CCS with EOR, assessing the suitability of existing monitoring regulations

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1 Executive Summary

EOR is currently presented as a solution to make CCS projects an attractive business case. This report explores how EOR fits under the current regulation for CCS and how EOR can be operated within the EU ETS3 monitoring and reporting guidelines. Does EOR fit in the existing regulations or are there significant hurdles?

When the regulatory aspects are compared for the situation where a CCS project with a ‘pure’ storage location is expanded to a ‘CCS-as-EOR’ project it can be concluded that only the application for a permit and the modeling in the exploration phase might become more complex. The situation does not become substantially different or more complex for the exploitation and closure phases. On the other hand, when an EOR project is expanded to a ‘CCS-as-EOR’ project a series of additional regulatory hurdles has to be managed. In the exploration phase a formal exploration permit and extensive modeling are required. Before the exploitation phase can start some critical financial security and liability issues have to be settled and an extensive monitoring has to be in place. After decommissioning of the site the monitoring has to be continued before the site can be transferred accompanied with a payment.

The concept of ETS-CCS injection into a reservoir (‘permanent storage’) while simultaneous hydrocarbon production is taking place from the same reservoir requires an accurate and strict bookkeeping to maintain ETS-credibility.

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2 Abbreviations

(this refers to abbreviations used in this document)

CBT	Cross Border Transport
CCS	Carbon Capture & Storage
CCTS	Carbon Capture, Transport & Storage
EGR	Enhanced Gas Recovery
EHR	Enhanced Hydrocarbon Recovery
EOR	Enhanced Oil Recovery
ETS	Emission Trading System
ETS3	Third Trading Period of the Emission Trading System
EU	European Union
MMP	Minimum Miscibility Pressure
OOIP	Original Oil in Place
SWAG	Simultaneous Water Alternate Gas (injection)
TPA	Third Party Access
WAG	Water Alternate Gas (injection)

3 Introduction: Background & rationale

EOR or Enhanced Oil Recovery is a technique to increase the oil production from an existing oil well by injecting a substance into the oil reservoir. Different materials can be injected, like (hot) water, CO_2 or other chemicals. EOR is also frequently referred to as EHR (or Enhanced Hydrocarbon Recovery), which also comprises EGR (or Enhanced Gas Recovery). Most of the content of this report is applicable to both recovery techniques, but the more common expression EOR will be used in the remainder of this report.

The CO_2 applied as injection material in an EOR application can be supplied by a fossil CO_2 capture process. Since the CO_2 is injected into an underground reservoir, the combination of fossil CO_2 capture and subsequent EOR injection could be classified as CCS (Carbon Capture and Storage). This useful application of the CO_2-injection creates an economic advantage which might help to close the business case for CCS projects. However, the European Union Emissions Trading System (or EU ETS) Monitoring & Reporting Guidelines on CCTS (Carbon Capture, Transport and Storage) (Commission regulation No. 601/2012 of 21 June 2012) and the EU CCS Directive (2009/31/EC of 23 April 2009) were not formulated in the anticipation of ‘CCS-as-EOR’ projects.

This report explores how CCS-as-EOR fits under the current CCS regulation as established in the CCS Directive and how a CCS-as-EOR project can be operated within the monitoring and reporting guidelines of the EU ETS3 (the third emissions trading period operating between 2013-2020). Before the applicable regulation and requirements are explored, first the basic concepts of the EOR techniques are introduced and discussed. The final chapter on system boundaries tackles the issue of the net emission reduction obtained with CCS and CCS-as-EOR projects compared with the baseline situation without CCS.

3.1 Research Objectives

EOR is currently presented as a solution to get CCS projects up and running. After a short familiarization with the technique, we will explore how EOR fits under the current regulation for CCS and how EOR can be operated within the EU ETS3 monitoring and reporting guidelines. Does EOR fit in the existing regulations or are there significant hurdles?

4 Introduction to EOR and Oil Production

Three different stages can be discriminated in the life cycle of an oil well:

- In the primary production phase of an oil reservoir the oil is produced using the pent-up pressure in the well fluids. Oil comes out of the well mixed with water, solids and/ or gas, this mixture is called the well fluid. Eventually, the pressure inside the well has reduced which results in a drop in oil production. At this point most of the oil is still trapped in the reservoir, and only 10-20% of the original oil content has been brought to the surface. A commonly used acronym related to these quantity ratios is OOIP or ‘Original Oil in Place’.

- In the secondary production phase a substance, usually water, is injected to re-pressurize the formation reservoir. The injected fluid sweeps the oil to the remaining production wells. This secondary production phase is often very efficient and can produce an equal or greater volume of oil than was produced in the primary phase of production. At this point 50-70% of the oil (OOIP) is still trapped in the reservoir, and some additional 20-30% of the original oil content has been brought to the surface in this phase.

- In the tertiary production phase a substance is injected into the oil reservoir that interacts with the oil to change the properties of the oil mixture and allow it to flow more freely within the formation reservoir. Such techniques are lumped into the category called EOR or Enhanced Oil Recovery. One of the more proven of these methods is the injection of CO_2 flooding. Pure CO_2 (>95%) mixes with the oil to produce a lighter mixture with a lower viscosity that detaches more easily from the rock surfaces. The high CO_2 purity is required since the presence of small contaminations of non-condensable gases can increase the MMP or Minimum Miscibility Pressure considerably. Below the MMP the CO_2 does not mix with the oil in the reservoir. A series of different techniques has been developed over time, ranging from continuous CO_2 injection, WAG or Water-Alternate-Gas injection (a combination of water flooding and gas injection), SWAG (or Simultaneous Water-Alternate-Gas injection), to a hybrid WAG process (starting with continuous CO_2 injection followed by WAG). The selection of the technique is determined by the local conditions and other factors like for instance the availability of CO_2. In this tertiary production phase again some additional 20% of the original oil content can be brought to the surface.

4.1 EOR Economics

The availability of low-cost high-purity CO_2 can be a critical factor in the decision to apply EOR. Examples are the existing EOR projects in the USA based on rich natural resources of CO_2. The CO_2 produced in a CCS-capture process could also be applied in an EOR project. The combination of CCS and EOR would create an efficient usage of the CO_2 stream, instead of just storing the CO_2 underground. The combination of the two technologies might result in an attractive business case, which could not have been obtained without giving the captured CO_2 this useful application. Given the current low carbon prices, EOR could be the solution for CCS project to arrive at a healthy business case.

In the CCTS chain from CO_2 source to CO_2 sink all the constituting elements will rarely be controlled and operated by a single company. There is also no formal need to build consortia specifically for CCS projects since the chain connections and transfers can be settled in business contracts. This situation does not change for CCS-as-EOR projects. One of the possible business models for such a project would be that the captured CO_2 would be transported to the EOR storage location. At this point the formal ETS-transfer of the CO_2 takes place. Up to this location of physical transfer all costs and all liabilities are taken care of by the party generating the emissions. Once transferred the oil production company accepts all further costs and liabilities for handling and storage of the CO_2. The financial advantage for the emission generator is the reduced number of EU emission rights that has to be handed over to the national emission authorities, whereas the EOR operator (or oil producer) receives the required quantities of CO_2 on location. The balance can of course be negotiated among these two parties. This mutual gain or 'win-win' situation is significantly different from the non-EOR CCS-situation where the storage operator only provides the CO_2 storage service. The storage operator receives a fee for this service, but has in return to accept the long lasting liability for the stored CO_2 including the provision of financial securities.

It is important to realize that the application of such EOR techniques is not technically possible and/or economically feasible at each and every oil reservoir; EOR is not the 'silver bullet' in the oil production industry. The specific local conditions decide whether EOR can be applied for a given oil reservoir, and if so, whether CO_2 is the most suitable injection material for that given oil well. Since the principle economic motivation to apply EOR will be the production of oil and not so much the storage of CO_2, the local geology and oil production conditions will determine if and which EOR technique is applied. With the current low CO_2 ETS-value prices this priority order situation is not likely to change.

A further consequence of the obvious priority for oil production over CO_2-storage is that the CO_2-injection rates are determined by the EOR process and not so much by the available CO_2 quantities. A much quoted graph illustrates the variation of the injected CO_2 quantity in EOR applications over time, see figure 4.1.

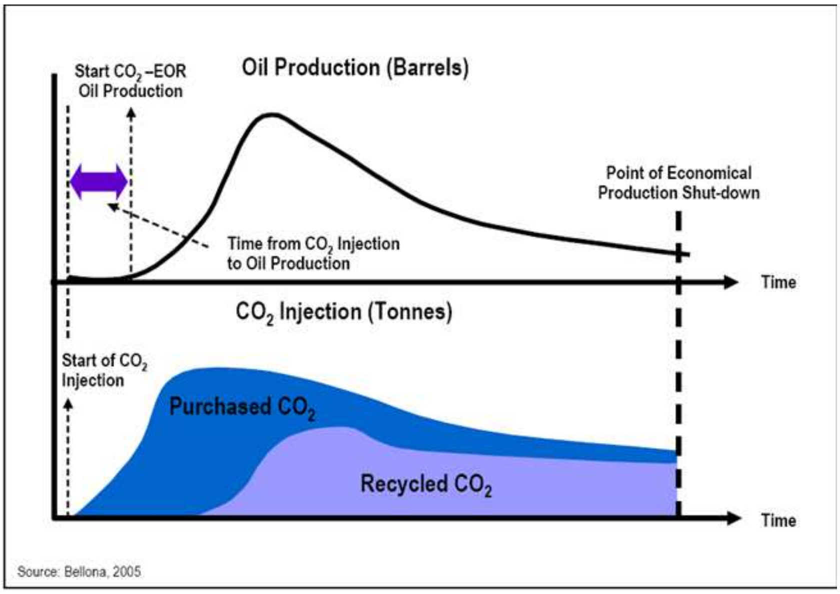
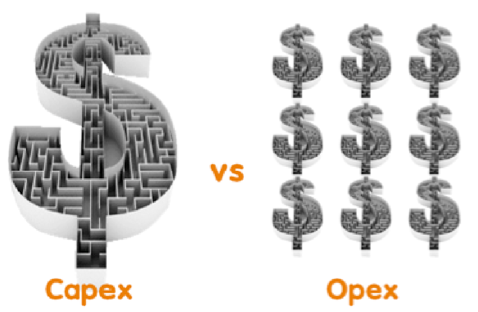


Figure 4.1: The variation of the injected CO_2 quantity in EOR applications over time (Source: Bellona, 2005)

Initially large quantities of CO_2 are injected, but once the injected CO_2 starts to appear in the well fluid at the oil production site after a given time (in the order of several years), this CO_2 is separated from the well fluid and recycled into the reservoir. The amount of 'fresh' CO_2 needed drops significantly from that time onwards. [Also note from the figure that there is likely a considerable time delay between the start of CO_2 injection and the start of EOR oil production.] In the ideal situation the CCS CO_2 supply and EOR CO_2 demand are balanced by creating some buffer capacity inside the CO_2 transportation network connecting multiple CO_2 sinks with multiple CO_2 sources. Still it will be a challenge to match the amounts of CO_2 required for optimized EOR operation with the amounts of CO_2 captured at the sources. With the combination of CCS and EOR the industrial activity of EOR becomes a climate change mitigation measure.

5 Relevant specific issues on EU ETS monitoring and requirements from the CCS Directive for CCS as EOR

For a given oil production location the first step will be to perform the reservoir geology assessment that CO_2 injection as EOR application is technically feasible and indeed the first choice as EOR technique. Once CO_2 injection has been selected as EOR technique for a given location, in the next step the logistics of EOR operation are investigated. One of the important parameters is for instance the availability of the required quantities of CO_2 at the site. Whether these logistics are manageable depends heavily upon the economic business case that can be obtained for the project; how do the costs (CAPEX and OPEX) compare to the revenues of enhanced oil production under different scenarios & uncertainties. Once the technical and logistic issues are dealt with and the economic prospects look favorable, ‘only’ the regulatory issues remain.



When the CO_2 injection is intended to take place within the ETS legal framework not only the environmental and safety permits have to be obtained from the local authorities, but also an ETS storage permit. Previous CATO reports [WP4.1–D01 “Support to the implementation of the CCS Directive, Overview and analysis of issues concerning the implementation of the CCS directive in the Netherlands” and CATO2-WP4.1–D04 on “Transboundary legal issues in CCS - Economics, cross border regulation and financial liability of CO_2 transport and storage infrastructure”] explored the practical implications from this obligation following from the CCS Directive. This report provides a short summary and highlights mainly the consequences of CO_2 storage in combination with EOR. The different phases in the permitting procedure will be described in chronological order. In the next chapter the ETS monitoring issues will be discussed in more detail.

5.1 Exploration phase

In the exploration phase preceding the exploitation phase of the storage site, a model has to be developed and approved to predict the behavior of the CO_2 injected in the reservoir. From the oil production at the site a significant amount of geological data for the reservoir will be available, but additional data will be required for this new and specific purpose. It is uncertain whether all the required additional data can be obtained with sufficient quality while the oil production is taking place at the reservoir. Also the actual modeling challenge is complicated by the simultaneous CO_2 injection and oil production. Following the CCS-Directive an exploration permit is required for the activities during the exploration phase. Part of the motivation for this obligation might be to maintain control over the activities at the different potential sites and prevent that two parties are investigating the same site at the same time. Still, for CCS-as-EOR it would be surprising when the company operating the oil production site would have to apply for an additional site permit to perform the exploration measurements. In the CCS-as-EOR case it is well imaginable that the oil production company could directly apply for a storage permit for the production site without the formal exploration phase permit, a simple notification to the authorities about the CCS-as-EOR explorations at the site might suffice preceding the storage permit application.

5.2 Exploitation phase

Before the start of ETS CO_2 injection a storage permit has to be obtained from the competent authorities. Within this crucial permit various elements have to be settled in detail, among which are the financial securities, liabilities and monitoring. Following the CCS Directive the operator has to provide several financial securities. First of all the operator has to make provisions for a number of ‘obligatory expenditures’. These expenditures will certainly take place at some point in the (near) future. Costs in this category are:

- Costs of monitoring during operation (until closure),
- Costs of decommissioning of the site,
- Costs of monitoring after closure until transfer (20 or more years!),
- Payment to the competent authorities for monitoring after transfer.

The decommissioning obligation already exists for the oil production wells. The monitoring obligations, certainly after closure, are new. It is rather unlikely that the operator of an oil production site has to provide financial securities for the decommissioning costs from the start of oil production onwards as is the case with CCS. However, since these costs are all manageable for companies in the oil production sector, these ‘obligatory expenditures’ will not become insurmountable issues in the permit negotiations. Such additional costs for CCS-as-EOR should be included in the business case on the value of the incremental oil.

In addition to these certain costs the operator also has to provide financial securities for more uncertain events. Following the CCS-Directive the operator holds the liability for these ‘low probability, large consequences’ events. Since the damage to people’s health, property, the environment and/or the ETS emission rights can be considerable in some extreme events, the liability can become a serious hurdle for operators. In addition to these damage costs the operator also has to bear the costs of the necessary corrective actions, either performed by the operator or the competent authorities following the CCS Directive.

Liability is not an unfamiliar concept in the oil production industry, but the provision of financial securities from the start of production for such liabilities is a novelty. Moreover, both oil production and oil transportation are globally such common and wide spread activities that insurance is offered in wide varieties. And, when things go dramatically wrong there is the International Fund for Compensation for Oil Pollution Damage as founded in 1971 and widened in 1992 and again further supplemented in 2003 [http://www.iopcfunds.org]. The IOPC funds are financed by contributions paid by entities that receive the certain types of oil by sea transport. These contributions are based on the amount of oil received in the relevant calendar year, and cover expected claims, together with the costs of administering the Funds.

The CO_2-storage liability aspects are not additionally complicated when the CO_2-storage is combined with EOR in oil production, but still they remain an issue, even for an oil production company.

As already indicated the operator of an ETS storage site also has the obligation to perform extensive monitoring. The behavior and distribution of the CO_2 injected into the reservoir has to be monitored using geological monitoring techniques. The monitoring results have to be compared with the model predictions as made during the exploration phase as part of the storage permit application. Also the chemical composition of the injected CO_2 stream has to be monitored in detail and furthermore the amount of injected CO_2 has to be measured with the high accuracies as required by the EU-ETS. These extensive monitoring and reporting activities are a clear addition to the oil production practice. Further aspects of the EU-ETS CO_2 stream monitoring are discussed in chapter 6.

In the current Dutch legislation (“Dutch mining act”) it is not possible to obtain a storage permit for a site where an active production permit is still valid. In other words the Dutch law does not allow simultaneous oil production and CO_2 storage. However, it’s likely that when a serious & favorable CCS-as-EOR project would appear on the horizon, this formal flaw in Dutch law would quickly be corrected by modification.

Further complications might arise when the CO_2 has to cross one or more national state borders. These cross border transport (or CBT) issues have been tackled and reported in previous CATO2 WP4.1 studies. TPA or third party access to the transport and storage facilities can be another complicating issue. Both the complication of CBT and TPA are not conceptually different for CCS-as-EOR projects compared to CCS projects. The most striking practical difference in the exploitation phase is more strict injection rate as required for an EOR application, as seen in Figure 4.1.

5.3 Closure and transfer

Once the EOR oil production has stopped because the production is no longer economically feasible, the production well is decommissioned. It's likely that the CO_2 injection into the reservoir will be terminated around the same time and also the injection well head has to be sealed off. Following the CCS Directive the operator of the storage site has to continue monitoring the behavior of the injected CO_2 in the reservoir for several years after closure. Does the volume of CO_2 follow the model predictions and is there indeed no CO_2 leakage from the underground? When the behavior doesn't present any (unpleasant) surprises the responsibility for site can be transferred to the competent authorities. The transfer is compulsorily accompanied with a payment to compensate for the future monitoring costs. Like in the exploitation phase there are no arguments why the situation would be significantly different for a CCS-as-EOR project to a CCS project on these aspects during the closure and transfer phase.

5.4 Summary on regulatory aspects

When the regulatory aspects are compared for the situation where a CCS project with a 'plain' storage location is expanded to a 'CCS-as-EOR' project it can be concluded that only the application for a permit and the modeling in the exploration phase might become somewhat more complex. The situation does not become substantially different or more complex for the exploitation and closure phases.

On the other hand, when an EOR project is expanded to a 'CCS-as-EOR' project a series of additional regulatory hurdles has to be managed. In the exploration phase a formal exploration permit and extensive modeling are required. Before the exploitation phase can start some critical financial security and liability issues have to be settled and an extensive monitoring has to be in place. After decommissioning of the site the monitoring has to be continued before the site can be transferred accompanied with a payment.

6 Monitoring in CCS-as-EOR projects

The CO_2 injected in the reservoir for CCS has to be monitored following the requirements from both the CCS Directive and the ETS Monitoring and Reporting Guidelines. The CCS Directive puts the emphasis on the quantity, composition & conditions of the injected CO_2-stream and the behavior of the underground CO_2-plume in the reservoir, whereas the ETS monitoring gives special attention to the CO_2 emissions from process equipment and the possible CO_2 leakages from the reservoir to the surface. Also accidental leakage amounts have to be reported as accurately as possible.

In the EOR situation part of the injected CO_2 can after a period of prolonged injection resurface as component in the well fluid (also called 'breakthrough' CO_2 in for instance EU-documents). This resurfaced CO_2 is likely to be separated from the produced oil on the site and immediately re-injected into the reservoir, since CO_2 is a valuable commodity in EOR business. In the 2009 EU CCS Directive the CO_2-resurfacing as a result from CCS-as-EOR is already introduced (direct quotation from the Directive 2009/31/EC introduction bullet (20)):

"Enhanced Hydrocarbon Recovery (EHR) refers to the recovery of hydrocarbons in addition to those extracted by water injection or other means. EHR is not in itself included in the scope of this Directive. However, where EHR is combined with geological storage of CO_2, the provisions of this Directive for the environmentally safe storage of CO_2 should apply. In that case, the provisions of this Directive concerning leakage are not intended to apply to quantities of CO_2 released from surface installations which do not exceed what is necessary in the normal process of extraction of hydrocarbons, and which do not compromise the security of the geological storage or adversely affect the surrounding environment. Such releases are covered by the inclusion of storage sites in Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community[1], which requires surrender of emissions trading allowances for any leaked emissions."

In short: the CCS-Directive recognizes EOR as CO_2 storage option and discriminates the CO_2 in the well fluid from leakage from the reservoir. Any CO_2 emission has to be reported within EU ETS, for the 'breakthrough' CO_2 EOR has only created a delay in the emission.

[1] Official Journal of the European Union L275, 25.10.2003, p. 32.

Two further elements are important:

1. Any CO_2 leakage that might occur between the resurfacing through the well fluid and the reinjection has to be reported with the ETS-required high accuracy. The same is true for any fugitive emissions that might occur between the location where the CO_2 is transferred to the storage location and the actual injection into the reservoir.
2. The amount of re-injected CO_2 has to be subtracted from the amount of CO_2 injected into the reservoir to calculate the 'net' annual CO_2 injection. The resulting amount calculated as 'net' annual CO_2 injection has to be equal to the quantity of captured CO_2 transferred to the injection or storage site, corrected for possible minor leakages during injection from the storage site. Put into an equation this calculation looks like (see also figure 6.1 for clarification):

$$CO_{2\_net\ injected} = CO_{2\_total\ injected} - CO_{2\_re\text{-}injected} - CO_{2\_injection\ leakage}\text{, or}$$
$$= CO_{2\_total\ injected} - (CO_{2\_re\text{-}surfaced} - CO_{2\_separation\ leakage}) - CO_{2\_injection\ leakage}$$
$$= CO_{2\_transferred} - (CO_{2\_separation\ leakage} + CO_{2\_injection\ leakage})$$

For clarification figure 6.1 provides a sketch of the different CO_2 streams in CCS-as-EOR situation with both the injection and production wells into the reservoir. Small quantities of CO_2 might escape as leakage from the system resulting in fugitive emissions.

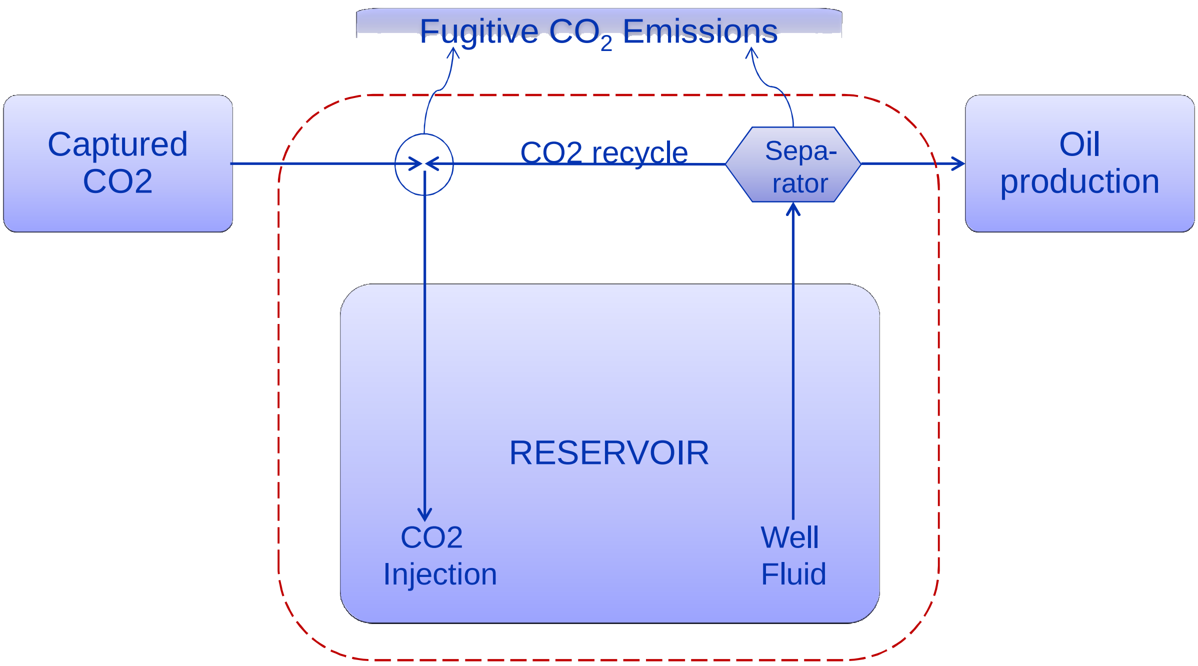


Figure 6.1 The different CO_2 streams in CCS-as-EOR situation with both the injection and production wells into the reservoir

The injected quantity has to be reported by the storage operator following EU CCS Directive requirements, and the transferred quantities have to be reported by the transport operator following the EU-ETS Directive requirements. Any additional ETS-emissions in the process have to be reported by both parties as well, both new combustion emissions and leakages. The recycled CO_2 will not generate any emission credits. The concept of ETS-CCS injection into a reservoir ('permanent storage') while simultaneous hydrocarbon production is taking place from the same reservoir requires an accurate and strict bookkeeping to maintain ETS-credibility.

The 2012 version of the EU-ETS Monitoring and reporting guidelines contains detailed guidance for the reporting of the emissions in each step in the CCTS chain (Annex 4, sections 21-23 from the Commission Regulation (EU) No 601/2012 of 21 June 2012, as prepared for the third ETS emission period 2013-2020). [The definitive 2012 document is not identical to the CCTS amendments to the previous MRG version as presented in the Commission Decision from 8 June 2010 (2010/345/EU). The essence is identical but the 2010 document provides a little more text with clarification in some places.]

For an ETS storage site the 2012 Guidelines state under section 23.A:
"Each operator of a geological storage activity shall consider at least the following potential emission sources for CO_2 overall: fuel use by associated booster stations and other combustion activities including on-site power plants; venting from injection or enhanced hydrocarbon recovery operations; fugitive emissions from injection; breakthrough CO_2 from enhanced hydrocarbon recovery operations; and leakages."

Section 23.B.2 elaborates on the quantification of CO_2 emissions with:

B.2. Vented and fugitive emissions from enhanced hydrocarbon recovery operations

Each operator shall consider the following potential additional emission sources from enhanced hydrocarbon recovery (EHR):

- *(a) the oil-gas separation units and gas recycling plant, where fugitive emissions of CO_2 could occur;*
- *(b) the flare stack, where emissions might occur due to the application of continuous positive purge systems and during depressurisation of the hydrocarbon production installation;*
- *(c) the CO_2 purge system, to avoid high concentrations of CO_2 extinguishing the flare.*

Each operator shall determine fugitive emissions or vented CO_2 in accordance with subsection B.1 of this section of Annex IV.

Each operator shall determine emissions from the flare stack in accordance with subsection D of section 1 of this Annex, taking into account potential inherent CO_2 in the flare gas in accordance with Article 48.

In the 2010 EU version of this text section the 'breakthrough of CO_2 with the produced hydrocarbons" was explicitly mentioned, but remarkably removed in the revised Guidelines. Concerning CO_2 leakage as a potential emission source the Guidelines mention the much discussed *"uncertainty over 7,5 %"* - penalty for this source, which remains a remarkable method to cope with uncertainty.

The possible breakthrough emissions from CCS-as-EOR can create a complicated situation (which might explain why the guidelines are not more explicit on this issue). The production of oil and gas is not an ETS Annex1 activity. As a result the CO_2 emissions from the gas separation processes as part of the oil and gas production don't have to be reported within the ETS annual emission report. In contrast, all emissions from combustion processes as part of the oil and production do have to be reported, at least when the (combined) power reaches 20 MW_{th} or more. The often irregular, and therefore complex, flaring emissions also have to be included in the emission report. This situation changes when the breakthrough CO_2 starts to resurface since these emissions should be reported as leakage when emitted. However, it is complicated to discriminate the inherent (or naturally present) CO_2 in the well fluid from the breakthrough CO_2. This aspect will certainly receive attention in the site-specific ETS Monitoring and Reporting Plan Document that has to be prepared and approved as part of the ETS Emission Permit application. The easy solution would be to re-inject all CO_2 that is separated from the well fluid. Informal communication with production companies indicates that total re-injection will indeed be applied, also since CO_2 is considered a valuable EOR-commodity.

In analogy with the EU ETS-treatment of CO_2 from biomass in mixed CO_2 streams, all streams have to be calculated with fractional quantities after division. For all CO_2 streams in the system it has to be calculated which fraction of the CO_2 is from fossil origin. The simplified approach by assuming that the small releases are completely from biogenic or inherent origin will not be accepted. Another argument why the concept of ETS-CCS injection into a reservoir ('permanent storage') while simultaneous fuel production is taking place from the same reservoir requires an accurate and strict bookkeeping to maintain ETS-credibility.

7 Boundaries or net emission reduction

The CO_2 emission reduction is the obvious main motivation for the application of carbon capture and storage. The net emission reduction for a CCS project can simply be calculated as the difference between the original emission without CCS ('the baseline') and the emissions in the CCS case. The balance has to be a positive number to make the CCS project worthwhile overall, which is generally the case. For proper comparisons two elements are important:

- express the system performance in identical performance indicators instead of absolute quantities (using units like ton CO_2 per MWh or TJ for example),
- draw both the system boundaries right: for instance, the additional emissions generated in the capture, transport and storage chain have to be included in the situation with CCTS.

The following two sketches illustrate the system boundaries for a combustion process with (Fig. 7.2) and without (post combustion) CCS (Fig. 7.1). In the second sketch the expression 'Yield' is introduced. The yield from a capture process indicates the fraction of the total amount of CO_2 produced that is actually captured. As a result 100% minus the yield is the fraction of CO_2 released to the atmosphere.

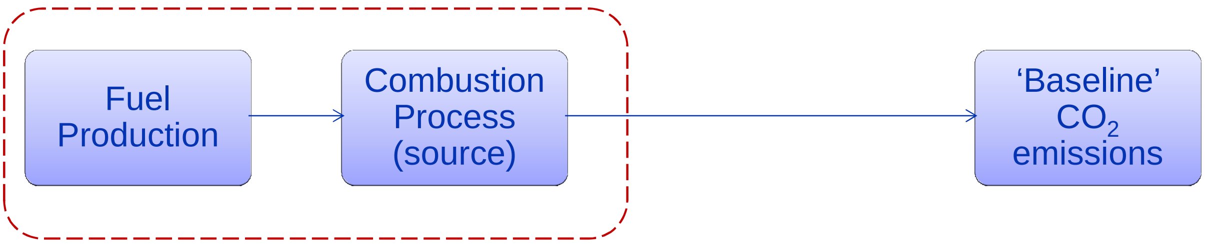


Figure 7.1 'Baseline' CO_2 emissions for combustion process (without CCS). The system boundary includes the fuel production process and its emissions.

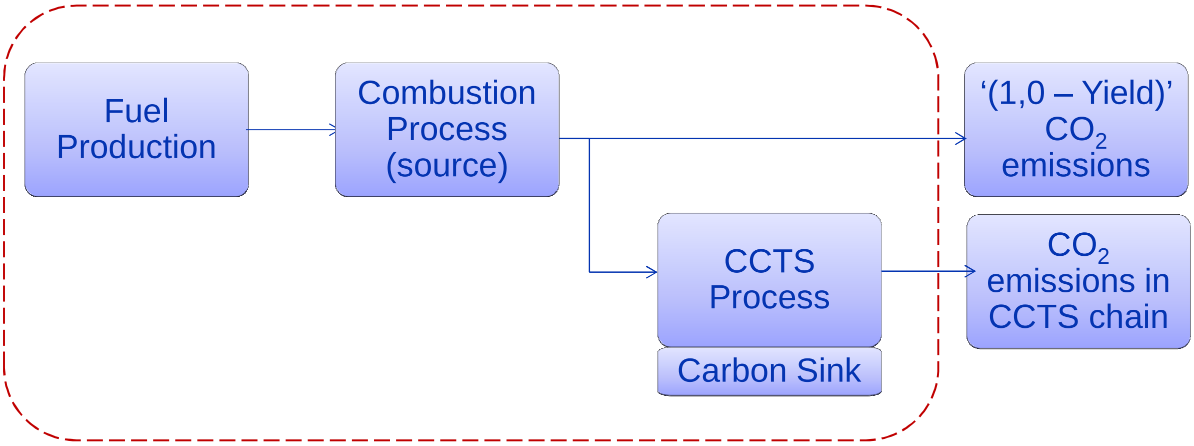


Figure 7.2 CO_2 emissions for combustion process with CCS. The system boundary now also includes the CCTS process and the emissions in the CCS chain. The 'Yield' or 'fraction of CO_2 captured' is a performance indicator for the capture process.

In the comparison for the situation with and without CCTS it was implicitly assumed that the combustion processes in the two situations are basically identical, for instance a coal fired power plant. The net emission reduction can then be calculated as the amount on CO_2 injected, corrected for the emissions and energy use within the CCTS chain. However, it could be considered more appropriate to compare the system performance of the CCS-equipped coal fired power plant with a gas fired power plant since in an energy and climate policy controlled environment the question is not so much 'if', but more 'which' emission reduction technique to apply.

When CCS-as-EOR is introduced the sketches for the comparison do not change essentially, with the exception that a prolonged time after the start of CO_2 injection the injected CO_2 might resurface with the produced oil. Since CO_2 is a valuable commodity in the EOR project this CO_2 is likely separated and re-injected at the site (see for instance the stream of recycled CO_2 in figure 4.1). Another difference with CCS-as-EOR is the stream of additional fuel generated while storing the CO_2 in the emission reduction project. Publications are available where the emissions from this additional fuel are included within the system boundary for the CCS case (see for instance the presentation "Global impacts and issues with CCS through EOR" by IEA's Sean McCoy for a clear overview available at http://www.iea.org/media/workshops/2012/ccs4thregulatory/Sean_McCoy.pdf or "Geologic sequestration through EOR: policy and regulatory considerations for greenhouse gas accounting" by Sean T. McCoy, Melisa Pollak and Paulina Jaramillo (GHGT-10) in Energy Procedia 4 (2011) 5794-5801).

Of course it is true that this additional fossil fuel could displace renewable energy, but following these lines of logic also the original process where the CCS is applied could have been performed in a 'green' or sustainable mode using renewable fuel or feedstock. For proper comparisons the emissions from the EOR-produced fuel should therefore not be included in the emission comparison for the cases with and without CCS. The emissions from these fuels should be taken into account in the processes where the fuel is used, certainly when CCS-as-EOR is taking place at a scale where the additional fuel production is not influencing global energy markets. This discussion is comparable to the question whether the oil producer or the oil consumer is accountable for the resulting CO_2 emission. In the current EU-ETS the emissions are attributed univocally to the actual emitter, or the consumer of the oil.

Furthermore it is certainly important to avoid double counting of the emission reduction obtained by applying CCS: when the combustion process receives these (ETS) credits the produced fuel can't be advertised simultaneously as '(light) green' fuel. The following sketch (Fig 7.3) illustrates the system boundary and the CO_2 emissions for a combustion process with (post combustion) CCS-as-EOR.

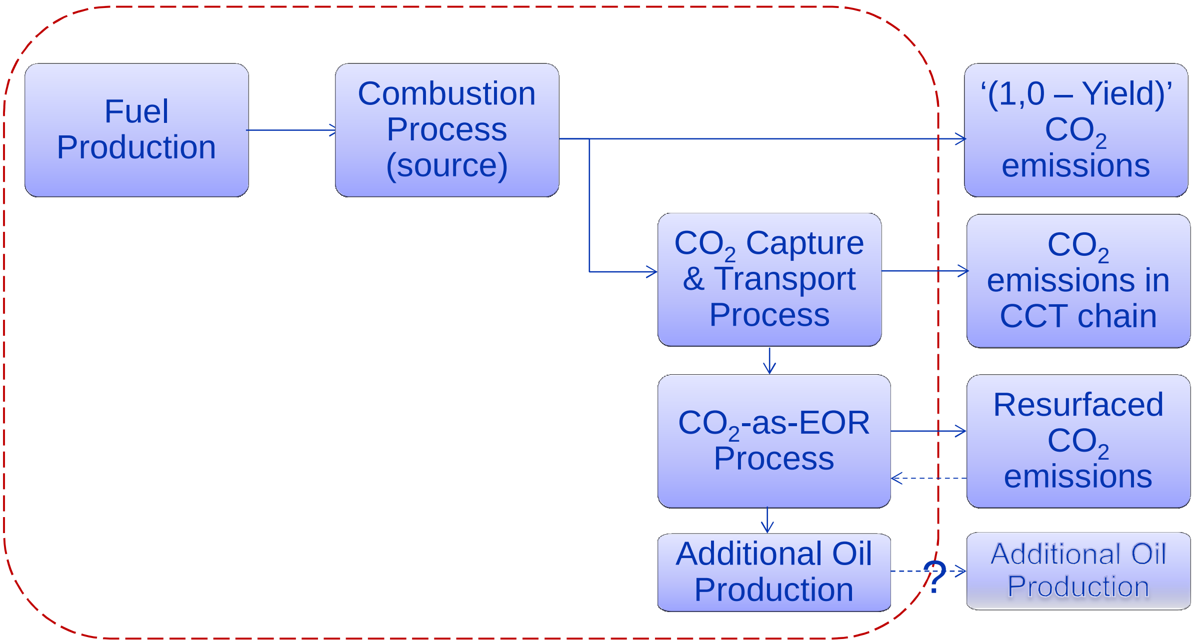


Figure 7.3 CO_2 emissions for combustion process with CCS-as-EOR. The system boundary now includes both the CCT and EOR process.

After successful application in the first demonstration projects the situation could develop where CCS-as-EOR is applied on a larger, global scale. When applied at such a scale that the amount of oil produced by CCS-as-EOR is large enough to influence the global availability of oil and as a result also the prices of oil and other fuels (compare the current situation with the production of shale gas in the US), the boundary discussion becomes relevant again.

8 Conclusions

The combination of the technologies CCS and EOR might result in an attractive business case, which could not have been obtained without giving the captured CO_2 this useful application. However, it is important to realize that the application of EOR is not technically possible and/or economically feasible at each and every oil reservoir oil production industry. The specific local geology and oil production conditions decide whether the EOR technique can be applied. With the current low CO_2 ETS-value prices this priority order situation is not likely to change.

Once the technical and logistical issues are dealt with and the economic prospects look favorable, 'only' the regulatory issues remain. When the regulatory aspects are compared for the situation where a CCS project with a 'plain' storage location is expanded to a 'CCS-as-EOR' project it can be concluded that only the application for a permit and the modeling in the exploration phase might become somewhat more complex. The situation does not become substantially different or more complex for the exploitation and closure phases.

On the other hand, when an EOR project is expanded to a 'CCS-as-EOR' project a series of additional regulatory hurdles have to be managed. In the exploration phase a formal exploration permit and extensive modeling are required. Before the exploitation phase can start some critical financial security and liability issues have to be settled and an extensive monitoring plan has to be in place. After decommissioning of the site the monitoring has to be continued before the site can be transferred accompanied with a financial contribution to the competent authority for post-closure monitoring and stewardship.

The CO_2 injected in the reservoir for CCS has to be monitored following the requirements from both the CCS Directive and the ETS Monitoring and Reporting Guidelines. The CCS Directive puts the emphasis on the quantity, composition & conditions of the injected CO_2-stream and the behavior of the underground CO_2-plume in the reservoir, whereas the ETS monitoring gives special attention to the CO_2 emissions from process equipment and the possible CO_2 leakages from the reservoir to the surface. The transferred quantities have to be reported by the transport operator following the EU-ETS Directive requirements. Any additional ETS-emissions in the process have to be reported by both parties as well, both new combustion emissions and leakages. The recycled CO_2 will not generate any emission credits. The concept of ETS-CCS injection into a reservoir ('permanent storage') while simultaneous fuel production is taking place from the same reservoir requires an accurate and strict bookkeeping to maintain ETS-credibility.

The CO_2 emission reduction is the obvious main motivation for the application of carbon capture and storage. The net emission reduction for a CCS project can simply be calculated as the difference between the original emission without CCS (‘the baseline’) and the emissions in the CCS case. The balance has to be a positive number to make the CCS project worthwhile overall. For proper comparisons it’s important to express the system performance in correct performance indicators and to draw the system boundaries right. When CCS-as-EOR becomes applied at such a scale that the amount of oil produced by CCS-as-EOR is large enough to influence the global availability of oil and as a result also the prices of oil and other fuels the boundary discussion becomes relevant again.