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Progress report on: CCS Implementation Plan: Six CCS implementation topics

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1 Executive Summary (restricted)

In this report six topics are described with relevance for the implementation of CCS. These topics provide background for the Implementation Plan and roadmap for CCS in the Netherlands. This Implementation Plan and roadmap will be released end 2013/start 2014.

Topics discussed are:

- Commercialisation
- Governance
- Regulatory issues
- Communication to the public
- Field strategy
- Interfaces

Distribution List

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Document Change Record

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2 Applicable/Reference documents and Abbreviations

2.1 Applicable Documents

(Applicable Documents, including their version, are documents that are the “legal” basis to the work performed)

	Title	Doc nr	Version
AD-01d	Toezegging CATO-2b	FES10036GXDU	2010.08.05
AD-01f	Besluit wijziging project CATO2b	FES1003AQ1FU	2010.09.21
AD-02a	Consortium Agreement	CATO-2-CA	2009.09.07
AD-02b	CATO-2 Consortium Agreement	CATO-2-CA	2010.09.09
AD-03g	Program Plan 2013b	CATO2-WP0.A-D03	2013.04.01

2.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Issue/version	date

2.3 Abbreviations

(this refers to abbreviations used in this document)

3 Introduction

If the capture of carbon dioxide and storage (CCS) is to make a significant contribution to reducing CO_2 emissions it is of utmost importance that the CCS demonstration phase is successful and the (large-scale) CCS deployment will become feasible. To support the commercial deployment of the technology the right conditions should be in place. Large scale implementation asks for clear and sustained regulatory, organisational and financing structures for CCS. Also the timing of decisions and corresponding actions will be crucial to get CCS successfully deployed. It is currently not clear what decisions and actions are exactly needed on the short, mid and long term to provide the right and sustained conditions for CCS deployment in the Netherlands. Also, the roles and responsibilities of stakeholders during and beyond the demonstration phase of CCS need to be clear and preferably based on consensus.

To increase the likelihood of a successful deployment of CCS, the various stakeholders in the Netherlands should agree on a CCS Implementation Plan. In such a plan, the main steps in developing and deploying CCS needs to be described, including the prime stakeholders responsible for carrying out the identified actions.

CATO is currently drafting such CCS Implementation Plan, including a CCS roadmap (deliverable D12, forthcoming). In this progress report, we describe six important CCS topics which description will be incorporated in the CCS Implementation Plan. The topics are:

- Commercialisation
- Governance
- Regulatory issues
- Communication to the public
- Field strategy
- Interfaces

These topics cover a wide range of aspects relevant for the further development and deployment of CCS.

4 CCS Commercialisation

4.1 Introduction

Unlike energy efficiency measures, whereby the initial investment is recouped through short or long term energy savings, the deployment of CCS will increase capital and operating costs and in most cases has no economic value to the operator. Policy interventions can be enacted due to the foreseen benefits to society of utilising CCS in order to reduce CO_2 emissions to the atmosphere, preventing dangerous climate change. By penalizing greenhouse gas emissions, or subsidizing non-commercial investments, policies create economic conditions whereby more costly production processes become economically viable given their added benefits to society as a whole.

The commercialisation of CCS can be accelerated through reducing the fixed and operating costs of the technology. Research and development activities, pilot and demonstration projects, can lead to cost reductions through a combination of technological improvement and market development. Such efforts may also lead to more confidence in the performance of the technology and its market. As CCS projects are large and multi-faceted, demonstration projects may also reduce organisational and transaction costs associated with planning capture, transport and storage infrastructure. Despite this, the capital and operational costs of CCS projects will remain significantly higher than non-equipped equivalents, meaning that long-term policy intervention is required to offset the additional costs of CCS to operators.

4.2 A policy strategy for the commercialisation of CCS

The International Energy Agency (IEA, 2012) has developed a policy strategy for the advanced deployment of CCS, which assumes a dynamic set of policies that are altered during the course of the development and deployment of the technology. With reference to Figure 1, the following text describes the potential implementation of the IEA's policy strategy in a European context.

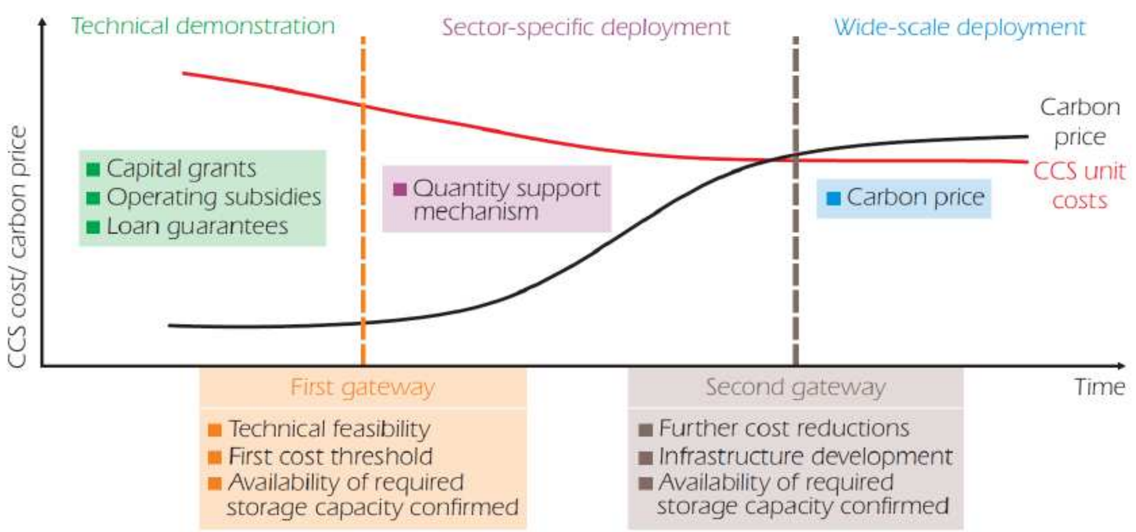

Figure 1. **A policy strategy for the commercialization of CCS (IEA, 2012)**

4.3 An emissions cap and trade system – The EU ETS

The underlying consistent policy measure of the policy strategy is a price on emitting CO_2, something that is achieved in the EU via the European Union Emissions Trading Scheme (EU ETS). A 'cap and trade' system such as the EU ETS is not specifically designed to incentivise CCS, however encourages emitters to invest in mitigation actions based on the prevailing carbon price. The carbon price is determined by supply and demand of emissions allowances. Supply of emissions allowances is fundamentally adjusted through the setting of the 'cap', associated with a desired greenhouse gas emission target at a specific time in the future. The cap must tighten gradually over a number of years/decades in order not to debilitate CO_2 emitters and allow time for CO_2 abatement measures to be planned and implemented, and to prevent exponential price increases in power and industrial products.

Demand for emission allowances is dependent on the emitters' options for reducing CO_2 emissions in order to minimise allowance requirements. If emitters are unable to reduce emissions, a decrease in supply of CO_2 allowances will increase scarcity and push the price of emitting higher. The CO_2 price acts as an additional operating cost, and exposure to it will impact an emitter's ability to produce power or goods competitively. Lower allowance prices may encourage minor investments in energy efficiency improvements, however with a continued reduction in allowance supply, emitters may be coerced to invest in more expensive mitigation options, amongst which CCS. A 'cap and trade' system allows market parties to decide how to reduce emissions in order to remain competitive, theoretically leading to the lowest cost of mitigation to society as a whole.

4.4 Supportive policy measures

With reference to Figure 1, the demonstration phase of CCS is characterised by considerably higher investment costs compared to the CO_2 price. At this stage, the CO_2 prices preceding the 'First gateway' are too low to incentivise CCS in the vast majority of applications. In order to stimulate demonstration of CCS, the incentive to reduce emissions via the CO_2 price must be complimented with auxiliary policy measures such as capital grants and operating subsidies. In the EU, a number of Member States such as France, the UK and the Netherlands have provided capital grants to potential CCS developers to offset capital investments. There are a number of possible ways that public finance can be used to support CCS demonstrations projects (Mikunda et al., 2011):

Loans

Governments can share the risk of an infrastructure project by providing loans through designated financial institutions such as multilateral agencies and development banks such as the European Investment Bank (EIB), the World Bank, the International Finance Corporation (IFC) and the European Bank for Reconstruction and Development. Government institutions may have access to finance at a lower cost compared to commercial companies.

Grants/Subsidies

A subsidy is a form of financial assistance to be paid to a business or economic sector. The rational for the disbursement of a subsidy can be that of national or supranational strategic interest. In Europe, an example of a subsidy is the New Entrants Reserve 300 (NER300). Guarantees can be provided by multilateral agencies to help facilitate financing of a project by providing risk coverage. The provision of guarantees to large infrastructure projects helps to lower the risk and may help the project sponsors raise long-term financing from lenders/equity institutions which in the absence of government guarantees would have not been willing to cooperate.

Assuming that CCS demonstration projects are successfully deployed, and a continued increase in CO_2 prices is evident, a gradual transition towards less intensive support mechanisms can be made. During the intermediate phase towards CCS commercialisation, the technology may become economically feasible for individual projects in certain sectors. Given that most large industrial installations have continuous operating campaigns of 30 years or more, the possibility of implementing capture equipment is not a decision of abatement costs alone. New build plants or plants undergoing refurbishment or expansion will prove better candidates for CCS given the lengthy period installation may take (2 to 3 years for example).

At an intermediate phase in the commercialization strategy of CCS, with a number of CCS demonstration projects realized, government support for CCS projects may be altered. Although still at this point the CO_2 price provided by the cap and trade scheme may remain insufficient to provide a business case for most CCS applications, the presence of demonstration projects may help to de-risk CCS investments and therefore improve access to capital to project developers. At this stage direct government investment used to offset the capital costs of CCS projects can be reduced or stopped, and could be replaced by a long-term operating subsidy or quantity support mechanism which completes the business case for potential CCS projects.

Quantity support mechanisms can involve providing a fixed price, or a price premium on electricity produced from power plants with CCS. A common form of quantity support mechanism is a Feed-in Tariff scheme, which sets a fixed price on each unit of electricity generated by a specific technology. The price must be sufficient to cover the additional investment and operational costs associated with a CCS project, with the combination of CO_2 price set by the cap and trade system and the feed-in tariff resulting in a business case. The establishment of an effective and efficient feed-in tariff is challenging given fluctuations in CO_2, electricity and fuel prices. A too generous feed-in will increase the costs to society, whereas a too conservative tariff will not achieve the desired deployment (Pearson & Whiriskey, 2013). For CCS projects in the industrial sectors such as cement and steel production, rewarding tonnes of CO_2 stored using a tariff scheme could be considered (IEA, 2012).

Feed-in tariff schemes for renewable energy technologies have been implemented in several European countries. In the United Kingdom, a form of feed-in tariff called Contracts for Difference (CfDs), is expected to become the first feed-in tariff to support low carbon energy generations including CCS and nuclear power, as well as renewable technologies (Allen & Overy, 2012). Low-carbon electricity generations are guaranteed a 'strike price' for every MWh produced. The feed-in is also capped so that if the market revenue of electricity exceeds the strike price the generator pays back the excess (Figure 2).

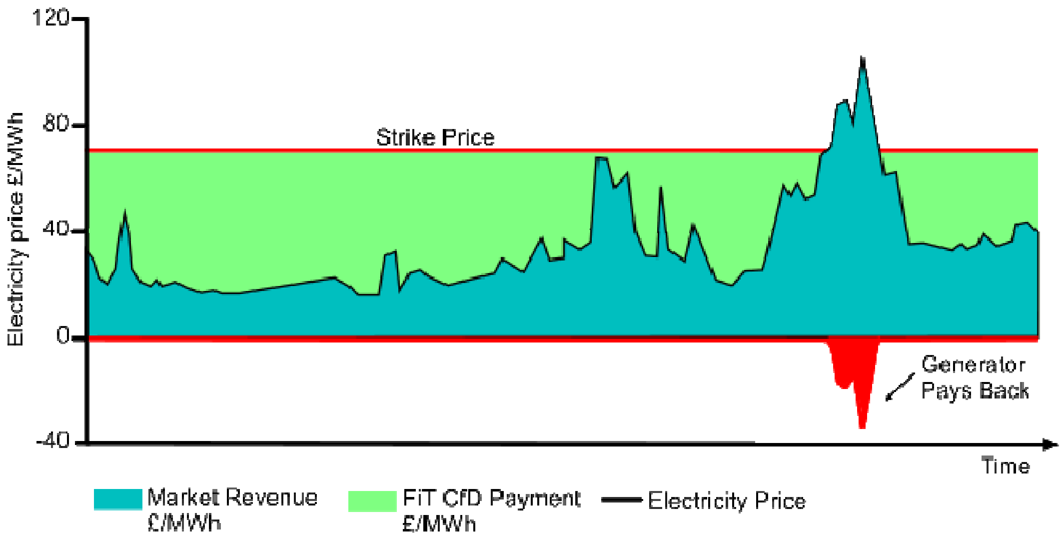

Figure 2. Graphical representation of a feed-in tariff scheme with strike price (Pearson and Whiriskey, 2013)

It is important to note that there are many other options to incentivise CCS deployment, with a comprehensive review provided by Pearson & Whirisky, (2012). Furthermore, supportive policy measures are not mutually exclusive, and CCS projects may well require a combination of loans, grants or guarantees, combined with quantity support schemes such as a feed-in tariff.

In the final stages of CCS commercialisation, the carbon price has reached a sufficient level whereby it is no longer economically feasible to operate installations emitting CO_2. At this stage the trade-off is between investing in CCS or in alternative production processes. For power generation, investments in renewables or nuclear power are possible alternatives for CCS. Given the intermittency issues associated with current renewable energy technologies, many regions will still require some form of 'power on demand' which could be provided by fossil and/or biomass-fuelled power stations. For energy-intensive industrial process such as steel and cement production, CO_2 abatement options in conventional processes are more limited, which could risk industrial downscaling and/or relocation if CCS is not available.

Box 1 narrates a possible development scenario of CCS in the EU by the Zero Emissions Platform**.**

Box 1. Stages of development of CCS according to Zero Emissions Platform (ZEP)

The Zero Emissions Platform (ZEP) distinguishes three stages of development of CCS [ZEP, 2012]:

- Short term, 2012-2020. Until 2020, individual components of the CCS value chain are proven, and large-scale CCS demonstration projects are realized. There is still little experience in stewardship transfer of storage sites and long-term liability. There are significant 'up-front' costs for early movers, and there is an uncertain environment for long-term investment.
- Medium term, 2020-2030. CCS demonstration projects boost confidence in both costs and performance. Equipment suppliers (and possibly transport and storage operators) will be able to take the necessary risks and offer contracts on commercial terms. There will also be a skeleton of pipelines and storage sites – at least some of which built with the capacity to take on additional CO_2 streams. Unabated fossil fuel power plants will gradually be replaced with new CCS-equipped plants. Non-ETS incentives will still be required and CO_2 transport infrastructure may require significant government intervention (on a commercial basis).
- Long term, 2030+. After 2030, the value of European Union Allowances (EUAs) under the ETS will be level with the cost of CO_2 abatement with CCS – at least for new fossil fuel-based base-load plants – while CO_2 transport and storage will be operated commercially by private companies. Non-ETS incentives will be needed for development of new CCS technology, but a level playing field under the ETS is the correct approach for commercial CCS technologies.

4.5 Alternative policy measures

Whereas a market based mechanism for CO_2 abatement has been initially favoured in the EU through the ETS, a recent communication released by the European Commission (EC, 2013) regarding the future of CCS in the EU reviewed alternative policy measures. With the EU ETS not currently providing a significant incentive for CCS, mandatory emission performances standards (EPS) for certain sectors could be introduced, which places a limit on the emissions intensity of production. These mandatory emissions standards have been introduced already in Norway and the State of California.

In a new UK Energy Bill, currently being reviewed within the UK parliamentary system, an EPS standard on all new fossil fuel power stations has been introduced (DECC, 2013a). The EPS has been set at an annual limit of 450 g/kWh assuming base load production and 85% capacity. The EPS means that new supercritical coal-fired power plants would need to be equipped with CCS to capture 40% of associated CO_2 emissions. Gas-fired power plants would be able to meet the emission performance standard without CCS. The EPS standard if passed in parliament will remain active until 2045.

It is unclear at this stage whether such standards would be considered by the European Commission, it could have major structural effects on the European energy system, fossil fuel imports and energy prices. Furthermore, an EPS set at a level such as in the context of the UK, does not guarantee CCS deployment, with coal-fired power plants being replaced with gas and nuclear installations.

4.6 How is CCS currently supported in the EU?

Within the EU there are both specific and non-specific policy mechanisms to support the demonstration and commercialization of CCS. The sections below provide details of these policies, and briefly assess their effectiveness at supporting CCS.

The EU ETS

The key policy mechanism to incentivise greenhouse gas mitigation investments in the EU is the EU Emissions Trading System (EU ETS). The EU ETS places a price on each ton of CO_2 emitted by fossil fuelled power stations and energy intensive industrial installations. Phase I of the system was in effect between 2005-2007, phase II in 2008-2012, and phase III between 2013 to 2020. Operators were initially freely allocated EU ETS emission allowances, termed EUA's, to cover their emissions based on historical data. Member states were able to auction (i.e. sell at market price) a small amount of allowances, 5% of total allowances in phase I and 10% in phase II. During phase III, all allowances are to be auctioned to emitters, with a few exceptions. Due to the threat of carbon leakage and international competitiveness issues, the majority of energy-intensive industries will continue to receive free allowances throughout phase III, albeit based on CO_2 intensity benchmarks of the top 10% performing installations in the relevant sector.

At the beginning of phase II of the EU ETS, the CO_2 allowances were being traded on the carbon market for a peak price of €30/tCO_2. However, with reference to Figure 3, the onset of the global economic crisis has coincided with the start of a steep decline to €10/tCO_2 in January 2009 and to less than €3/tCO_2 in 2013. This rapid drop in CO_2 prices highlights one of the weaknesses in market-based mechanisms, being that the prevailing market price may not be a true indication of supply and demand. The turmoil on international capital markets, has led to long-term investors and carbon market speculators withdrawing from the system. Since then, the stagnation in EU economic growth, the lack of a global GHG agreement and no additional measures being agreed at EU level to maintain a CO_2 price, has meant that the carbon price has not recovered.

The European Commission has estimated an oversupply of approximately 2.3 billion EUAs up to 2012 (European Commission, 2012), and this could reach 2.5 billion with maximum use of international credits (Verdonk and Volleberg, 2012). This equals to around 15% of the amount of allowances to be auctioned between 2013-2020. Regardless of the overall performance of the EU ETS, even at the higher prices seen in 2008, the CO_2 price has never reached a sufficient price to incentivise CCS in the vast majority of applications. More generally, the absence of political signals in support of adjusting the EU ETS to maintain EUA prices has been highly detrimental to planned CCS demonstration activities.

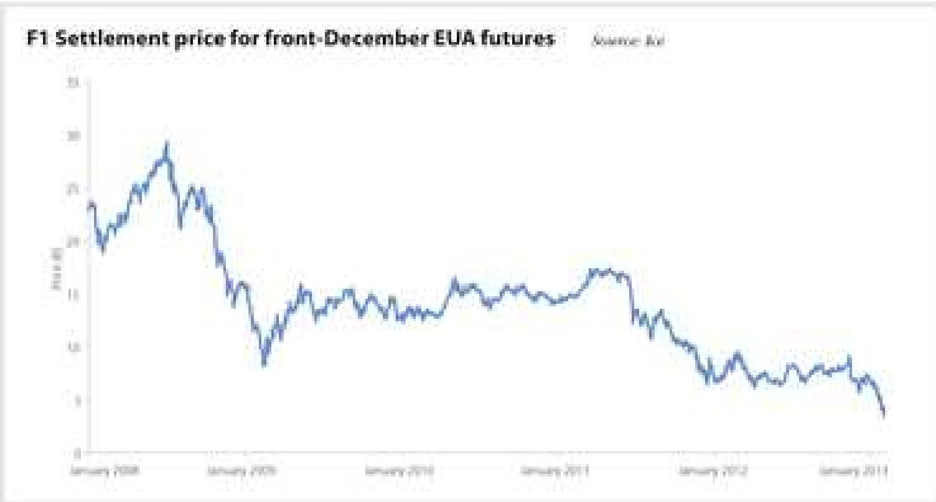

Figure 3. Development of EUA prices between January 2008 and January 2013

Funding mechanisms - The EEPR and the NER300

Since 2009, the EU has launched two financing programmes in which CCS technologies could receive funding for demonstration, the European Energy Programme for Recovery (EEPR) 2009, and NER300 (New Entrants' Reserve) in 2010.

The EEPR comprises a budget of approximately €4 billion, consisting of four sub-programmes: gas infrastructure; electricity infrastructure; offshore wind energy; and Carbon Capture and Storage. The budget for CCS amounts to €1.0 billion. The CCS sub-programme is to provide financial support to six projects in the power generation sector in Italy, Germany, the Netherlands ('ROAD', Rotterdam Capture and Storage Demonstration), Poland, Spain, and the UK, of which €392 million have already been paid to the beneficiaries as of March 2012. It is uncertain to which extent the EEPR budget for CCS demonstration projects of €392 million has indeed been exhausted, as only the 'ROAD' project has proceeded to an advanced stage upon which a final investment decision can be made. The EU has pledged financial support of €180 million from the EEPR programme to the demonstration CCS projects 'ROAD' in Rotterdam, initiated by E.ON and Electrabel. The Dutch government is willing to support with an additional €150 million. Nevertheless, due to the low price of CO_2 in the EU ETS, the ROAD consortium did not yet (July 2013) make a positive Final Investment Decision (FID) for 'ROAD'.

The NER300 is a financing instrument that contains the provision to set aside 300 million allowances in the New Entrants' Reserve of the European Emissions Trading Scheme for subsidising installations of innovative renewable energy technology and carbon capture and storage (CCS) in the EU. CCS operators would be able to receive up to 50% of the relevant capital costs and operating costs during the first 10 years of operation. In the Netherlands, Air Liquide had requested subsidy from the NER300 programme for their 'Green Hydrogen' project in Rotterdam. The Dutch government supported this project and were committed to contribute €90 million to the project. By the end of 2012, none of the CCS projects submitted under the first round of NER300 had received financial support mainly because of the unclear financial substantiation. In the first quarter of 2013, Air Liquide abandoned their plans for CCS on their hydrogen plant in Rotterdam and dismantled the CCS team.

The key issue with the NER300 is that the total amount of funding to be generated from the auctioning of the set-aside allowances is linked to the prevailing EUA price. At the time the NER300 was launched in 2010, the EUA price was approximately €15, meaning total funding of €4.5 billion would be available for selected projects. By the time the first auctions commenced in 2012, lower EUA prices reduced the total expected funding to approximately €1.5-2 billion. A restriction in the NER300 stated that each individual project may not receive more than 15% of the maximum funding available, leaving many CCS projects short of the amounts applied for.

Unilateral Member State actions

The United Kingdom operates the national CCS Commercialisation Programme Competition, with a total funding capacity of £1 billion, to support two CCS demonstration plants by 2020. Two preferred bidders have been selected, with the projects currently undergoing front end engineering and design (FEED) studies. The commercialisation of CCS in the UK may also be supported by emission performance standards on power stations, and a feed-in tariff for operating CCS projects (see sections 3.1.2 and 3.1.3 of this report). In addition, between 2011 and 2015 £125 million has been made available for fundamental research for CCS and the development of pilot projects (DECC, 2013b). The Dutch government has also pledged a total of €250 million split between two potential CCS demonstration projects in the Rotterdam harbour industrial zone. It is not currently clear if these projects will be implemented.

4.7 Summary – the way forward

The IEA stresses that a dynamic approach is needed to support the commercialisation of CCS, with the type of policies reflecting the risks at various stages of technology development. This includes public funding of projects, either through direct grants, loans or guarantees, quantity support mechanisms such as feed-in tariffs, underpinned by an emissions trading system which provides a sufficient price incentive for long-term investment. Despite the existing EU funding programmes, the economic conditions for demonstration CCS projects in the EU are not conducive to CCS deployment and funding appears to be insufficient to trigger CCS demonstration projects against the backdrop of low EU-ETS prices. The following points include suggestive actions to achieve CCS commercialisation.

Long-term climate objectives must underpin active policies

CCS is an expensive and multifaceted technology, and investments will only take place when investors are confident that returns can be made without disproportional risk-taking. Multi-million euro investments in the power and industrial sectors must be recouped over 20 to 30 years, and are inherently exposed to changes in demand, fuel and raw material prices. If CCS is to make an impact in reducing EU CO_2 emissions, political objectives must be underpinned with a clear long-term policy roadmap for the technology.

The EU-ETS needs to deliver a stronger and more consistent price signal

The demand for EUAs is currently very weak, and based on current policies and targets and foreseen economic growths, this surplus of EUA's is predicted to grow towards 2020. There are multiple causes of the current state of the EU-ETS, which includes a combination of over allocation based on pre-crisis emissions levels, and access to credits from flexible mechanisms such as the Clean Development Mechanism, which dropped to under €1 per reduction unit in 2012. Action must be taken to reduce the surplus towards 2020 and in setting ambitious targets afterwards.

The surplus can be reduced by retiring, preferably permanently, a substantial proportion of the allowances expected to be distributed in phase III up to 2020. In addition, the annual linear reduction factor[1] could be adjusted upwards, and the use of international credits must also be reflected in the amount of EUAs allocated within the overall system.[2] It has been argued that the EU ETS needs a carbon price floor to reduce uncertainty to investors regarding the profitability of long-term investments. In the short term, it is unlikely that a price floor would be introduced that could sufficiently support CCS commercialisation in most applications, which would mean either a future adjustment of the price floor or some form of indexation based on prevailing prices. Long-term firm supportive policies combined with prospects of stable CO_2 prices may give sufficient confidence in the market to continue or increase research and development in CCS technology to reduce costs.

Re-calibrating the EU ETS to reflect the surplus of credits, by setting a more ambitious target with corresponding increases in the annual reduction factor, could provide a sufficient price signal without the need for continual adjustment of a price floor.

European wide indecision could lead to incompatible national actions

A lack of action by the European Union in strengthening the EU ETS could drive a plethora of incompatible unilateral approaches to reduce CO_2 emissions. For example, in early 2013 the UK have introduced a CO_2 floor price of £16 (approximately €19), with the intention of this rising to £30 (€36) by 2020, and £70 (€84) by 2030. Also in January 2013, the Netherlands introduced a tax on coal of approximately €14 per tonne in order to complement the EU ETS price. Therefore we see two different countries adopting diverse policy actions to reduce national CO_2 emissions, which could undermine or complicate the development of regional policies to support CCS.

CCS must be demonstrated in the EU before it can be applied in a commercial market

All three chain elements of CCS (capture, transport and storage) have been proven individually on large scale, however the integration of the technology has not yet been demonstrated in the EU. Successful demonstrations of the technology will provide valuable performance data on the integration of capture, transport and storage processes. In addition, demonstration can overcome hesitancies and concerns regarding CCS possibly held by policy makers, industrial stakeholders and the general public.

Regulatory burdens during demonstration phase must be reviewed

A legal framework in which CCS can operator is essential for commercialisation, and this was achieved in the EU with the development of the EU Directive on the geological storage of carbon dioxide (2009/31/EC). Certain components of the regulation impose quite considerable financial burdens on operators, such as a 'worst case scenario' financial security provision, and a liability phase of 20 years after operational storage site closure which has no scientific basis.. Such burdens compound the multitude of challenges faced by technologies in demonstration phase. Long-term liability for storage sites and the provision of significant financial security for CO_2 stored are parts of the Directive industry stakeholders have mentioned as possible 'show stoppers' to CCS demonstration. Member States could support potential project developers by sharing the regulatory burden during the demonstration phase, e.g. government re-assurance for liability coverage, or some form of government pooling to overcome financial security requirements.

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[1] Currently 1.74% per year

[2] The possibility for emitters to utilize international credits as a form of compliance is estimated to account for 75% of the surplus to 2020. It may not be politically appropriate to reduce the use of international credits for overseas development reasons; however EU allowance allocations could be retired to compensate for the influx of international credits.

4.8 References

Allen & Overy (2012). “UK Electricity Market Reform: The draft Energy Bill”

DECC (2013a). *Energy Bill. Department of Energy and Climate Change*, UK. Available at (22/05/2013) http://services.parliament.uk/bills/2012-13/energy.html

DECC (2013b). UK carbon capture and storage: government funding and support. CCS Commercialisation Programme. https://www.gov.uk/uk-carbon-capture-and-storage-government-funding-and-support

European Commission, (2012). *Commission Staff Working Document*, COM(2012) 416 final, 25 July 2012, European Commission, Brussels.

Mikunda, T., Haan-Kamminga, A., de Wolff, J., de Joode, J., Meindertsma, W., Nepveu, M. (2011). *Transboundary legal issues in CCS Economics, cross border regulation and financial liability of CO_2 transport and storage infrastructure*. CATO D4.1.4

Peason, I. and Whiriskey, K. (2013). *Driving CO_2 capture and storage in the EU: New policies, new perspectives*. Bellona Working Paper, Bellona Europa, Brussels.

Verdonk, M. & Vollebergh, H., 2012. *Evaluation of the European Commission's proposal to set aside emission allowances - Effects on the EU carbon price and Dutch ETS companies*.

ZEP (2012). *CO_2 Capture and Storage – Creating a secure environment for investment in Europe*. European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), July 2012. http://www.zeroemissionsplatform.eu

EC (2013). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Consultative Communication on The Future of Carbon Capture and Storage in Europe*, COM(2013) 180 final

5 CCS governance

5.1 Introduction

CCS deployment requires a clear governance structure to regulate the market and to be able to operate and develop the technology. Governance of CCS implies the processes and actions required to successfully develop and deploy the CCS technology. Governance implies that regulation is in place, it should prevent lock-in situations and establish sufficient and well-designed incentives to support the large-scale deployment of the technology.

Especially for CCS, a proper governance structure is required as there are many stakeholders involved in the CCS implementation and creation of the market. Stakeholders in this structure are e.g. operators of capture, transport and storage systems, the government, executing authorities, financers and investors. The stakeholder's responsibilities and actions are often highly depending on each other. Examples are:

- Investing and financing of CCS: stakeholders have to agree on who is going to invest in what part of the CCS value chain and how to share the risks, costs and revenues;
- Timing of the process: all elements should be in place at the right time, however many implementations are difficult to plan due to high uncertainties. Should a CCS plan start with storage location, and perform a geological survey until a location is found where it is proven that sufficient CO_2 can be stored;
- The set-up and organisation of transport and storage infrastructure;
- Physical conditions of the CO_2 stream: the CCS chain elements should connect to each other and the properties of the CO_2 stream should be agreed on and monitored;
- International cooperation, including standardization of CCS operations.

At the start of the gas market in the Netherlands, similar considerations were made (see Box 2). Learning from existing governance structures, such as for natural gas, could be beneficial when developing good governance for CCS. Based on such lessons from existing governance structures and from suggestions in CCS literature we provide below some key elements of governance specifically for CCS.

Box 2. the natural gas market

The natural gas market incorporates a large international market and a grid that is managed, owned and used by several stakeholders. To keep everything working transmission system operators (TSOs) manage the grid and virtual trading points that enables gas trade. Further, regulations and processes for investment are provided by government and European organisations. In the gas market the many tasks and responsibilities are assigned to the stakeholders, providing a governance structure that enables the functioning of the system.

5.2 Elements of governance for CCS

Independent designer & director

The government needs to steer the development of a CCS governance structure. It has been argued that the creation of the governance structure for CCS would benefit from an independent designer.[3,4] It might be difficult to have a fully independent designer, but independency should be

[3] (Apotheker 2007)

pursued perhaps by means of an organisation or authority that is transparent, can monitor the market and has no other interest than a well-structured CCS market.

With creating the governance structure it is important to indicate what authority or authorities should be directing the system. Steering of the system is important to take care of the general public interest, i.e. to coordinate efficiently the regulation including licensing and permitting, spending of (R&DD) investments, having a transparent and effective transport and storage plan, and manage international coordination for implementation of CCS. This may require for example a 'CCS authority'.[5] Further, one can think of an overarching representative organization for companies, which influences the respective authorities and thereby the direction within the CCS governance and organisation.

Regulation

An important precondition for the deployment of CCS is a regulatory framework to balance the different interests of all involved stakeholders. The regulatory framework should address risks (human health risks, environmental risks, property risks and financial risks), but should also support the objective of CCS: maximise CO_2 emissions avoided. Regulation should therefore encourage responsible operation and investment and it should provide ease of implementation for both regulators and industry. Regulation should balance between regulatory stability and predictability on the one side and flexibility and adaptability on the other hand. Regulations cannot be fully developed for long terms as insights may change with growing knowledge and expertise and as there are still uncertainties to be solved. One example is the (long term) performance assessment of CO_2 in geological reservoirs and site-specific monitoring requirements that requires flexibility in the regulatory framework. CCS needs regulations geared to each project stage: capture, transport, site selection and permitting, site operations and closure, and long-term stewardship.

Financing

Another condition that should be met is the availability of financing and its place in the governance structure. Literature presents several financing options for the CCS market. Public-private partnerships provide incentives for early projects that do not yet benefit from technological improvement or economies of scale. According to some scholars this type of financing should be present in the organisation of the CCS markets in the early phases of the technology development.[6] Further, private funding sources could be another financing option. According to Sanders[7] *to mobilize and attract private funding, investors suggests that CCS projects will have to be structured in such a way that different investors can be attracted to different projects. In general private funding is available for large riskless and small risky investments. Structuring the projects would thus involve shifting risk out of the large investments (e.g. to governments and large corporations' balance sheets) and cutting up projects in which the risks cannot be shifted.* It is important to realize that the optimality of a project might differ for engineers, politicians and investors; the best technical system might not fit to the desires and requirements of investors. The private funders require a specific place within the organisational structure. An important function of governance that is needed to enable financing by private parties is that authorities or operators provide insight into risk profiles of CCS projects to investors. Besides that, extensive

[4] (Breevoort, Groenenberg et al. 2010)(Blank and Spoelstra 2010)(Harmelink, Welle et al. 2010)(IEA 2011)
[5] (Hagedoorn, Brug et al. 2008)(Harmelink, Welle et al. 2010)(Mozaffarian, Groenenberg et al. 2010)
[6] (IEA 2011) (van Alphen, Noothout et al. 2010)
[7] (Sanders 2010)

information sharing by operators and clearly regulated investment conditions will connect investors to projects and can be beneficial for the development of CCS market. O*bjective, verifiable information is a necessary condition, but not sufficient. Investors need to personally engage in the project. That investment precedes any resources being committed to CCS.*[8] This link should be incorporated within the governance structure and requires attention from operators.

The importance of identifying risks, mitigating and sharing them is important when financing projects, as highlighted above, but risks play a more extended role in the CCS market and projects. CCS projects encounter several risks. Examples are liability issues due to the risks taken when CO_2 is transported and stored, and risks due to fluctuating supplies of CO_2. These risks hinder the initiation, development and implementation of CCS projects. For different risks different governance structure solutions are possible.

Liability can be mitigated by agreeing on liability transfer from project operator to authorities after closing the project or by insurances or funds that protect against costs in case of damages due to CO_2 leakage.[9] Otherwise, operators remain liable for indefinite term what will likely stop operators from commencing projects. It is therefore strongly recommended that liability issues are clearly addressed within the governance structure.

Physical transport and storage infrastructure

The next important precondition to enable CCS is to identify and organise the users, managers/operators and owners of the physical grid. Examples from other large grid systems, like railways, gas, electricity and phone lines, show a spectrum of possibilities to organise these elements. The owner of the grid can differ from the licensed manager of the grid that differs again from the final user of the grid. Also the juridical and economical owners can be separate. For example, the juridical owner of the Dutch gas transport network is Gasunie, whereas the economic owner and administrator is Gasunie Transport Service (GTS)[10] and further this grid is used by gas producers and traders. Without stating which construction should be applied, issues as capacity management, use, liability and ownership regarding the CCS network require attention in order to create clarity and certainty for operators and investors and should be addressed.

The examples of the Dutch electricity and gas market show the relative large role the public authorities played in the realization of the grids used for public services.[11] Due to fact that these large grids are expensive and serve public needs, the required effort and investments are often realised by government. The difficulty with these markets and so-called large technical systems is that, at once, at least a small, but complete grid with related stakeholders and governance structure is required to start up and make it beneficial to the stakeholders. A similar division of roles could be fulfilled for the CO_2 grid. Similar to other grids, the government should provide a level playing field and enable commercial exploitation of and access to the CCS grid by third parties.

Independent of who finances the start-up of the CCS infrastructure, long-term contracts between capture, transport and storage stakeholders are required to enable large investments needed for the development of an efficient infrastructure. Cost of CCS will be lower when flows of CO_2 are large, predictable and anticipated for a long timeframe. This will require agreements on standards and contracts between stakeholders on the supply, transport and storage of CO_2. Such

[8] (Sanders, Fuss et al. 2012)
[9] (Dooley, Trabucchi et al. 2010)(Harmelink, Welle et al. 2010)
[10] (Hagedoorn, Brug et al. 2008)
[11] (Hagedoorn, Brug et al. 2008)

contractual links and responsibilities between capture, transport and storage site operators and even with financers is an important part of the governance structure.[12]

Organisational structure

Another precondition is a clear and transparent organisational structure. [13] Organisational structure considers the mutual relationships and connections (actions/responsibilities) between stakeholders and it places stakeholders within the system. An example of an organisation structure is presented in figure 1.

The paragraphs above describe several interactions between stakeholders. The *independent designer* should take these linkages into account and create an organisational structure. A well-defined organisational structure is required to map the many stakeholders and to enable them to create required connections more easily and to identify who has specific tasks within the system e.g. coordination, supervision or financing. ,[14]

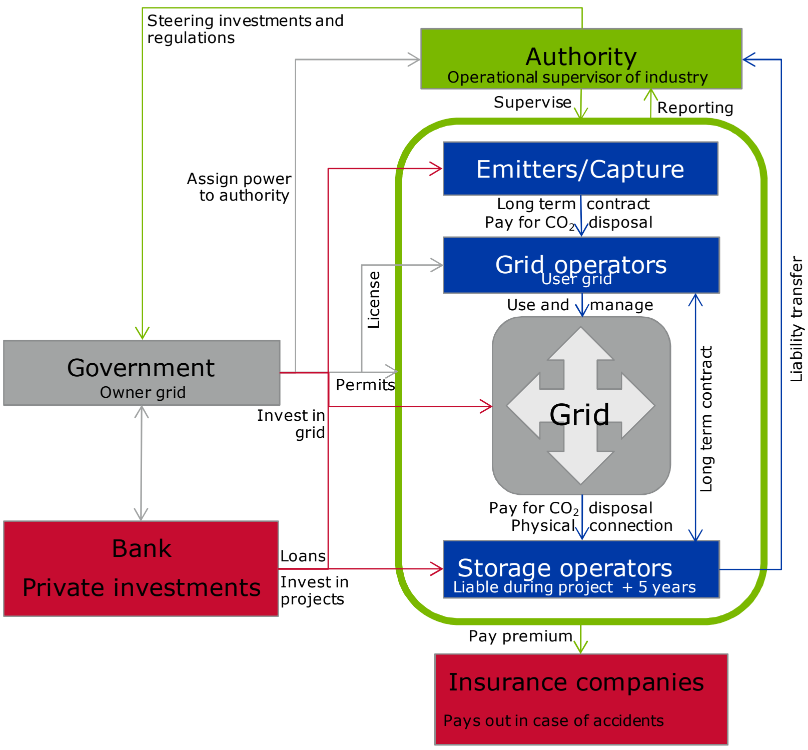

Figure 4. Example of an organisational structure for stakeholders involved in CCS in 2050 in the Netherlands. Boxes represent the stakeholders and lines between suggest responsibilities towards other stakeholders. Note that this is a simplified representation and by no means a prescription of how stakeholders should be organised in the future

[12] (Blank and Spoelstra 2010) (Harmelink, Welle et al. 2010)
[13] (Harmelink, Welle et al. 2010)
[14] (Blank and Spoelstra 2010)(Apotheker 2007)(van Alphen, Noothout et al. 2010)

International coordination

International coordinated efforts and support for CCS might enable an international regulatory framework, standards and enable the possibility of connecting (regional or national) CCS networks. An international governance structure should be supported and connected to the national governance structures. It likely requires many similar preconditions as described above.

5.3 Summary – the way forward

Some preconditions for good governance of CCS are presented. However, this does not imply that these points add up to a complete CCS governance structure. It should be noted that governance can take many different forms and will develop over time. It is not suggested that a certain form of governance should be adopted; it is merely stressed which elements should be taken into account when designing and implementing good governance structures for CCS. This includes:

- Actions and responsibilities of stakeholders
- Identify and share risks along the CCS value chain
- Enable long term investment and support various financing options, especially for transport and storage infrastructure
- Assure level playing field
- Independent designer & director of governance structure
- Set clear regulatory framework and organisational structure
- Enable international cooperation and coordination

5.4 References

Van Alphen, K., P. M. Noothout, et al. (2010). "Evaluating the development of carbon capture and storage technologies in the United States." Renewable and Sustainable Energy Reviews 14(3): 971-986.

Apotheker, D. F. (2007). A DESIGN APPROACH FOR THE ECONOMIC REGULATION OF INFRASTRUCTURES APPL IED TO A CO_2 P I P E L INE NETWORK IN A CARBON CAPTURE & STORAGE SYSTEM, Delft University of Technology, Ecofys.

Blank, F. T. and H. Spoelstra (2010). Practical guidance for monitoring plans for CCS, under the Monitoring and Reporting Guidelines for CCS of the EU Emission Trading System. CATO 2, KEMA.

Breevoort, P. v., H. Groenenberg, et al. (2010). First evaluation of competition between different CCS chains and other carbon low supply and energy efficiency options in the medium and long term: The impact of low carbon policies on the deployment of CCS. CATO 2, Ecofys.

Dooley, J. J., C. Trabucchi, et al. (2010). Design considerations for financing a national trust to advance the deployment of geologic CO_2 storage and motivate best practices.

Hagedoorn, S., E. v. d. Brug, et al. (2008). Organisatie van een CO_2 infrastructuur in Nederland- Op weg naar grootschalige realisatie van CCS, Ecofys.

Harmelink, M., A. v. d. Welle, et al. (2010). “Support to the implementation of the CCS Directive” Overview and analysis of issues concerning the implementation of the CCS directive in the Netherlands. CATO 2, RUG, Harmelink consulting, ECN, KEMA, TNO.

IEA (2011). Technology Roadmap: Carbon Capture and Storage in Industrial Applications, OECD/International Energy Agency and United Nations Industrial Development Organization.

Mozaffarian, M., H. Groenenberg, et al. (2010). Proceeding Workshop I on licensing activities: Best practices in CCS demonstrations. CATO 2, KEMA, ECN, TNO.

Sanders, M. (2010). Inventory and first assessment of different funding sources and incentive structures to mobilize resources effectively. CATO 2, Utrecht School of Economics- Utrecht University.

Sanders, M., S. Fuss, et al. (2012). Mobilizing Private Funds for Carbon Capture and Storage: A field study in the Netherlands, Faculty of Economics, University of Utrecht, Utrecht, the Netherlands, International Institute for Applied Systems Analysis, Ecosystems Services and Management Program Laxenburg, Austria.

6 CCS regulatory issues

6.1 Introduction

The objective of CCS is to safely sequester large amounts of carbon dioxide (CO_2) for a long period of time (hundreds to thousands of years). CCS policy development is focused on long-term (stable) carbon pricing; the need to accelerate development through large-scale demonstration and increased R&D; and to develop the necessary regulatory infrastructure. To achieve the objectives, CCS regulation must establish a framework encouraging responsible operation and investment. It should balance stability and predictability, with flexibility and adaptability to new scientific information, but it should also provide ease of implementation for both regulators and industry.

A rapid expansion and scale-up of CCS technology raises a number of regulatory issues that need to be addressed in parallel with on-going efforts to demonstrate the technical, safety and environmental viability of full scale CCS projects. Regulatory frameworks are required to ensure the effective stewardship of CO_2 storage sites over the long term, the protection of public health and the environment, and the security of CCS activities. Appropriate regulatory frameworks are also required to clarify the rights and responsibilities of CCS stakeholders, including relevant authorities, operators and the public. Additionally, regulations are needed to underpin performance and associated incentive schemes, commercial transactions relating to CCS operations, and also to build public confidence in, and acceptance of, the technology. In addition, issues related to competition, climate regime commitments, tax policy, financial responsibility, property rights and international treaties will also shape the CCS regulatory framework. Another challenge involves creating a transparent permitting framework which facilitates stakeholder involvement.

The absence of an appropriate regulatory system and permitting procedures may seriously delay or even block the development of CCS projects; comprehensive policies and regulations are crucial for the widespread deployment of CCS. A badly-designed regulatory system will delay current demonstration projects as well as the large-scale commercial stage. Various CCS activities can draw on regulation for existing activities, but for a part regulation should be developed for CCS specifically. The IEA concluded that integrating carbon capture permitting regulation with transport and storage legislation would provide CCS project proponents a greater degree of certainty, in particular, reducing the administrative burden imposed by permitting requirements at various stages of the CCS project cycle. Tailored, end-to-end policies and laws, harmonised across national boundaries, offer the best chance to rapidly and efficiently promote large scale investment in CCS. Here, we present a basic view on regulatory and permitting issues for CCS in the Netherlands.

6.2 Key regulatory issues for CCS

The IEA identified twenty nine key issues as being critical to the regulation of CCS activities, subdivided in four categories (see Box 3). The regulatory issues refer to all stages of the CCS chain, including CO_2 capture, transportation and storage. However, the main focus is on regulatory issues associated with CO_2 storage, which is commonly accepted as presenting the most novel and complex challenges to CCS regulation. Regulatory issues associated with CO_2 capture and transport are generally likely to fall within the scope of existing regulatory frameworks related to areas such as oil and gas, mining, waste, health and safety, property rights and gas transportation, with little or no modification to those existing frameworks.

Box 3. Key issues relating to CCS regulatory framework (IEA, 2010)

Broad regulatory issues: Classifying CO_2; property rights; competition with other users and preferential rights issue; transboundary movement of CO_2; international laws for the protection of the marine environment; providing incentives for CCS as part of climate change mitigation strategies.
Existing regulatory issues applied to CCS: protecting human health; composition of the CO_2 stream; the role of environmental impact assessment; third-party access to storage site and transportation infrastructure; engaging the public in decision making.
CCS-specific regulatory issues; CO_2 capture; CO_2 transportation; scope of framework and prohibitions; definitions and terminology applicable to CO_2 storage regulations; authorisation of storage site exploration activities; regulating site selection and characterisation activities; authorisation of storage actives; project inspection; monitoring, reporting and verification requirements; corrective measures and remediation measures; liability during the project period; authorisation for storage site closure; liability during the post-closure period; financial contributions to post-closure stewardship.
Emerging CCS regulatory issues: sharing knowledge and experience through the demonstration phase; CCS ready; using CCS for biomass-based sources; understanding enhanced hydrocarbon recovery with CCS.

6.3 EU and international-based legislation

Various international laws and regulations have impact on the development and deployment of CCS in the Netherlands. Examples are the EU directive on geological storage (CCS Directive), the EU-ETS, and the London Protocol. In 2011, the Netherlands transposed the CCS directive into national legislation (see Box 4).

Box 4. Implementation scheme of CCS directive in the Netherlands

The implementation of the EU CO_2 Storage Directive in the Netherlands entered into force by the following means:

- The law to amend the Mining Law in order to implement the EU CO_2 Storage Directive was accepted by the first chamber of the Parliament in May 2011. It was published on 6 June 2011 in the Staatsblad (Stb 2011-381) and is in force as of 10 of September 2011. This amending law was also the implementation of OSPAR Decision 2007/2 on the storage of carbon dioxide streams in geological formations.
- The Ministerial Decree to amend several existing decrees regarding environmental impact assessments, environmental permits for large combustion engines and mining was published on 9 September 2011 in the Staatsblad (Stb. 2011-406) and also entered into force on 10 September 2011.
- The regulation to amend the Mining Regulation was published on 15 September 2011 in the Staatscourant (Stscrt 2011-16804) and entered into force on 16 September 2011.

The question is whether it sufficiently accommodates the practical issues that project developers encounter in making their business case. For instance the issue of the legal prohibition in the Netherlands of holding a CO_2 storage license in combination with an oil/gas production license. The current legislation gives no restrictions on using CO_2 for EOR/EGR, however no EU-ETS credits can be acquired. The Dutch Mining Act prevents the operator of an oil/gas field to simultaneously hold a storage license and a production license (art 26 – 6 Mining Act). Combining CCS and EOR is interesting, as the injection of CO_2 initially increases the oil production and gradually the field can be reused as storage location once the production ends. However, the

CCS Directive determines that the exploration permit[15] should be issued in competition. This means that the operator of the production phase cannot be guaranteed to also receive the storage license. Furthermore, the production license comes with obligations for closure and removal of the equipment. Not fulfilling these obligations creates risks and liabilities for the licensee. These uncertainties complicate the transition from production to EOR and eventually storage.

As the CCS Directive is written assuming that transport will take place by pipeline, there are uncertainties as to how the regulation applies to transport by ship. A main issue is the integrity of the monitoring of emissions through transport and storage.

Furthermore, the EU-ETS does not provide an incentive for capturing CO_2 from biomass-fuelled plant, as no negative emissions can be credited to the operator. Moreover, legislation actually deters operators from co-firing biomass in a capture-equipped plant, as extra energy will be needed to capture, treat and compress the CO_2 from biomass plant (potentially up to 20%), which is not entitled to gain EU ETS credits. This means operators will avoid striving for negative emissions, which are becoming more relevant as a mitigation measure given the delay in tackling climate change.

When CO_2 is to be stored outside the country, it has to cross borders of one or more states. However, the London Protocol - based on art 6 - prohibits transboundary movement of CO_2 for storage, as long the adopted amendment has not yet been ratified by the EU member states bordering the North Sea.

6.4 Current experience with regulation in demonstration projects

In the Netherlands, three main CCS projects have been developed which required permitting: CRUST, Barendrecht project and ROAD. For the Barendrecht project, tens of acts, regulations and exemptions were applicable to transport and storage of CO_2. In this project no permits applied to CO_2 capture as CO_2 was already separated in the original process without CCS. Some of the experience gained in the eventually suspended Barendrecht project has proved to be useful for follow-up demonstration CCS projects in the Netherlands. For the ROAD project initiated by E.ON and Electrabel various permits, acts, and regulations/exemptions are applicable [ROAD, 2011a; ROAD, 2012; ROAD, 2013]; see Box 5. ROAD is the first in line of possible CCS projects in the Netherlands. In this project, the National Coordination Regulation (RCR) and the General Environmental Conditions Act (Wabo) were applied for the first time to a CCS project. The RCR streamlines the procedure and links the initiators with the coordinating Ministries of Economic Affairs (EA) and Infrastructure and Environment (E&I).

In case of a demonstration CCS project, CO_2 capture – retrofitting of a coal-fired power plant (ROAD), or industrial CCS – does not necessarily incur permitting issues. However, the CO_2 storage permit does not have precedence. In case of 'ROAD', minor issues related to the onshore CO_2 pipeline – it is state-of-the-art, considering the substantial experience with CO_2 transport by pipeline in Zuid-Holland (industry, horticulture) – propagated into the procedure for transposition of a draft CO_2 storage permit into a final permit. Based on existing (ROAD) or already cancelled projects (Barendrecht, Green Hydrogen) experiences have been gained for permitting. Box 5 presents an overview of the main permits related to CCS projects.

[15] It is possible to skip the exploration phase, which is likely in case of an existing and active though almost empty gas field. However, if the exploration phase is skipped, the storage license should be issued in competition.

Box 5. Main permits, exemptions, and acts with relevance to 'ROAD' or a generic CCS project

Permits, acts, regulations or exemptions	**Explanation**
Environmental Impact Assessment (EIA) (MER procedure)	The Environmental Management Act requires an EIA for the whole chain of a CCS project, i.e. CO_2 capture, transport and storage with Ministries of EA and I&E as appropriate authority
Emission permits (emissievergunningen)	In case of a CCS project, emission permits are needed for the CO_2 capture plant, for CO_2 transport, and for CO_2 storage from the Emission Authority (Nederlandse Emissie Autoriteit, NEA)
All-in-one permit for physical aspects	For 'ROAD', the General Environmental Conditions Act requires a permit for CO_2 capture from 'Zuid-Holland'
Environmental permit (milieuvergunning)	An environmental permit is needed for a fossil-fuel based power plant or industrial plant needs; for 'ROAD' an amendment on that permit for CO_2 capture from 'Zuid-Holland'
Building permit (bouwvergunning)	A building permit is needed for the CO_2 capture plant; in case of ROAD from the municipality of Rotterdam (ROAD, 2011)
Permit under the Nature Conservation Act	A permit is needed under de Nature Conservation Act for CO_2 capture to prove that there are no significant effects on nature
Water permit	A water permit is needed for the for the discharge of cooling water by the CO_2 capture plant, for 'ROAD' from the Ministry of I&E
State Zoning Plan (bestemmingsplan)	For transport of CO_2, planning permission for construction and use of the CO_2 pipeline falls within the scope of the Mining Act
Water permit	Under the State Water Management Works Administration Act, a Water permit is needed for the CO_2 pipeline to cross a dike of the State Water Authority
Permit under the Railways Act	For a CO_2 pipeline, a permit is needed to cross a railway under the Railways Act, governing the construction, maintenance, access, and the use of railways
Flora and Fauna Act exemption	For CO_2 transport, an exemption is needed from the Flora and Fauna Act from the Ministry of I&E
All-in-one permit for physical aspects	CO_2 storage requires an All-in-one permit for physical aspects based on the General Environmental Conditions Act (TAQA B.V.)
Storage permit (opslagvergunning)	CO_2 storage requires a storage permit, which may be obtained based on quantification by TAQA B.V. ('ROAD') how much CO_2 could be leaked to the subsurface in case of a leakage incident

Source: ROAD, 2011a.

6.5 Outlook for permitting in the Netherlands

Compared to other EU Member States, the Netherlands transposed relatively fast the EU CCS Directive and streamlined the permitting procedure. The National Coordination Regulation, with applicability to large energy-related projects[16] and infrastructure, among which CCS projects, is regarded as a showcase for environmental policy. Future CCS projects may profit from lessons learned for the ROAD project by the industry and the Ministries of Economic Affairs (E&A) and Infrastructure and Environment (E&I). Postponement by the ROAD consortium of the Final Investment Decision, FID, by one-and-a-half year [CSLF, 2011][17] does not have much to do with CCS permitting, but with financial uncertainty due to the low EU ETS CO_2 price: 'the ETS underpins not only the long-term, but also partly the short-term business model as every CCS project will need to recover its investment over the medium to long term' [ZEP, 2012].

Nearly three years after the start of the permitting procedure, ROAD has at its disposal all final permits and TAQA only needs to get its final storage permit [ROAD, 2011a]. Therefore, a permitting timeline of about three years appears to be feasible with the current permitting practice. As said before, the length of the permitting procedure should be optimized, but this has to be part of an encompassing strategy, including stakeholder involvement (a prerequisite for the EIA procedure).

6.6 Summary – the way forward

Development of a regulatory framework is necessary but not sufficient to catalyse CCS deployment. Economic and political barriers will also need to be addressed. In fact, regulations governing geological storage site performance, climate liabilities, and long-term stewardship cannot be finalised in the absence of a climate regime.

CCS regulation must evolve as scientific and technical knowledge expands. An evolutionary regulatory process is required because full-scale CCS projects are urgently needed (and must be regulated), but key uncertainties prevent design and implementation of a comprehensive regulatory framework at this time. The first stage, essentially underway, will or need to consist of several dozen full-scale CCS projects worldwide, operated under existing regulations modified to account for specific features of CCS. The second stage in the evolution of CCS regulation has to use data from early CCS projects to design general CCS regulations to manage widespread commercial deployment.

Early projects should emphasize the collection and sharing of technical data to support decisions regarding regulatory framework, indemnification, liability transfer[18] and operational standards [Wilson et al., 2008]. Issues have been experienced with permitting for coal-fired power plants. Permitting for CCS as such does not necessarily incur problems. Today, nearly three years after the start of the permitting procedure, ROAD has at its disposal all final permits.

Risks related to climate change present particular problems to the insurer and the insured: first, there is no clear damage definition, i.e. no well-defined impact; second, there is no universally accepted cost, and therefore compensation; and third, there is currently no legal regime on which to base claims. Early CCS projects that receive special treatment regarding liability considerations (e.g. government risk sharing) should, in return, make commitments to

[16] See for instance [RCI, 2011], which makes mention of the Pegasus project, a Zero Emission Power Plant (ZEP).
[17] According to [CSLF, 2011], the Final Investment Decision was to be made in the second quarter of 2011, whereas it is doubtful whether the FID for the ROAD project will be taken in the second quarter of 2013.
[18] In the Shell Quest project in Canada, Shell has said that it cannot manage the liabilities, and the understanding is that the Alberta authorities have taken the liability exposure.

transparency regarding project performance, data availability and independent assessment of risks and performance.

In 2011, the Netherlands transposed the CCS directive into national legislation. The question is whether it sufficiently accommodates the practical issues that project developers encounter in making their business case. Remaining issues are the legal prohibition in the Netherlands of holding a CO_2 storage license in combination with an oil/gas production license. The current legislation gives no restrictions on using CO_2 for enhanced hydrocarbon recovery; however no EU ETS credits can be acquired. The Dutch Mining Act prevents the operator of an oil or gas field to simultaneously hold a storage license and a production license (art 26 – 6 Mining Act). Combining CCS and EOR is interesting, as the injection of CO_2 initially increases the oil production and gradually the field can be reused as storage location once the production ends.
Furthermore, the EU-ETS does not provide an incentive for capturing CO_2 from biomass-fueled plants, as no negative emissions can be credited to the operator. Moreover, legislation actually deters operators from co-firing biomass in a capture-equipped plant, as extra energy will be needed to capture, treat and compress the CO_2 from biomass plant (potentially up to 20%), which is not entitled to gain EU ETS credits. This means operators will avoid striving for negative emissions, which are becoming more relevant as a mitigation measure given the delay in tackling climate change.

The main actions with regard to regulation of CCS are therefore:

- Allow combining CCS and EOR (action Dutch government), and provide an incentive for capturing CO_2 from biomass-fueled plant in the EU ETS (action European Commission, implementation by the Dutch government);
- The transboundary issue of CO_2 transport has to be solved, allowing cross-border transport from one country to another. Action is needed of signatories to the London Protocol;
- The second stage in the evolution of CCS regulation has to use data from early CCS projects to design general CCS regulations to manage widespread commercial deployment;
- Award in the EU-ETS, or by some other means, CO_2 stored from biomass sources;
- Design a transparent and comprehensive public consultation process.

6.7 References

CATO2 (2012): *Briefing on identified best practices in relevant networks (2012)*. CATO-2 program, work package 4.2, CATO-2-WP4.2.B-D08-REP, 2012.12.31.

CSLF (2011): *Strategic Plan Implementation Report*. Carbon Sequestration Leadership Forum (CSLF), London, UK, February 2011, p. 22.

GCCSI (2012): *The Global Status of CCS: 2012*. Global CCS Institute (GCCSI), Canberra, Australia, 2012.

IEA (2010): *Carbon Capture and Storage – Model Regulatory Framework*, Information Paper, International Energy Agency, Paris

RCI (2011): *CO_2 capture and storage in Rotterdam*. Rotterdam Climate Initiative (RCI), Rotterdam, May 2011.

ROAD (2013): *Permitting Process – Special report on getting a CCS project permitted*. ROAD Maasvlakte CCS Project C.V., Rotterdam, January 2013.

ROAD (2012): *Project Execution Strategy ROAD – Special Report for the Global Carbon Capture and Storage Institute*. ROAD Maasvlakte CCS Project C.V., Rotterdam, March 2012.

ROAD (2011a): *Permitting Process – Special Report for the Global Carbon Capture and Storage Institute*. ROAD Maasvlakte CCS Project C.V., Rotterdam, December 2011.

ROAD (2011b): *Non-confidential FEED study report – Special Report for the Global Carbon Capture and Storage Institute*. ROAD Maasvlakte CCS Project C.V., Rotterdam, November 2011.

Wilson, E.J. (2008): *Regulation of Carbon, Capture and Storage - Policy Brief*. International Risk Governance Council, Switzerland, 2008.

ZEP (2012): *CO_2 Capture and Storage – Creating a secure environment for investment in Europe*. European Technology Platform for Zero Emission Fossil Fuel Power Plants, July 2012, p. 7. http://www.zeroemissionsplatform.eu/

7 CCS communication to the public

7.1 Introduction

The public attitude towards CCS is important for the success and speed of CCS project implementation. It is therefore important that the public is informed about the relevance and impact of CCS both on national and local (project) level. In this way, the public can form an opinion on the applicability and desirability of CCS. However, the transfer of information to the public is complex and should be done carefully to avoid misperceptions. It is therefore necessary that the provided information is not only correct, evidence based and balanced, but also that the source of information is credible (Koot et al., 2012; Ter Mors et al., 2010; Terwel & Daamen, 2012; Terwel et al., 2009a, 2009b, 2011, 2012). A lack of public trust in the communicator negatively affects the way people process information. It may also lead to rejection of the communication, which may result in unsubstantiated negative attitudes to the technology among the public. Equally important is that the context of the technology is made clear. In the case of carbon capture and storage, this refers for example to defining the causal chain from energy use to climate change and explain the possible role of CCS in this chain. Studies indicate that only a small part of the population has sufficient knowledge about this relationship (Paukovic et al, 2011, 2012).

Research indicated that the vast majority of the Dutch public is neither enthusiastic nor seriously opposed to CCS. The case of Barendrecht, however, showed that the position of local public confronted with an actual transport and storage project may be very different (Terwel et al., 2012). In this case the local public fiercely opposed the CO_2 transport pipeline and the injection and storage of CO_2 in an empty natural gas field in the subsoil below the village. Over eighty per cent of the local population qualified the plan as (very) bad and as (very) unsafe and many were concerned about loss of property value. Inadequate communication and anti-process sentiments played a role, most notably perceived procedural unfairness and lack of public trust in decision-making authorities and project proponents (Ashworth et al, 2010; Desbarats et al, 2010, Terwel et al., 2012). In 2011, the government cancelled the Barendrecht CCS project; the public opposition was a main reason for this decision.

Clearly, communication to the public plays a vital role in the acceptance or rejection of technology. Therefore the development of effective communication on CCS and its role in climate action is required.

7.2 People's attitude towards CCS

In general, people's opinion towards carbon capture and storage is to a large extent explained by whether they perceive CCS to have benefits, such as its role in climate change mitigation (e.g., Brunsting et al., 2012; De Best-Waldhober et al., 2009, 2012, Ter Mors et al., forthcoming). When people perceive more benefits of CCS, their attitude towards CCS becomes more positive. Misperceptions about CO_2 also seem to influence the opinion about CCS, but not as much and indirectly. Misperceptions were found a strong predictor of people's perception of the safety of CO_2 transport and their perception of risks related to leakage of CO_2. These risks perceptions in turn were a strong predictor of the people's opinion on CCS (cf. Terwel et al., 2012). When the safety risk is perceived higher, opinion of CCS became more negative (Paukovic et al., 2011).

7.3 Sender credibility

Effective communication is all about trust in the stakeholders communicating the message (Koot et al., 2012; Ter Mors et al., 2010; Terwel & Daamen, 2012; Terwel et al., 2009a, 2009b, 2011, 2012). Public trust in CCS stakeholders can be thought of as people's willingness to rely on these organisations. The reason that trust in stakeholders plays such an important role in opinion formation is that most people lack the knowledge or motivation to judge the merits of CCS by themselves. People put more trust in environmental NGOs than in industrial organizations, because they perceive NGOs to be more concerned with public interest (Terwel et al., 2009a). Nevertheless, both types of organization are perceived to be equally competent with regard to CCS. Communication can be done most effectively by a coalition of stakeholders, e.g. formed by NGOs and industrial organizations (Ter Mors et al.,, 2010).

7.4 Framing the message

Equally important is the framing of the message (De Vries et al., forthcoming, 2010, 2012; Terwel et al., 2009a). Industrial organizations may frame their communications in ways so the general public learns that the investment in CCS is motivated by the positive environmental consequences associated with CCS. This could lead to a better corporate image, but it also may lead to accusation of corporate greenwashing, i.e. presenting themselves as “greener” than they are. In building public support for corporate policies about environmental issues like CCS such accusations need to be avoided. In general, industrial stakeholders do better if they confirm public expectations about their business motives, i.e. economic gain, in addition to public motives, i.e. concern about the environment. Providing only socially desirable information causes distrust rather than trust (De Vries et al., forthcoming; Terwel et al., 2009a).

7.5 Communication strategies and engagement

Roughly we can distinguish two levels of communication: informing the general public on national level with emphasis on the relevance and impact of the technology in relation to combating climate change and on local level where an actual project is planned or takes place. There are various communication channels possible, such as television, newspapers, information market, scientific papers, social media and internet. The way of communicating and the information provided should not be static but needs to be adjusted depending on the stage of development of CCS.

Climate campaign: climate change, climate actions and the role of CCS

For the public to be able to grasp the relevance of CCS, its potential role in the energy and climate system needs to be understood. Currently, the Dutch public is hardly aware of the energy use in the Netherlands and its relation to climate change. When attempt is made to communicate the concept of CCS to the public, small steps in the causal chain should be spelled out. If the general population does not understand the problem our society faces when we do not mitigate CO_2 emissions, it will be extremely hard to get their approval of any kind of CO_2 mitigation option, be it large wind turbine parks, CCS, or home renovations to improve energy efficiency (Paukovic et al., 2011b).

Communication to local public

There is a wide range of factors important when communicating to the public in the vicinity of (planned) CCS projects. It is relevant to undertake preparatory research of locally salient issues and to initiate a dialogue with local stakeholders early on in the planning stages, well before new CCS demonstration or commercial projects are implemented. It is important to use high quality communications material preferably in a mix of formats: formal, informal, technical and simple. Information itself must be clear and trustworthy; persuasive communications that aim to promote CCS are likely counterproductive. It is better to provide balanced factual information about CCS that does not focus solely on the benefits of CCS. Provision of such information may at least help to reduce misunderstandings, even if it cannot wholly avoid these. The communication needs to be in an open, two-way dialogue: the public rightly expects procedural justice and for their concerns to be listened to and to be taken seriously. Despite all efforts, it should be realised that there may be irreconcilable differences between objectors and developers that cannot be overcome via consultation, listening, or minor changes to projects or processes. To engender trust in the project developer it may be helpful to involve independent experts. Gaining trust also takes time and in practice may involve managing a lengthy process of public relations.

Compensation schemes

In the case the local population contributes disproportionally to solve a societal problem, it may be regarded fair compensating the local public for hosting CCS projects (Ter Mors et al, 2012). An organisation that wants to implement a project with adverse local impacts can offer the members of the affected community compensation in return for having to bear the burdens associated with the project. Compensation measures can take various forms, e.g. public goods compensation or monetary compensation, fixed versus variable compensations, and also insurance-like compensation, i.e. if something happens it will be compensated in a certain pre-defined way. Whether host community compensation helps to prevent or solve facility siting controversies depends on many factors including: context, timing, perceived procedural fairness, type of compensation and trustworthiness of the organisation offering the compensation. Consultations with local residents are important in the process of deciding on community compensation measures (Terwel et al., submitted for publication).

Whether and to what degree standardization of compensation is desirable and feasible is yet unclear; it makes compensation less arbitrary, but proper criteria may be hard to develop as the circumstances between the individual projects may differ significantly. Standardization may also lead to less flexibility in addressing local circumstances.

7.6 Summary – the way forward

Studies suggest that people well informed on CCS probably agree with large-scale implementation of CCS, although reluctantly (De Best-Waldhober et al., 2009). In practise, however, the (future) position of the general public towards large-scale deployment of CCS and towards CCS projects is less certain as it is likely that many people will not be well informed on this technology. Evidence based and balanced, but also timely communication is therefore crucial for public opinion on the technology both on national and on local project level. Inadequate communication may lead to misconceptions, dissatisfaction in the decision making process and distrust in the organisations involved. To develop and improve communication to the public the following actions may need to be taken.

- The role of CCS in the energy system and its role in combating climate change need to be explained in a well-planned and prepared communication strategy. One instrument may be a government steered ‘carrier wave’ campaign in which the position of CCS as a climate change mitigation measure is explained step by step. A prerequisite is that the government has a clear vision on CCS. The government may need to set up an organizational structure to develop, implement and maintain such communication strategy, including understanding who is informing who.
- Development of a communication strategy for local public affected directly by CCS projects. Stakeholders like the government or industrial organizations with a (commercial) interest communicating individually may not be fully trusted by the public. The presence of stakeholder coalitions speaking with one voice is therefore essential to gain trust in the information provided.
- Evidence based communication both in terms of the strategy used and the information presented – instead of ‘gut feeling’ communication - is key to successfully convey the message. Communication methods have to follow the loop of developing, testing, adapting, deploying and monitoring its effect. The communication approach should continuously be improved and adapted.

- Compensation measures for local public for CCS projects need to be developed and tested. A detailed understanding is needed of compensation mechanisms that can work for CCS projects. Relevant aspects are types of compensation (monetary or public goods), timing of compensation, party's trustworthiness and procedural fairness.

7.7 References

Ashworth, P., Bradbury, J., Feenstra, C.F.J., Greenberg, S., Hund, G., Mikunda, T., Wade, S. (2010). *Communication, project planning and management for carbon capture and storage projects: An international comparison.* GCCSI report, 2010

Breukers, S.C., Pol, M., Upham, P., Lis, A., Desbarats, J., Roberts, T., Duetschke, E., Oltra, C., Brunsting, S., De Best-Waldhober, M., Reiner, D., Riesch, H. *Engagement and communication strategies for CCS projects: Gaps between current and desired practices and exemplary strategies*. NearCO_2 report, September 2011.

Brunsting, S., De Best-Waldhober, M., & Terwel, B.W. *I reject your reality and substitute my own!' Why more knowledge about CO_2 storage hardly improves public attitudes*. Paper presented at: 6th International Conference on GreenHouse Gas Control Technologies (GHGT-11), Kyoto, Japan, 18-22 November 2012. To be published in Energy Procedia.

De Best-Waldhober, M., Daamen, D. , & Faaij, A. (2009). *Informed and uninformed public opinions on CO_2 capture and storage technologies in the Netherlands*. International Journal of Greenhouse Gas Control 2, 322-333.

De Best - Waldhober, M, Daamen, D., Ramirez-Ramirez, A., Faaij, A., Hendriks, C., & De Visser, E. (2012). *Informed public opinion in the Netherlands: Evaluation of CO_2 capture and storage technologies in comparison with other CO_2 mitigation options*. International Journal of Greenhouse Gas Control 10, p.169-180.

Desbarats, J.,Upham, P., Riesch, H., Reiner, D., Brunsting, S., de Best-Waldhober, M., Duetschke, E., Oltra, C., Sala, R., McLachlan, C. *Review of the public participation practices for CCS and non-CCS projects in Europe.* NearCO_2 report, February 2010.

De Vries, G., Terwel, B. W., Ellemers, N., & Daamen, D. D. L. (forthcoming). *Sustainability or profitability? How communicated motives for environmental policy affect public perceptions of corporate greenwashing*. Accepted for publication in Corporate Social Responsibility and Environmental Management.

De Vries, G., Terwel, B. W., Ellemers, E., & Daamen, D. D. L. (2011). *Framing effects in communication about CCS: The dilution effect in evaluations of the persuasiveness of* Information. Leiden University, CATO-2 deliverable WP5.2-D04.

De Vries, G., Terwel, B. W., Ellemers, E., & Daamen, D. D. L. (2012). *Framing effects in communication about CCS: F raming and blaming: How framing affects attitude and elicits inferences of manipulativeiIntent*. Leiden University, CATO-2 deliverable WP5.2-D05.

Koot, C. , Ter Mors, E., Ellemers, N., & Daamen, D.D.L. (2012) *De invloed van waargenomen bronexpertise op het vormen van gesloten attitudes*. In: Strick, M., Strick, M., Baas, M., Baas, M., Dillen, L., van, Dillen, L., van, Dotsch, R., Dotsch, R., Lakens, D., Lakens, D., Vries, M., de, Vries, M., de (Eds.), Jaarboek Sociale Psychologie 2012**,** pp. 113-120. Groningen: ASPO Pers.

Paukovic, M., Brunsting, S., Straver, K., Mastop, J, 2012. *The Dutch general public's opinion on CCS and energy transition in 2011: Development in awareness, knowledge, beliefs and opinions related to information and media coverage.* ECN, CATO-2 deliverable WP5.3-04.

Paukovic, M., Brunsting, S., & De Best-Waldhober, M., 2011. *The Dutch general public's opinion on CCS and energy transition1: Development in awareness, knowledge, beliefs and opinions related to information and media coverage.* ECN, CATO-2 deliverable WP5.3-D02a.

Ter Mors, E., Terwel, B.W. ,& Daamen, D.D.L. (2012) The potential of host community compensation. International Journal of Greenhouse Gas Control**,** 11, pp. S130-S138.

Ter Mors., E., Terwel, B. W., Daamen, D. D. L., Reiner., D. M. , Schumann, D., et al. (forthcoming). A comparison of techniques used to collect informed public opinions about CCS: Opinion quality after focus Group discussions versus information-choice questionnaires. Accepted forpublication in International Journal of Greenhouse Gas Control.

Ter Mors, E., Weenig, W.H., Ellemers, N., & Daamen, D.D.L. (2010) *Effective communication about complex environmental issues: Perceived quality of information about carbon dioxide capture and storage (CCS) depends on stakeholder collaboration*. Journal of Environmental Psychology**,** 30, pp. 347-357.

Terwel, B. W., & Daamen, D. D. L. (2012). *Initial public reactions to carbon capture and storage (CCS): Differentiating general and local views*. Climate Policy, 12, 288–300.

Terwel, B. W., Harinck, F., Ellemers, N., & Daamen, D. D. L. (2009a). *How organizational motives and communications affect public trust in organizations: The case of carbon dioxide capture and storage.* Journal of Environmental Psychology, 29, 290-299.

Terwel, B. W., Harinck, F., Ellemers, N., & Daamen, D. D. L. (2009b). *Competence-based and integrity-based trust as predictors of acceptance of carbon dioxide capture and storage (CCS)*. Risk Analysis*, 29*, 1129-1140.

Terwel, B. W., Harinck, F., Ellemers, N., & Daamen, D. D. L. (2010). *Voice in political decision making: The effect of group voice on perceived trustworthiness of decision makers and subsequent acceptance of decisions.* Journal of Experimental Psychology: Applied, 16, 173-186.

Terwel, B.W., Harinck, F., Ellemers, N., & Daamen, D.D.L. (2011). *Going beyond the properties of CO_2 capture and storage (CCS) technology: How trust in stakeholders affects public acceptance of CCS*. International Journal of Greenhouse Gas Control 5, 181-188.

Terwel, B. W., Kouwenburg, F., & Ter Mors, E. (submitted). *Public responses to community compensation: The importance of prior consultations with local residents*. Manuscript submitted for publication.

Terwel, B. W., Ter Mors, E., & Daamen, D. D. L. (2012). *It's not only about safety: Beliefs and attitudes of 811 local residents regarding a CCS project in Barendrecht*. International Journal of Greenhouse Gas Control, 9, 41–51.

8 CCS field strategy

8.1 Introduction

Studies have shown that sufficient national storage capacity is available, both onshore and offshore, to store CO_2 at the rate required for large-scale deployment of CCS. However, the time required to prove the feasibility of CO_2 storage, to meet regulatory requirements and to develop the necessary infrastructure can be considerable and can be a bottleneck in the development of CCS projects. Current demonstration projects aim to use depleted gas fields or deep saline formations for storage space. Both types of storage require long-term planning and preparation, to ensure timely availability for future CCS projects.

This implies that storage appraisal and certification is to start well ahead of the development of capture installations to provide potential CCS projects with the certainty of storage capacity. Such assessment could be laid down in a (national) storage strategy to provide clarity for potential CCS project about their options for storing the captured CO_2. A field strategy for CO_2 storage will provide all stakeholders with a common view of the expected short-term and long-terms development and availability of CO_2 storage capacity, in line with CCS developments and developments in the exploration and production of hydrocarbon assets.

In the following sections the most important questions related to a field strategy are discussed in more detail.

8.2 Why should the field strategy be developed?

The time required to prove the feasibility of CO_2 storage in a depleted gas field is of the order of one to two years. For the development of a deep saline formation this period is probably twice as long. Including the development of installations (platforms, wells) brings the lead time for depleted gas fields to at least five to six years and six to eight years for saline formations (*Neele et al.,* 2012). This implies that storage appraisal and certification is to start well ahead of the development of capture installations to provide potential CCS projects with the certainty of storage capacity. Project implementation could, however, considerably be shortened with the presence of storage strategy providing qualified storage locations. Another major benefit is that the project risk of the CCS project can be reduced potentially leading to lower costs for implementing CCS.

8.3 When should de field strategy be developed?

In its most recent roadmap, the IEA uses the term ‘pre-competitive storage assessment’ (*IEA,* 2013), implying that the storage qualification should take place before the actual development of a commercial CCS project.

8.4 Who should develop the field strategy?

As offshore activities are costly, these qualifications can be typified as high risk – low reward. To facilitate and speed up project implementation such task could be performed or led by the government, at least until a sizable transport and storage industry is present. In the case of hydrocarbon fields that are expected to be part of the future storage infrastructure a storage feasibility study should be carried out as soon as possible, but at least before the end of production. In this way a series of tested and prepared storage sites is created. The government could recover the costs from operators who make use of the qualified and certified storage locations. A database of these locations, as well as of as yet unproven locations, should be maintained.

8.5 How often should the strategy be updated?

A field strategy describes a forecast of the development of CCS into the future both on short-term and over several decades. It will provide insights in the planning of infrastructure and availability of storage reservoir capacity. However, the storage capacity remains to be proven and some of the assets may not represent economically feasible storage locations. The strategy therefore needs to be updated regularly, as new knowledge about storage capacity or infrastructure development becomes available. Changes in the regulatory environment are also highly relevant and may affect infrastructure development and should therefore be included in an update.

In practice, developments may have different dynamics. For example, the construction of a pipeline to a hydrocarbon reservoir is likely to trigger additional CCS related activities. Also, the local availability of CO_2 will enable the use of CO_2 for the testing of virgin aquifer structures in the vicinity of the pipeline by a pilot injection test. Field strategy updates may, therefore, be required every few years, once the development of CCS gains momentum.

8.6 What should be described in the field strategy?

Specific elements for CO_2 storage that are to be addressed in a field strategy are the storage assets and their capacity, availability, location and overall performance & suitability. The strategy further needs to be based on a common vision on the development of CCS in the Netherlands and surrounding countries, and should also be in line with other national strategic (spatial) plans. The field strategy obviously needs to align with long term development scenarios for hydrocarbon production. This shows that a high degree of coordination is required to set up an overall CO_2 infrastructure approach and to match hydrocarbon production with subsequent CO_2 storage.

Examples of important elements that need to be included in the field strategy are described below in more detail.

Storage options

The total storage capacity in the Netherlands is estimated at about 4.0 Gt of which 2.5 Gt offshore and 1.5 Gt onshore. In 2011, the Dutch government decided not to allow injection of CO_2 into the Dutch onshore subsurface. As onshore storage has been put on hold, recent studies (Neele et al., 2011, 2012) focus on offshore storage capacity. The larger part of the offshore capacity is present in depleted gas fields and saline formations.

Until this ban on onshore storage is removed, CCS projects are therefore depending on offshore storage reservoir capacity or exporting the CO_2 abroad for injection elsewhere. gives some details on the various types of offshore storage reservoirs in the Netherlands. A database of potential storage locations was compiled in recent years and is currently maintained by TNO. This database is currently based on publicly available data.

Box 6. Offshore storage options in the Netherlands

Depleted gas fields. The storage capacity in offshore gas fields is of the order of 1 Gt (*NOGEPA*, 2008; *EBN-Gasunie*, 2010; *Neele et al.,* 2012). This number assumes that the majority of currently producing gas fields can be re-used for CO_2 storage. The total storage capacity is significant, but most fields are small and many fields will be required to reach significant storage capacity.
Under the current regulations, production installations have to be removed within two years of the end of production. As the majority of offshore gas fields is expected to reach the end of production by about 2025, this means that measures must be taken to benefit from existing infrastructure for storage of CO_2. These measures should include adequate preparation of reservoirs, wells, pipelines and platforms. Issues that play a role in the regulating the transition from production of hydrocarbons to injecting CO_2 include the uncertainty in the end of production date and, hence, the availability of storage capacity, the transfer procedures from production to storage, the feasibility of using the reservoir for storage and re-using the production installations for injection.
Combining storage of CO_2 at a certain stage with the production of natural gas could have benefits such as enhanced gas recovery (EGR), reducing the risk of subsidence at the surface through pressure support, and reducing the probability of earthquakes.

Deep saline formations. A recent study suggests that significant storage capacity of about 1.5 Gt is available in offshore saline formations (*Neele et al.,* 2012). Such estimates are uncertain as - in the absence of hydrocarbon production - often little data is available about the properties of these structures. Proving the feasibility of storing CO_2 in a deep saline formation requires therefore an effort that is comparable to a hydrocarbon exploration survey, including drilling at least one appraisal well.

Oil fields, EOR. Options for storing CO_2 in oil fields in the Netherlands are limited, due to the small size of offshore oil fields. Enhanced oil recovery (CO_2-EOR) is expected to contribute little to the economics of offshore CO_2 storage (*Neele et al.* 2011). In other parts of the North Sea CO_2-EOR could be an enabler.

Dutch offshore storage assets

In the Netherlands an important storage asset is represented by the P18 field, which is planned to be used by the ROAD project at the Maasvlakte near Rotterdam. Recent scenario studies consider likely candidates for storage for potential follow-on CCS projects. These projects may utilize the infrastructure provided by the ROAD project. Consequently they are likely to use nearby gas fields, such as those in the P15 block. Subsequent, sizeable storage capacity of about 200 Mt can be found in the saline formation in the Q1 block. After that, the large capacity represented by the gas fields and gas fields in clusters in the central offshore area can be developed. Recent studies have identified the larger gas fields in this area as key assets that could act as gateways to the storage capacity in the different clusters nearby. Examples are the L10 and K04-K05 fields, with about 150 to 200 Mt of storage capacity in smaller fields in each cluster.
Another key saline formation is the formation in the P blocks with a capacity of about 360 Mt, but there is less information available compared to the Q1 formation. As mentioned above, testing and developing a storage site within such structure will take a period of at least 7 years before injection can start.

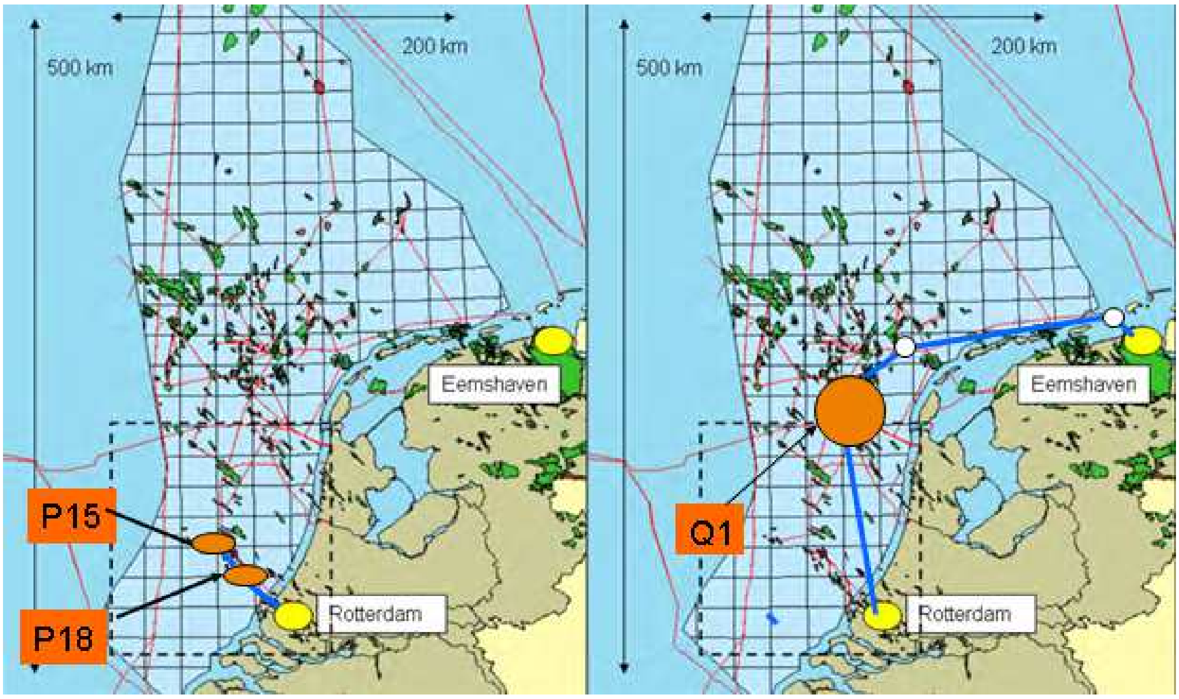

Figure 5. Example of offshore storage assets (P15, P18 and Q1) and possible transport routes from Rotterdam and Eemshaven harbour to these assets.

Timing of storage capacity

The timing of utilizing the (Dutch) storage capacity depends on various factors, but mostly on the availability of suitable storage capacity and the rate of development of CCS. The field strategy can for example contain a number of scenarios that, together, span the minimum and maximum rates. A recent study (*Loeve et al.*, 2013ab) explored such scenarios until about 2030 for utilizing offshore storage reservoirs. The scenarios build upon current plans from the Rotterdam area (the ROAD project) and the Eemshaven area. The storage compartments included were those mentioned above (see also
Figure 5). *Loeve et al.* (2013ab) first showed the potential timing of the start of injection in each of the storage sites used. They also explored the benefits of cooperation in transport and storage between the two regions and concluded that cooperation can result in significantly lower cost.

International issues

The larger part of storage capacity in Europe is located in the North Sea (*Geocapacity*, 2009) and with long-term outlooks on the size and scale of CCS, it is to be expected that the countries bordering the North Sea will cooperate in the transport and storage of significant volumes of CO_2. To date, inventories of storage capacity - storage atlases - have been made in the UK, Norway, Germany and The Netherlands. In almost all cases the storage capacity listed in the atlases is theoretical, i.e. the capacity remains unproven. Several CCS projects are currently being developed which plan to use offshore storage capacity. These will, when operational, represent the first parts of a North Sea transport and storage infrastructure. However, there are currently no definite plans in any of the country bordering the North Sea describing how and when nearby storage assets could or should be developed on a longer term. A combined international storage strategy could yield economic benefits but is also not yet developed.

EOR could be part of such international storage strategy. Transport of CO_2 across the North Sea for the purpose of EOR is possible. EOR, however, will become a real option only when significant volumes of at least 5 to 10 Mt per year are available, exemplifying the need to coordinate actions internationally. Benefits from sharing transport and storage infrastructure can be identified early, for example by enabling EOR projects. Early cooperation and coordination among the North Sea bordering countries is also necessary to develop a common technical standard that allows connecting the CCS infrastructure on a longer term.

For offshore storage an important legal barrier is the London Protocol, which prohibits transporting CO_2 over the international waters of the North Sea when the aim is to store the CO_2. An amendment of the Protocol removing this barrier is in place, but comes only into force after ratification by two-thirds of the contracting nations (27 nations to ratify); currently only Norway has ratified the amendment.

8.7 Summary – the way forward

A field strategy provides clarity for potential CCS project about their options for storing the captured CO_2. It is therefore essential to define and publish the strategy as early as possible. The suggested way forward includes the following actions:

- Show firm government commitment for the development of storage capacity (offshore, onshore or both);
- Create a field strategy that shows the vision on long-term development of storage and transport infrastructure and that lists key assets for the development of longer-term CCS infrastructure. Align this strategy with similar international initiatives;
- Maintain and keep up-to-date a publicly available database on the deep subsurface;
- Support pre-competitive storage qualification, for example, by providing a risk reward for projects or operators who explore deep saline formations;
- Provide clarity on the transfer from production to storage for (nearly) depleted gas fields, financially, and as far as liability is concerned.

8.8 References

EBN – Gasunie, *CO_2 transport- en opslagstrategie (CO_2 transport and storage strategy)*, April 2010.

IEA, *Technology Roadmap - Carbon capture and storage*, 2013 edition, 2013, Paris, France.

Loeve, D., Neele., F., Hendriks, C. and J. Koornneef, *Transport and storage economics of CCS Networks in the Netherlands: Phase 1*, CATO-2 report D05, 2013.

Loeve, D., Neele., F., Hendriks, C. and J. Koornneef, *Transport and storage economics of CCS Networks in the Netherlands: Phase 2*, CATO-2 report D08, 2013.

Neele, F., Nepveu, M., Hofstee, C. and W. Meindertsma, *CO_2 storage capacity assessment methodology*, TNO report TNO-060-UT-2011-00810, 2011 (http://www.globalccsinstitute.com/publications/CO2-storage-capacity-assessment-methodology)

Neele, F.P., ten Veen, J., Wilschut, F. and C. Hofstee, *Independent assessment of high-capacity offshore CO_2 storage options*, TNO report TNO-060-UT-2012-00414/B, 2012 (http://www.globalccsinstitute.com/publications/independent-assessment-high-capacity-offshore-CO2-storage-options).

NOGEPA, *Potential for CO_2 storage in depleted gas fields on the Dutch continental shelf – Phase 1: technical assessment*, 2008.

GeoCapacity. *Assessing European Capacity for Geological Storage of Carbon Dioxide*, EC - Sixth Framework Programme/Geological Survey of Denmark and Greenland. 2009

9 CCS Interfaces

9.1 Introduction

The capture, transport and subsurface storage of CO_2 involves a chain of interconnected elements including a power plant or industrial installation, capture unit, compressor, pipeline, injection well, and storage compartment. The physical connection between these elements are defined here as 'interfaces'. These interfaces arrange the physical transfer of CO_2 from one element of the chain to another. They may also be the point in the infrastructure where 'CO_2 ownership' and liability transfers from one actor to another. They are thus also an important point from organizational perspective within the CCS chain.

All in all, interfaces are of great importance for the start and development of a CCS infrastructure. And they are key during the design of the physical and organizational structure of CCS infrastructure as they influence:

- The physical connection between elements of the CCS infrastructure;
- Contractual arrangements between actors of the system (e.g. liability)
- Cost-effectiveness of CCS systems;
- Access by third parties;
- Cross-border connectivity.

To optimally design a CCS infrastructure requires considerable time and efforts. For example, several CATO2 work packages have been involved in setting up the entire chain from the EON coal fired power station to the P18-4 depleted gas reservoir. In this section, an overview is given of the various interfaces in the CCS chain.

Figure 6. Simplified over illustration of elements (boxes) and the interfaces (stars) in the Carbon Capture and Storage chain. Note that intermediate storage elements are optional

9.2 Physical interfaces

Obviously, the interface is the geographical link between two or more elements of the CCS chain. The physical link relates more to the physical aspects of the flow that is to be transferred. Key aspects of the physical interface between elements of the CCS chain are:

- CO_2 quality: the range and amount of impurities in the CO_2 flow.
- Physical state: The physical state of the CO_2 (gas, liquid or dense phase) depending on temperature and pressure.
- Volume (or rate) of CO_2. The volume of CO_2 that needs to be transferred.
- Temporal variations. The three aspects mentioned above can change in time depending on the operating conditions of the elements of the CCS chain. The temporal variability is of importance for the operation of the whole CCS chain.

Per interface, for instance the interface between capture and transport, the key aspects mentioned above may vary in how they impact the design of the infrastructure. This is discussed below for the most important interfaces.

Capture - Transport interface

The interface between the capture facility and the transport network, via compression, depends on the type of capture technology. Post-combustion capture, pre-combustion capture, oxyfuel installations and capture solutions for industrial sources each have their own typical pressure, temperature and composition of CO_2 at the capture system outlet. They set different demands on the compression of the CO_2. This especially holds for oxyfuel combustion where CO_2 compression can be an inherent part of the power plant and its pollution control[19].

Key aspects of the capture – transport interface are:

- CO_2 quality. The quality depends on the CO_2 source (e.g. coal or gas combustion) and the capture and compression process. The overall transport system will be able to accept a range of impurities; the CO_2 delivered by new entrants should fit into the system. On a shorter time scale, variations in supply rate of the capture installations will result in variations in the quality of the CO_2 transported. Safe operation must be ensured at all times, by monitoring the supply and off take (storage) of CO_2 in the system on a real-time basis.
- Physical state: The physical state of the CO_2 (gas, liquid or dense phase) is a key transport parameter; the required level of preconditioning at (rather, after) the capture process depends on the capture technology used.
- Volume (or rate) of CO_2. The volume of CO_2 which needs be transported and subsequently stored is dependent on the capacity of the capture installation. The transport infrastructure needs to be designed to allow the transport of the foreseen volume rates.
- Temporal variations. The three aspects mentioned above can change over time depending on the operating conditions of the capture unit (e.g. ramp-up/down). Capture installations at power plants may not be running at full load continuously, due to intermittency of electricity demand. Another reason for variation can be maintenance of the capture unit or operation at offset condition due to flue gas quality and quantity. The temporal variability is of importance for the operation of the whole CCS chain.

Transport

The transport part of the chain is formed by the facilities between the capture installation and the injection site. The transport network, which may consist of intermediate storage, pipeline and ship connections, will gradually evolve. Connections with other transport systems can be expected. The construction of new transport links must be initiated and managed.

Efficient transport requires the CO_2 to be in single phase during transport, which in most cases means at a pressure and temperature well above or below the pressure and temperature range where two phases can occur simultaneously. Two-phase flow, i.e. simultaneously transporting

[19] The integration of the capture unit with the power plant or industrial application can also be seen as another interface. For instance the post combustion capture technology is an end-of-pipe application and therefore suitable as a retrofit option for existing power plant and industrial sources. Pre-combustion and oxyfuel technology will be heavily integrated and might require significant changes of the power plant or industrial source. The different level of integration will affect the operational performance of the power plant or industrial application and the production of CO_2.

fluid and gaseous CO_2 stream, is detrimental to transport operations. Liquid CO_2 pipelines operate at pressures typically of about 100 bars or higher, to account for a range of temperatures along the pipeline route. Pipelines transporting gaseous CO_2 operate at pressures in the range of 30 to 60 bars. For transport by ship the CO_2 is typically conditioned to minus 55°C and 6.5 bars.

Transport also results in requirements regarding the composition of the CO_2. Impurities in the CO_2 affect the phase behaviour of the mixture. In most cases impurities requires the transport pressure to be increased to avoid two-phase flow.

A critical impurity is water. The presence of free water in the transport system should be avoided, as it creates a highly corrosive environment. There is a relation between the water content in the CO_2 stream that is transported in the system, the pressure and temperature conditions in the system, the impurities in the CO_2 stream and the occurrence of free water. Special attention should be paid in the event of a shutdown of the systems, which in the case of a pipeline may lead to cooling down of the CO_2 in the pipeline. The temporal change in the transport conditions may lead to potential dangerous situations like corrosive environment or the occurrence of two-phase flow in the system.

The water and impurities content depend on the capture technology and on the possible pre-conditioning of the CO_2, after capture and prior to entering the transport system. This illustrates that the transport system design is the result of an optimization process that includes all elements of the CO_2 infrastructure.

Storage compartment – transport interface

Geological storage reservoirs strongly influence the lay-out and design of the CCS system. The main reservoir properties that may impact the CCS system are:

- The geometry of the reservoir, which controls the location of the well(s) used in the storage process;
- Reservoir temperature, pressure and mechanical strength. These properties determine the ranges of acceptable injection flow rates, injection pressure and temperature[20];
- Temporal variation in reservoir properties due to injection of CO_2 over time: the possible flow rates and injection pressure may decrease due to gradually filling of reservoir space. Operation and maintenance may influence the availability of injection capacity.
- The composition of the reservoir (fluids, matrix), which limits the range of impurities that is acceptable.

The properties of the reservoir and its response to injection are investigated in a storage feasibility study or site characterization study. The outcome determines the injection strategy, which prescribes the location of the wells, the injection conditions, like acceptable ranges in flow rate, pressure, and injection temperature of the CO_2, the duration of injection and the composition of the CO_2 stream. The injection strategy determines the operating conditions of the storage site and, hence, the interface with the transport system, most often a pipeline, ship or intermediate storage facility.

[20] For a depleted gas field at low pressure after production, the pressure and temperature of the CO_2 during injection can be critical, due to potential formation of hydrates that can block the system, or to temperature effects that can lead to fractures in the reservoir. A deep saline formation might accept the CO_2 in a relatively wide pressure and temperature range.

At the transport side of the interface, relevant parameters include the properties of the CO_2 stream (again, pressure, temperature and composition), as well as temporal variations in these properties. The latter can arise from transport network maintenance, or from variations in the supply of CO_2, due to varying load factors at the capture installation.

In the case of ship transport, a local buffer may be required before injecting the CO_2 in the reservoir. Ships can remain on site only for one or two days[21] , resulting in high flow rates, which not all storage reservoirs may accommodate. The CO_2 may have to be heated, prior to injection, especially in the case of injection into depleted gas fields. In some circumstances, heating may also be required for pipe transport.

Additional requirements can arise when the CO_2 is injected for enhanced hydrocarbon production. Such operations may use CO_2 intermittently. This may lead to the requirement for a parallel storage location also able to operate with an intermittent supply of CO_2.

The amount and properties of the CO_2 to be injected varies over time. Maintenance will lead to a certain amount of down time. And as storage reservoirs are gradually filled, their maximum rate of injection will decrease. Timely transition, buffer (intermediate storage) and redundancy of storage capacity must be managed.

In general, the design of the storage-transport interface should be the result of an optimization process, including both transport and storage and should take into account expected future developments, physical conditions (quality and state) and temporal variations in supply of CO_2.

9.3 Organizational aspects

The first CCS project will produce the first CCS infrastructure. When possible, later projects will utilize elements of these early projects, gradually expanding the infrastructure. It is essential for a cost-effective development of CCS that the infrastructure of different CCS projects is designed on the same technical basis, enabling such a gradual build-out. This suggests that (international) technical standards should be defined or should gradually be developed.

Once CCS is operational on a large scale, with multiple suppliers of CO_2 and a transport network to link these to several storage locations, it can be expected that the various elements of the CCS chain are managed by different operators. While capture installations will be managed by the industrial site or power plant, there may be an independent transport operator and perhaps several storage operators. Each of these operators will have its own maintenance schedule and supply or storage rate and variability. The quality of the CO_2 fed into the system may vary over time, possibly affecting the operational conditions in the transport system. The number of suppliers and storage sites will also vary over time. This suggests that an operational governance and coordination over the entire CCS chain is necessary. At a technical level, CCS chain management is required to ensure safe and reliable system operation. At an organizational level, supply and demand must be matched continuously, in a way that is comparable to the current natural gas transport infrastructure, albeit at a different level of complexity.

In addition, the operators in a CCS system will arrange contracts for the delivery and off take of CO_2. These contracts represent a level of interfaces of their own. These contracts will need to be managed, again similarly to it is currently done within the natural gas infrastructure.

[21] This is the typical duration of favorable weather.

9.4 Summary – the way forward

It is important already at an early phase in CCS deployment to have a clear and agreed view on the roll out of CCS infrastructure to reduce costs, increase clarity among stakeholders and increase safety and acceptance for the technology. While interfaces within a single CCS chain may be solved by the project, it is essential that chains that are likely to be connected in the future can do so at minimum additional cost. This should be done throughout the development of CCS infrastructure. This requires regional and even international cooperation from the moment the first individual CCS projects are developed. Coordination at these levels is to be supported at a national and international level.

The following optimization issues of designing and developing a CCS infrastructure need to be solved:

- The quality (level of impurities) of the CO_2.
- Pressure and temperature level(s) for CO_2 transport
- Initial size of transport infrastructure taken into account time dependent flow rates of individual sources and of new sources entering the system.
- Size of intermediate and redundant storage capacity (if any)
- Emergency shutdown and start-stop operation requirements
- Regulatory / legislation items such as open access to infrastructure for third parties
- Monitoring, measurement and verification in relationship with transfer of CO_2 ownership (and liability) across elements and stakeholders in the CCS chain

In case national borders are crossed, there will be additional interfaces and the considerations above need to be reviewed again against the backdrop of specific national strategies and regulatory frameworks.

Actions to support the optimization of CCS chains, especially for multi-user and inter-region or even cross-border systems include:

- Encourage early CCS projects to take into account access by future third parties;
- Support the development of international standards;
- Support the exchange of knowledge and experience between CCS projects.