approaches for monitoring and reporting using their own no-tier estimation method.

There are many arguments that plead for the transport network to play an important role in the monitoring at the transfer points. The main advantages lie in the fulfilment of the required uncertainty, the continuous availability of measurement data, Quality assurance of the metering systems, safeguarding and control of the composition of the CO_2-streams and the neutrality of the organisation.

The Storage directive requires that the monitoring for EU-ETS is incorporated in the monitoring plan for the Storage directive. In the supply of information the network operator can also play a major role. In many cases the monitoring and reporting effort for EU-ETS at the storage site would be minimal. It is advisable that the emission authority only receives the part that handles on the EU-ETS monitoring. Otherwise it will bother any verifier and the emission authority with unnecessary information and procedures.

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