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Het Rotterdam Climate Initiative is het klimaatprogramma van de gemeente Rotterdam, Havenbedrijf Rotterdam NV, Deltalinqs en DCMR Milieudienst Rijnmond.

CO_2 Capture, transport and storage in Rotterdam - report 2009

Executive summary

1. RCI's 2008-2009 Work Programme

1.1 Introduction

The goal of the RCI's current work programme (2008-2009) was to develop a more refined understanding of the potential for the near and long-term deployment of a CCS network in Rotterdam, by providing:

- estimates of the costs of CO_2 capture at stakeholder facilities;
- more detailed – possible – designs for transport and storage infrastructure, including potential pipeline routes, realistic expansion phases, compression requirements, storage availability, storage site suitability and storage site sequencing, as well as the cost impact and sensitivity to the timing and volume of CO_2 flows for these designs;
- financial analysis of the Rotterdam CCS network for various CO_2 capture, transport and storage scenarios;
- an initial overview of options for financial project structuring and risk allocation.

1.1.1 The RCI's 2008-2009 Work Programme - Core Participants

The stakeholders involved are active across the entire CCS value chain. Participating companies include:
CO_2 transport business case: Port of Rotterdam Authority, GDF Suez, EBN, TAQA, Gasunie, OCAP, Wintershall and Stedin;
CO_2 Liquid Logistics Shipping business case: Anthony Veder, Gasunie, GDF Suez and VOPAK;
possible capture projects: EON, Shell/Essent, Air Products, Air Liquide, C-gen, AVR, And 3 other companies that cannot be mentioned because of confidentiality.

In addition to stakeholder involvement, RCI hired via a competitive tender process Foster Wheeler to provide independent technical and cost validation of stakeholder CO_2 capture plans and Climate Change Capital to provide project structuring and financial advisory services.

The Clinton Climate Initiative acted as a supporting partner of this programme. The European Climate Foundation (ECF) also provides financial and advisory support.

1.2 Report contents

This summary describes the results of the different work flows and outlines key conclusions and next steps to move forward with the future of CCS in Rotterdam. The document is organised as follows:

2. CO_2 capture in Rotterdam: validation of technical feasibility and costs of CO_2 capture projects under consideration by key Rotterdam industrial facilities;

3a. Transport and storage of CO_2: technical and cost scenarios of potential CO_2 pipeline and storage scenarios by the Transport & Storage Working Group;

3b. Transport and storage of CO_2: consideration of the potential for CO_2 shipping by terminal and shipping companies operating out of the Port of Rotterdam;

4. Comprehensive financial analysis: Rotterdam CCS network financial, risk and commercial structure considerations;

5. The way forward: policy considerations (funding and regulation) and roadmap;

6. Ensuring the implementation of CCS: How can the use of CCS be guaranteed?

2. CO_2 capture in Rotterdam

2.1 Introduction

In addition to any potential CO_2 capture projects, there is 2 Mt of CO_2 available each year from relatively pure CO_2 sources in the Port of Rotterdam. This 'pure CO_2' is relatively cheap to capture and could drive economies of scale in CO_2 transport and storage and provide an immediate basis for network expansion. These pure CO_2 sources were not assessed as part of this work plan. In addition, synergies of capture plants with their surroundings, like steam integration and gas/syngas flexibility are not included in these figures.

Based on the analysis undertaken with the private sector emitters and outlined in this chapter, RCI believes that the prospects are excellent for an Early User Network of CO_2 capture demonstration projects, representing 3.5-5 Mt CO_2 each year and a phased expansion into a longer-term network of approximately 20 Mt CO_2 each year. The July 2009 bid for EEPR funding by E.ON and Electrabel and applications for EU NER funding by a broader group of Rotterdam projects in 2010 represent key steps towards the deployment of this Early User Network by 2015.

2.2 CO_2 capture work plan

Over the past year, RCI engaged private industry in the Port to discuss plans for CO_2 capture and solicited their participation in RCI's work plan, based on a common interest in the optimised and accelerated demonstration and deployment of CCS. RCI then signed letters of cooperation (LoC) with nine potential capture project proponents, outlining their ambitions for CCS and their agreement to share data on the technical design and cost of CO_2 capture at their facilities. The following companies signed a LoC with the RCI: E.ON, Shell/Essent, Air Products, Air Liquide, C-gen, AVR, and 3 other companies that cannot be mentioned because of confidentiality reasons. Many of the proponents that signed an LoC had already performed a significant amount of analysis on the potential for CO_2 capture at their facilities. The following table provides details on the nine LoC signatories, some of whom have asked that their interest in CO_2 capture remain private at this date.

Table 2.1: overview companies who signed Letter of Cooperation

Plant type & size	**Capture type & size**	**Target capture operational date**
Ultra Supercritical Pulverised Coal Power Station with Biomass Co-Firing, 1080 MW	Post-combustion capture, 1.43 Mt CO_2/yr	2015
Ultra Supercritical Pulverised Coal Power Station with Biomass Co-Firing, 800 MW		
Integrated Gasification Combined Cycle with potential biomass co-firing and hydrogen offtake, 900 MW	Pre-combustion capture, 5.07 Mt CO_2/yr	2015
IGCC, 450 MW	Pre-combustion capture, 2.5 Mt CO_2/yr	2015
IGCC, 350 MW	Pre-combustion capture, 2.0 Mt CO_2/yr	2015
Hydrogen plant	Pre-combustion capture, 0.5 Mt CO_2/yr	2015
Hydrogen plant	Pre-combustion capture, 0.5 Mt CO_2/yr	2015
Furnaces in crude distillation unit	Post-combustion capture, 0.9 Mt CO_2/yr	
Waste heat incinerator	Post-combustion capture, 0.15 Mt CO_2/yr	

RCI hired the engineering consultancy Foster Wheeler to provide independent and expert validation of the data supplied by the participating emitters. Foster Wheeler's scope of work included:

- performing an independent assessment and the techno-economic validation of the CO_2 capture feasibility studies undertaken by the individual plant operators,
- aggregating and structuring the technical and cost data received from individual plant operators into a cohesive and normalised portfolio, based on common assumptions,
- preparing cash flow models to estimate the cost of capturing CO_2 at each plant.

Once the data had been analysed, aggregated and normalised, Foster Wheeler was asked to draft reports on each of the CO_2 capture facilities, as well as a summary report.

2.3 Technical validation summary and planning & construction schedule

Foster Wheeler is able to validate that the planned capture processes submitted by individual emitters are viable and optimised. The table below outlines some of the key technical parameters reviewed.

Table 2.2: Technical validation summary

Item	Unit of measurement	Pre-combustion IGCC	Pre-combustion H2 plant	Post-combustion
Units affected by the CO_2 capture process in the plant	-	Whole plant	CO_2 capture & compression, Utilities	CO_2 capture & compression, Utilities
Power demand of the CO_2 capture & compression units	kWh/t of CO_2(1,2)	60 (4) - 100	100 - 115	110 - 135
Overall additional power demand of the whole plant (electrical parasitic losses)	kWh/t of CO_2(1)	130 (4) - 160	105 - 125	120 - 145
Steam demand of the CO_2 capture unit	MJ/kg of CO_2(1)	-0.02 - -0.04	0.5 - 1.0	3 - 5
Efficiency of plant without CO_2 capture	%	38 - 45	Not applicable	43 - 46
Efficiency penalty for case with CO_2 capture	Percentage points	6 (4) - 10	Not Applicable	9 - 12 (3)

Notes:
(1) Figures referred to the "abated" CO_2.
(2) Compression is up to 20 bara. If compression up 150 bara is considered, the additional consumption for the compression from 20 bara to 150 bara is from 35 to 40 kWh/t of CO_2.
(3) Plant efficiency reduction with maximum CO_2 capture.
(4) Low values are referred to liquid feed-based IGCC plants. Higher values are referred to coal feed-based IGCC.

Each of these facilities will require roughly five years from the start of a next stage detailed feasibility study to the commissioning and operation of the plant. However, this estimate is based on three key assumptions, namely that:

- the EEPR and NER allocation proceeds as planned;
- the planning permission procedure proceeds efficiently;
- certainty regarding CO_2 transport and storage is established in line with the investment steps of capture plant development.

2.4 Cost validation summary

Foster Wheeler's (FW) cost validation process aimed at estimating the differential capital and operating costs between the plants studied with and without CO_2 capture.

The accuracy of the validated cost estimate is ±30%. The table below shows the results in ranges based on underlying projects and are aggregated to preserve confidentiality. Calculating the cost of CO_2 capture and of CCS is highly dependent on the assumptions and methodology used. All of the participating emitters have agreed with FW's assessment based on how its calculations were derived. It should, however, be noted that these individual emitters may employ different approaches to calculating costs for their specific facilities.

For example, in order to normalize its CO_2 capture cost calculations across a diverse range of emitter facilities and capture technologies, FW used a common set of assumptions. The assumptions are outlined in FW's report (see attachment) and include parameters like electricity and fuel costs which effect CO_2 capture cost estimates. These parameters are based on current averages in the Netherlands market and are assumed to remain constant during the entire operating life of the plants.

Furthermore, in order to harmonize the capture cost calculations with the Transport & Storage Working Group's cost calculations, FW assumed that CO_2 compression at each capture site would only be to 20 bara, rather than 120 – 150 bara as in many of the individual emitter plans, with the remainder of the compression taking place as part of the the Transport & Storage network. This implies a significant difference in capital, operating and fuel costs between many of the emitter and FW's capture cost calculations (and a similar difference in transport and storage costs as calculated in external and RCI plans).

Finally, a few other cost factors, like land use and foundation costs for the capture unit, are not included in the FW validations.

Table 2.3: Economical validation summary

Item	Unit of measurement	Pre-combustion		Post-combustion	
		IGCC	H2 plant	USC-PC	Others
Specific investment cost of the CO_2 capture & compression units (2)	$\frac{€}{(kg/h)}$ (1)	140(3) - 220	950 - 1100	680 - 760	1700 - 1900
Specific investment cost of the whole CO_2 capture plant (TIC)	$\frac{€}{(kg/h)}$ (1)	480(3) - 680	1000 - 1200	850 - 950	2000 - 2200
Operating & Maintenance costs	€ /t of abated CO_2	5(3) - 10	10 - 12	4 - 5	75 - 85
CO_2 abated cost	€/t	35 - 50 (3)	35 - 45	40 - 60	110 - 130

Notes:
(1) Figures referred to the "abated" CO_2.
(2) Compression is up to 20 bara. Higher investment cost is required for compression up to 150 bara. Additional investment cost for the further compression from 20 bara to 150 bara is ranging from 50 to 120 $\frac{€}{(kg/h\ of\ CO_2)}$ depending on the size of the compression unit: for smaller units the higher cost shall be considered and vice versa.
(3) Comparison with a similarly sized conventional coal power station. FW also calculated CO_2 abated cost referred to liquid based CO_2 IGCC and coal based IGCC without CO2 capture. Follwing this methodology, the CO2 abated cost are 20 – 35 €/t. The Low data refer to the liquid-based IGCC and the high data to coal-based IGCC.

The economic validation shows that the introduction of CO_2 capture in the plants leads to a significant increase of both the capital and the operating costs, particularly for post-combustion cases other than conventional coal-fired power stations, like the CO_2 capture from process furnaces in various chemical applications. This is primarily due to the need to produce the energy required by the CO_2 capture process, which results in the use of additional fuel in the plant and the addition of new, dedicated utility units for their production. This is further explained in the Foster Wheeler report.

2.5 Conclusion and next steps

The primary conclusions that can be drawn from the Foster Wheeler analysis are:

- CO_2 capture in Rotterdam is both technically feasible and cost competitive. Planning is well advanced and a number of projects are on track for operation in 2015;
- The high level of private industry participation in RCI and Foster Wheeler's work underlines the strength of the Rotterdam network concept and the excellent long-term prospects for a CCS network in Rotterdam;
- FEED studies are a next step to improve the quality of technical and cost data. This will require further clarity on which projects will move forward as part of the Early Mover Network. FEED studies are very costly and time intensive (approximately one year).
- Securing EU EEPR and NER funding for two to three capture projects could be instrumental in forming the basis for an 'Early User Network' representing roughly 3.5-4 Mt CO_2 each year (excluding 'pure CO_2') that could be in operation by 2015;
- In order to secure this funding, these projects will require co-funding from the national government;
- Ensuring that these projects go through the planning permission processes efficiently and establishing a comprehensive plan for transport and storage will also be critical to successful funding applications and timely operation;
- Greenhouse/food quality CO_2 specifications involve significant higher specific cost (5-15%) than EOR CO_2 specifications as the figures shown in the table 2.3 are referred to EOR CO_2 quality.

3. CO_2 transport & storage

3.1 Business case: transport (pipeline) & storage

3.1.1 Introduction

For the past ten months, on behalf of RCI, Port of Rotterdam (PoR) has been developing a business case (BC) for the phased development of large-scale CO_2 transport and storage infrastructure. PoR's partners in this project are Gasunie, OCAP, Gaz de France Suez, TAQA, Wintershall, EBN and Stedin. The project is supported by the Clinton Climate Initiative.

<u>Basic assumptions</u>

The BC is structured on several basic assumptions:

- expected growth in CO_2 volumes in Rotterdam and other areas,
- available CO_2 storage capacity in offshore gas reservoirs,
- development of an 'open access' transport infrastructure,
- CO_2 specification,
- 20 bar compression system by CO_2 capture party.

<u>Design</u>

The CO_2 transport and storage infrastructure in the BC is designed by matching expected CO_2 volumes and available storage capacity with a phased approach. The primary components of the transport and storage infrastructure are:

- existing on- and offshore pipeline infrastructure,
- new onshore pipelines and connections to capture sites,
- new offshore pipelines to various existing offshore platforms,
- new onshore compression stations.

Several phases of development are distinguished in order to develop a BC for the most cost-effective infrastructure. The focus is on the starting phases, for which the most realistic volume assumptions can be made. In this phased approach, there will be overcapacity in the transport infrastructure in the early phases in order to be able to build up an overall infrastructure with minimum long-term costs. Therefore it's worthwhile(for the Rotterdam Port Authority) to look into the possibility to use and exploit this overcapacity making use of the common carrier principle. There are phases based on the accumulation of investments in transport and storage infrastructure. These phases in the BC are:

Phase 1 – Storage of 1 Mt in Q8A starting in 2013

Phase 2 – Storage of 5 Mt in Q8A, P15, P18 starting in 2015

Phase 3 – Storage of 9 Mt in Q8A, P15, P18, P6 around 2017

Phase 4 – Storage of 15-30 Mt in P15, P18, P6, L10 during the 2020-2030 period

3.1.2 Transport and storage rate

In a financial cash flow model, the capital expenditures and operational expenditures are used as input to derive a tariff for CO_2 transport and storage from the Rotterdam area. In the model, the phased approach is used in which first the OCAP infrastructure is extended to make it possible to inject CO_2 in Q8A (Phase 1). Starting in Phase 2, CO_2 is also stored in P15/P18 and P6 and, after 2020, in the K and L blocks as well. Based on an internal rate of return of 10%, the tariff during Phase 1 for transport and storage, including compression, is roughly €25/ton. This rate generally remains level during the next phase, during which volumes grow and a new infrastructure is developed. A key assumption underlying these figures is direct use of 100% of the capacity of the connected gas fields. More gradual growth of capacity transported and stored (and paid in a tariff), for example, gradual growth over five years to full capacity, would mean a increase of 10% in tariff. The financial model also indicates that the all-in infrastructure tariff of €25/ton does not change very much if some storage fields from the early phases prove unsuitable for CO_2 storage. This also indicates that in the future total costs will also depend on the suitability and cost effectiveness of the storage locations used.

A rough analysis on the resulting fee when excluding overcapacity in Phase 2 (P15/P18 storage) in the pipeline infrastructure leads to a €4/ton tariff reduction.
During the initial phases, the costs of pipeline infrastructure comprise the largest part of the fee: around 40%. During the last phase (storage in K&L), pipeline costs make up 30% of the fee. Compression costs reduce from 40% of the fee during Phase 1 to 30% during the last phase. The share of storage costs in the fee increases from roughly 20% during Phase 1 to 40% during the last Phase

The model is not only used to calculate a rate per ton, but can also show sensitivities and resulting tariff with fluctuations in power prices. The BC assumes and uses an 'all-in' power price of €60/MWh. A 50% increase in this price would lead to an approximately €2/ton tariff increase. A 50% overall increase or decrease in OPEX costs would lead to a €6/ton difference in the fee.

The cost estimates for onshore pipelines and compression are based on engineering studies conducted by various parties. All cost estimates related to offshore infrastructure (pipelines and fields) are calculated by DHV and TNO in the NOGEPA report (Phase 2).

There is tremendous uncertainty in the offshore storage costs, mainly due to:
no clear definition of the operational conditions for injection,
no clear scope of monitoring cost during and post injection,
no clear knowledge about the possibilities of reuse of existing offshore facilities.

NOGEPA recommends detailed analyses of operational costs. The financial model makes clear that the suitability of storage locations and consequently the operational costs of different storage locations can have an important effect on the overall costs and play a decisive role in optimum infrastructure development.

Generally, the costs of onshore infrastructure have been worked out in more detail than the costs of offshore infrastructure. For this reason, it is important to emphasise that the transport and storage tariffs calculated in the financial model can only be used as an estimate of the transport and storage costs, which will be further fine-tuned based on detailed engineering studies, particularly with respect to offshore gas reservoirs and offshore facilities, before investment decisions can be taken from a cost perspective.

3.1.3 Main risks

The main risk to be mentioned for this BC are:

- limited knowledge or experience with CO_2 transport in the Netherlands (technical),
- new legislation still has to be put in place for CO_2 and these will impact this project (political),
- the prices of CO_2 allowances (ETS system) will remain unfavourable on the short term, as a result of which companies will be less inclined to invest in CO_2 infrastructure (capture, transport and storage facilities) (economical),
- sources identified for the different phases might not be able/want to participate anymore (commercial),
- current selected CO_2 storage locations might not be suitable or may only be available at much higher costs or availability will be delayed (technical, commercial),
- public opinion may cause delays for CO_2 transport and storage projects (political).

3.1.4 The way forward

Given the information currently available on volumes and storage capacity, the BC outlines the most logical and cost-effective infrastructure development path for the short term (2010-2015) and possible further expansion in long term. The first important step is that there should be an expectation that a bankable business plan can in one way or another be developed. However, the current value of CO_2 under the ETS system is far from able to cover the business risks associated with the initial infrastructure investment.
Phase 1 (1 million tons of CO_2) could be operational in 2013, provided that an investment decision is made by the end of this year. The costs in this phase total about €80 million (as described in last year's report for the extension of the pipeline to Q8A field + compressor station). For Phase 2, detailed offshore studies on P15, P18 and other fields, as well as on the use of existing pipelines have to be commissioned and conducted as soon as possible. The results of these studies are essential for the development of a more detailed business plan based.
As regards long-term infrastructure development, master plans for the transport and storage of CO_2 are essential. In RCI's view, Gasunie and EBN are responsible for this (c.f. policy letter of the Dutch Cabinet to Parliament).

3.1.5 Supplementary scenario

In response to a recently emerging new opportunity, an alternative supplementary scenario is in development: storage in depleted oil fields. These offer an estimated storage capacity in excess of 150 million tons and are located in the Q blocks of the Dutch continental shelf. An existing pipeline connects the depleted oil fields to shore and ends in the Amsterdam industrial area, about 3 km from the existing OCAP pipeline.
The depleted oil fields and pipeline could become available for CO_2 transport and storage during the 2013-2014 period.
Given the size of the storage capacity and the layout of the existing pipeline infrastructure, this option seems to be the most promising scenario for starting the infrastructure. However, a detailed subsurface study will need to be performed to determine technical feasibility for CO_2 injection and storage. Capital and operational cost estimates will then need to be made in order to determine the economical feasibility and risk profiles associated with the field operation.

3.1.6 Conclusions and recommendations

The realisation of a large-scale CO_2 infrastructure for transport and storage requires large-scale investments, which cannot be covered by the current value of CO_2 under the CO_2 emission trading system. In addition, the proposed open access network infrastructure model for transport and storage, which facilitates the cost-effective achievement of the long-term CO_2 reduction objectives (with CCS as a key component) of RCI, the Dutch government and the EU, entails investments that exceed the investments needed for a single project connecting one plant (emitter) to one CO_2 storage reservoir with a dedicated (single) pipeline.

Companies (active along the entire CCS chain), governments and the financial sector need to work together to create the CCS chain. Balanced risk sharing is needed, which entails finding a formula offering sufficient 'comfort' to each investor and minimising the risks to an acceptable level. For this reason, RCI feels it is essential that the EU charges the EIB with the development of such a formula.

In its letter to Parliament (Parliamentary Papers 2008-2009, 31510, no. 36), the Dutch government announced that it would take a decision at a later stage on how to use the income generated through the auction of CO_2 allowances. One alternative is to spend it on temporary subsidies to ensure the completion of CCS pilot projects, including transport and storage. This would be a temporary measure as the 'polluter pays principle' should be effected structurally starting in 2020 by means of the ETS. This might be one of the building blocks of the above mentioned formula.

It is obvious that emitters, transportation companies and offshore operators will have to join forces to make the first investments. Allocation of European and national subsidies will play a crucial role. Once operational, the CCS chain will attract more users and investors, facilitating efforts to upscale it. Infrastructure subsidies are also necessary to make it possible to start with a degree of overcapacity in the first years of development to optimise capital expenditures in the longer term.
However, financing is not the only obstacle for a quick start. Relevant legislation and regulations regarding liability, planning permission and procedures should be developed and enacted. In order to stimulate decision making: offshore operators and transportation companies should have a clear view of the conditions for the transport and storage of CO_2. For this reason, we recommend that the government take the following legislation and measures to further reduce the investment risk for transport and storage:

- the national government subsidises investments in the pipeline network infrastructure,
- the national government ensures the development of a master plan with the associated legislation to ensure the timely availability of suitable reservoirs and pipelines in the Dutch continental shelf (with fields like Q8A, P18, P6, L10, K7 or suitable equivalents) to offer emitters the required storage capacity for their CO_2.

Last, but not least are the studies and researches needed before starting investments:

- detailed reservoir investigations are needed (for oil and gas reservoirs as well as aquifers (saline formations)) to more accurately assess CAPEX and OPEX, CO_2 injectivity, capacity, and reservoir behaviour, also taking into account a lower-cost operating scenario,
- optimising the phasing of infrastructure investments to facilitate lower transport and storage rates,
- expansion of the current model (including transport and storage capacity) to 2045 (i.e. a 30-year horizon after the start-up of new power plants (2015) and an annual CCS capacity of 20 Mt of CO_2 each year starting in 2025),
- planning and timing of engineering, commercial and policy activities in line with the results of the working group (i.e. 'critical path analysis').

3.2 Business case: shipping – CO_2 liquid logistics route

3.2.1 Introduction and conclusions

As part of the CCS Project of the Rotterdam Climate Initiative (RCI), NV Nederlandse Gasunie, Koninklijke Vopak NV, Anthony Veder Group NV and Gaz de France/Suez E&P Nederland BV have studied the potential of transporting liquid CO_2 using a CO_2 Hub in the Port of Rotterdam as a collection point, from which it will be shipped in sea-going vessels to offshore depleted gas fields. This is jointly known as the Liquid Logistics Shipping Concept (LLSC). At the CO_2 Hub, a unique process integration has been designed to use the cold generated during the re-gasification of LNG to liquefy the CO_2. The use of LNG cold significantly reduces the project's OPEX.

In the future, this option, spearheaded by the private sector, is expected to be necessary in addition and complementary to transporting CO_2 gas or supercritical CO_2 via pipelines, given the large volumes of CO_2 which will flow from emitters to permanent (offshore) storage.

Based on the work done to date, it can be concluded that the CO_2 LLSC is already a feasible option for CO_2 transport and storage. Under the right conditions (in terms of distance and volume), it is cost competitive and certainly offers the very necessary degree of flexibility in routing and managing variations in volumes. As the LLSC still finds itself in the steep upward part of the learning curve, it can be expected that further innovations will result in substantial cost reductions.

3.2.2 Description of the CO_2 LLSC

The broad concept involves the possible compression of CO_2 captured at the emitter site and the transport via a collection network (i.e. common carrier) to the Rotterdam CO_2 Hub situated next to the Gate LNG terminal. At the CO_2 Hub, a unique process integration has been designed to use cold generated during the re-gasification of LNG to liquefy the CO_2. The CO_2 is then stored in the intermediate storage tanks at the CO_2 Hub and shipped to an offshore discharge location were the CO_2 will be discharged to the (depleted) gas fields.

Additional considerations can be attached to this broad concept:

- The CO_2 Hub with liquid storage also allows collecting CO_2 from more remote emitter locations outside the Rotterdam region where CO_2 is liquefied again and pumped into dedicated barges. These barges can subsequently unload at the Hub, from which the CO_2 will travel on to offshore empty gas fields. This introduces a great deal of additional flexibility on the collection side of the CO_2 transport and storage infrastructure.
- On the Hub discharge side, the sea-going vessels can deliver CO_2 relatively easy to different empty gas fields at the same time (i.e. one voyage to the first field, a second voyage to the second field, etc.), possibly reducing 'mothballing expenses' for these fields in the period between gas production and CO_2 storage operations. In addition, a ship can easily reach the smaller and more remote fields where offshore pipelines are too expensive, facilitating full utilisation of these small fields for CO_2. This would otherwise be impossible. Work is underway to develop offshore unloading from the ship without the need for a platform, further reducing mothballing expenses and the costs of modifying the platforms in question.
- When onshore pipelines of any length need to be constructed, the planning permission process can be a very time consuming and complex necessity. If the CO_2 is transported by barge or ship, this is far less complicated in terms of permits and routing constraints and handling times are relatively short.
- Transport by ship creates flexibility for variations in volume over time. Ships and storage vessels can be designed for alternative services, making it possible for to be re-assigned to these other services in response to changes in the CO_2 transport market. This reduces the risks associated with the investments in the CCS chain.
- Process integration with LNG achieves cost effectiveness through substantial energy efficiency improvements and reduced CO_2 emissions.
- The technical aspects of the entire LLSC is based on proven technology.
- Another potential advantage to a Hub to handle supercritical CO_2 combined with an offshore shipping transport solution is that such facilities will make it easy to make the CO_2 available to Enhanced Oil Recovery (EOR) projects. This is expected to generate additional income for the emitters and the government, which face substantial costs for demonstrating CO_2 capture and storage.

3.2.3 Costs and timing

Extensive research has been conducted to clarify the costs of LLSC. Within a range of 150 km to 180 km or more to the depleted gas fields and a minimum quantity of CO_2 to be shipped offshore of, for instance, 2 to 3 Mt each year, the liquid route is comparable to the all pipeline solution costs and certainly competitive when long onshore pipelines (outside the Rotterdam region) are also required for collecting the CO_2.

Smaller-volume emitters can be served this way as long as several of them can be served by the CO_2 Hub and the collective outgoing transport per sea vessel exceeds the above indicated volume range. This type of cost sharing is the direct consequence of the 'open access strategy', which the LLSC Partners intend to introduce to the LLSC.

The necessary facilities can be available at some point in 2014 depending on the emitters' needs. Additional details are included in the attachment about CO_2 liquid logistics.

3.2.4 The way forward

The LLC Partners are planning several more steps during the coming period in order to bring the current conceptual level down to the level of real businesses:

Close cooperation with emitters to identify – on a case by case basis – the best possible ways to transport CO_2 to permanent storage. From this work, one or two 'initiating' customers are expected by the end of 2010 or early 2011.

Additional cost reductions can be achieved through:

1. close cooperation between the LLSC Partners in order to come to further technical improvements resulting in lower costs for the emitters (firm solutions available at the end of 2011),
2. close cooperation with the RCI organisation to make sure the Rotterdam project will be one of the leading European flagship programmes, resulting in some form of subsidy for initial emitters being served by the LLSC Partners (firm decision taken by the EU Commission in 2011),
3. the use of liquid CO_2 from the LLSC in EOR projects will be further investigated in order to create additional added value for some of the CO_2 volumes,
4. where relevant and necessary, the LLSC Parties will support the development of the necessary legal framework as discussed in the RCI report.

4. Comprehensive financial analysis

4.1 Introduction and overview

Climate Change Capital ("CCC") has been appointed as financial advisor by the Rotterdam Climate Initiative ("RCI") to assist in the preparation of a Business Plan for a carbon capture and storage ("CCS") Network in the Port of Rotterdam.

The RCI is one of the first major CCS projects in the world (if not the first) to subject itself to rigorous financial scrutiny. This is again an example of the RCI keeping CCS in Rotterdam ahead internationally and we believe that if the lessons of this process are absorbed into the next stage of development then it will maintain its position as the leading CCS network concept in Europe.

4.2 Emitter cost analysis

CCC analysed the cost of 7 Emitters based on the inputs provided by Foster Wheeler:

- A PC power plant using post-combustion capture;
- 3 industrial plants (refineries / hydrogen plants) using post-combustion capture; and
- 3 IGCC power plants using pre-combustion capture.

Table 4.1: Cost of capture (support required) by Emitter category

(real costs – 2009 inflation basis, 2% annual rate)	**Post-combustion plants**		**Pre-combustion plants**
	PC Plant	**Industrials**	
Using central case assumptions			
In € per tonne captured	33	24 - 78	10 - 14
In € per tonne abated	45	24 -109	12 - 19
In €m per year	48	13 -70	20 - 66
After sensitivity analysis on CAPEX, OPEX and commodity pricing			
In € per tonne captured	24 - 42	17 - 90	6 -19

Note that the above numbers represent the additional support required over and above a prevailing long-term view of EUA price. Despite some issues with the analysis and data, the capture costs exhibited at Rotterdam appear, in CCC's view, to be internationally competitive, consistent with other studies at a similar stage, and consistent with the expectations of policy-makers for levels of required support.

4.3 Transport and Storage cost analysis

There are many potential options for Transport and Storage in the Rotterdam area, not only in terms of CO_2 stores but also in terms of mode of transport. For this report, the only stores for which data was available were depleted gas fields (namely Q8A, P18, P6 and the L and K clusters in the North Sea.

Table 4.2: Cost of Transport and Storage across Scenarios

(real costs – 2009 inflation basis, 2% annual rate)	**Early Phases / low volumes**		**Later Phases (post-2020, volumes over 17 Mton per year)**
	Volumes up to c. 5-6 Mton per year (up to 2015)	**Volumes of between c. 5-6 Mton per year and c. 10 Mton per year (2015 to 2020)**	
In € per tonne stored	20 – 29	13 -21	13 – 38
In €m per year	23 – 135	60 -156	229 - 482

Note: the costs reported above include compression, transport and storage

In contrast to the Emitter analysis, the Transport and Storage data is very open and a very wide range of scenarios has been assessed. This allows our financial analysis to fully inform the next stage of development of the Transport and Storage strategy.

4.4 Full Chain Scenario cost analysis

CCC selected a simple Full Chain Scenario in order to illustrate the costs of a realistic first step for the Rotterdam Network:

- Emitters: 2 capturing power plants – one PC plant capturing 1.4 Mton of CO_2 per year and one IGCC plant capturing 2.5 Mton of CO_2 per year;
- Transport and Storage: pipeline to a single sink (depleted gas field P18).

Table 4.3: Full Chain additional costs for the selected scenario

	Cost in € per tonne stored (real)	**Cost in €m per year (real)**
Single system (i.e. including both Emitters + full Transport and Storage infrastructure)		
Full chain system	42	163
Emitter perspective (costs of a single Emitter using the Transport and Storage infrastructure)		
PC Plant perspective	54 – 89	78 - 127
IGCC Plant perspective	36 – 48	88 - 119

These illustrative Full Chain costs are, in CCC's opinion, within the ranges likely to be expected by policy-makers for early mover CCS projects. This shows that it is possible to implement an internationally competitive early Full Chain project in the Port of Rotterdam.

4.5 Conclusions and actions

The analysis performed by CCC has confirmed that Rotterdam has costs of CCS which are internationally competitive and consistent with other work and policy expectations.

Emitter data generally validates market estimates; however the lack of common benchmark is likely to make interpretation of figures difficult for policy makers and potential sources of funding. Therefore a more rigorous and transparent Emitter analysis is required.

The options that are currently considered for Transport and Storage infrastructure appear expensive (especially in the case of certain stores) and over-complex (at least for the first stages of CCS deployment in Rotterdam). We therefore recommend that a comprehensive storage study be performed in the Rotterdam area and we suggest targeting concrete steps for the Transport and Storage infrastructure.

While estimates for capture, transport and storage are widely ranged we would recommend to improve the data accuracy to lead projects to enter FEED.

CCC's analysis has confirmed that the RCI should continue to develop a major CCS hub in the Port of Rotterdam. The key next steps we have identified are the following:

- To perform a more rigorous and transparent Emitter analysis;
- To perform a comprehensive storage study in the Rotterdam area and to target a simple first step for the Transport and Storage infrastructure;
- To verify the benefits of centralized compression vs. compression at capture sites;
- For lead projects to enter the FEED stage;
- To enter a detailed dialogue with policy makers on establishing an appropriate support framework for CCS in the Netherlands.

5. The way forward

5.1 Introduction

During the past year, a substantial effort to realise CCS has been made.

- The EU has also contributed to a policy framework and has made substantial funds available to support CCS demonstration.
- The national government has made substantial progress in the development of a stable policy framework and the establishment of the second phase of the R&D programme for CCS (CATO-2).
- RCI, in cooperation with private partners, has further developed possible CCS projects.
- In the RCI region, E.ON and Electrabel have joined forces to start a capture demonstration project and submitted a project proposal to the EEPR subsidy scheme.

5.2 The strategy

RCI has developed a phased approach for the large-scale demonstration.

<u>Phase 1: Pure sources</u>
In the Port of Rotterdam Authority's business case, the first phase of the CCS cluster can be up and running by as early as 2013. This will serve as an incentive, promoting the further rapid deployment of the CCS cluster. Part of this phase involves the storage of CO_2 from Shell's Pernis oil refinery in an empty gas field near Barendrecht. The Ministry of Housing, Spatial Planning and the Environment (VROM) has made funds available for this project (provided the permits required are granted). An – independent – second part involves the expansion of the OCAP network to include additional greenhouses.

A third part is the possible extension of the OCAP line to an offshore storage site – Q8A – with an annual storage capacity of 1 Mt of CO_2. The current assessment is that ETS prices will not be high enough to cover the entire financial gap for investment and operation. Additional public funds would be needed, as part of general infrastructure financing. See 3.1.4.

<u>Phase 2: Establishing the demonstration cluster</u>
The business case shows that RCI is ready to have its demonstration cluster operational by 2015. This cluster involves the development of a large-scale demonstration of CO_2 capture from non-pure sources, particularly from a conventional coal-fired power plant and an IGCC, and the expansion to include other pure CO_2 sources. A significant element of this phase is the establishment of a regional infrastructure for the collection of the captured CO_2, which in turn has to be connected to a national infrastructure for transport and storage.
This cluster-approach has advantages for CO_2-reduction objectives, cost reductions and acceleration of project realisation.

5.3 Funding

EU funding
E.ON/Electrabel have submitted a proposal for a capture project for EU EEPR funding. Other companies and E.ON/Electrabel intend to apply for EU funding for the (other) parts of the demonstration cluster. This EU-funding is designed to support up to twelve commercial European CCS demonstration projects. This will be done by capitalising, on means out of an auction, 300 million CO_2 allowances from the NER.

The EU expects public and private national stakeholders to finance at least 50% of the demonstration projects – the maximum of NER funding is 50% of the eligible project costs (including possible EEPR funding). State investment in infrastructure can be seen as a contribution to NER demonstration projects.

State funding

Ideally, government funding for this demonstration phase should focus on investment in the national infrastructure based on the common carrier principle. Specifically, this would be a joint investment with regional parties in infrastructure for transport and storage by state-owned companies (e.g. Gasunie and EBN). Gasunie and EBN have already been asked to provide the 'building blocks' for a transport and storage strategy for CO_2 by the end of 2009. These companies should also be asked to take subsequent steps in developing a master plan for transport and storage of CO_2. Aquifers should also be considered possible storage reservoirs. The mission statement of Gasunie and EBN should include CO_2 transport and storage.

The critical timeline shows that the development of a transport and storage strategy is already on a very tight schedule. If the national government does not take the lead, there is the risk that individual projects will go 'cherry picking' (i.e. choosing the least expensive transport and storage options and laying their own dedicated infrastructure). From a national point of view, this will result in sub-optimal use of storage capacity in the Netherlands. A coordinated approach will substantially decrease the overall national costs of transport and storage.

In its policy letter (Parliamentary Papers 2008-2009, 31 510, no. 36), the Dutch government has indicated that it is seriously considering substantial financial support and that it expects to take a decision on this in the spring of 2010. As regards the timeline for EU funding, this decision most likely has to be taken by no later than March 2010.

In the same letter, the government announced that it would take a decision at a later stage on how to use the income generated through the auction of emission allowances. One alternative is to spend it on temporary subsidies to ensure the completion of CCS demonstration projects, including transport and storage. This would be a temporary measure as the 'polluter pays principle' should be effected structurally starting in 2020 by means of ETS. Some people state that such a spending of income out of auction of emission allowances is not according the "polluter pays' principle. But this is a misunderstanding. The polluter pays on the auction for emission allowances. They have the right to sell their emission allowances, which brings extra income to the companies to compensate for CCS costs. While they have bought these earlier on the auction, this is according the 'polluter pays principle'.
A separate matter is what the Government will do with the income of the auction of emission allowances. The Cabinet's policy letter to Dutch Parliament mentions several option's. One of them is temporarily investing in CCS, until the 'market', ETS suffices and does the job. All this is structurally according to the 'polluter pays' principle.

Funding from private companies

The government rightfully states in its policy letter that private stakeholders should also contribute significantly to the demonstration project.
LoCs have been signed with nine CO_2-emitting companies, seven of which have already had their business cases validated. With these LoCs, the companies have demonstrated their willingness to participate in the development of CCS. As regards the next logical and necessary step, RCI feels the companies with whom an LoC has been signed should perform the FEED studies. To maintain the pace and establish their frontrunner position, the LoC companies should perform the FEED studies in the next year to come.

Phase 3: Mature CCS

Once achieved (2020), a mature CCS system should be able to support itself via EU-ETS (i.e. from that moment on the 'polluter pays principle' applies). However, RCI expects the ETS price to be insufficient in the coming decade, at least in many years to come, critical years to make CCS real. For this reason, additional measures have to be prepared to ensure full-scale CCS in 2020. Alternatively, additional measures may have to be taken (see also the document Ensuring implementation of CCS in the attachments).

5.4 Policy support and regulations

The national government has asked Gasunie and EBN to provide the building blocks for an implementation strategy, which is to be prepared at the start of 2010. The timeline shows that developing this strategy is on the critical path. The first storage locations have to be identified as soon as possible, even before a full transport and storage strategy has been approved, followed by the realisation of the relevant infrastructure. For this reason, RCI recommends performing a comprehensive storage study. This study should not exclude any storage option, including oil and gas fields as well as aquifers, should include a detailed analysis of the most probable reservoirs and make a selection. In line with the Cabinet's policy letter to Dutch Parliament, the national government should encourage state-owned companies Gasunie and EBN to deliver this study.

To remain on the critical path for CCS development, the national government has to maintain the pace of introduction of the directive on CO_2 storage, as well as the additional regulations and legislation on liability issues and the conservation of depleted gas and oil fields.

Successful demonstration in itself will not result in large-scale market use of CCS. Other incentives are needed. The most obvious incentive is the use of the ETS. Future prices of CO_2 allowances will likely remain uncertain and volatile. This increases uncertainty for investors in CCS. These circumstances may lead to a substantial risk that the prices for CO_2 allowances after 2020 will be too low and/or too uncertain to commercially facilitate the application of CCS. The Dutch government and the National CCS taskforce are studying the possible additional incentives (if needed to ensure the long-term viability of CCS:

- Design specific aspects of the ETS auction (e.g. set minimum prices to increase the ETS price, redirect revenues to CCS or separate lots for companies applying CCS).
- Regulate using either emission performance standards (ceilings, gCO_2/ kWh) or mandatory use of technologies (for CCS or otherwise).
- Make the use of existing CCS plants from the demonstration phase compulsory.
- Impose a levy on CO_2 emissions.

DCMR has a preference for mandatory use of CCS for coal-fired power plants. To ensure a level playing field, DCMR proposes initiating the multilateral (involving the UK, Germany, Norway, France , Belgium and Denmark) implementation of such a measure in the north-west European region.

5.5 Communication and public awareness

Global CO_2 emissions are increasing faster than expected. Without supplemental policy, emissions in the Rotterdam area are also set to increase considerably. Despite an all-out effort on energy efficiency, the use of biomass and use of residual heat, CO_2 emissions in the Rijnmond region will increase substantially, particularly due to growth in the 'energy port' of Rotterdam. To face these challenges of further growth and ambitious CO_2 reduction targets, CCS is essential for realising the regional goal. In addition, CCS is needed to maintain the affordability of the climate change measures. International institutes (e.g. International Energy Agency and the Intergovernmental Panel on Climate Change) emphasise the crucial role of CCS. If the public is not aware of the need for CCS, it can never come to accept and even support CCS activities in their backyard. Government, companies and NGOs should join forces to create public awareness on the need of CCS to mitigate climate change. Government and companies have to take a leading role in this matter.

5.6 Roadmap and recommendations

	Volume of CO_2 captured	Sources of CO_2 (cumulative)	Usage and proposed storage locations	Full chain costs (cumulative) €/ton	Total CAPEX (cumulative) €m
2010	1 Mt	Refinery and other pure CO_2 sources.	Greenhouses (re-use) Barendrecht or North Sea fields (storage)	€54	
2015	5 Mt	Post combustion PC plant capturing + pre combustion IGCC	North Sea fields (storage)	€42	€920m
2020	15 Mt	2 additional hydrogen plants, full scale capture 2 PC plants and + additional IGCC capturing.	North Sea fields (storage)	€35	€1,690m
2025	20 Mt	Additional 5Mton IGCC and retrofit existing industrial sources.	North Sea fields (storage)	€31	€2,550m

To implement this roadmap the following conditions apply:

- The European Commission should award the E.ON/Electrabel demonstration project and the national government has to co-finance the project (end 2009).
- Gasunie and EBN have to develop the transport and storage master plan, including the study into the storage capacity and costs of reservoirs (including aquifers) in the North Sea (end 2009), as well as look into additional options such as the alternative scenario described in 3.1.5., the room for the transport and storage operations of other companies and the role of the Port of Rotterdam Authority to optimise the use of the transport infrastructure by practising the common carrier principle.
- The companies that signed a Letter of Cooperation should further develop their studies into actual projects, for which NER funding proposals can be submitted.
- The national government has to make funds available for the development of a common carrier infrastructure as part of co-financing in the EU EEPR and NER programmes and to participate in EU decision making to commission the EIB to develop a formula by which companies (active throughout the entire CCS chain), government and the financial sector (including EIB) share the risks in a balanced manner, offering investors sufficient comfort and minimizing risks to an acceptable level.
- To remain on the critical path for CCS development, the national government has to keep pace with the implementation of the directive on CO_2 storage, as well as the additional regulation and legislation on liability and the conservation of depleted gas and oil fields.
- The European Commission should select Rotterdam as a European demonstration project (end 2011), possibly as part of a larger national programme.
- To ensure full-scale implementation of CCS starting in 2020, by which time the polluter pays principle should be applied, application of ETS will have to suffice in making CCS feasible. In addition, the government is urged to prepare additional measures in case the price for CO_2 allowances remains too low.
- Focus on public awareness of CCS and communication of the necessity of CCS is paramount.

Provided these conditions are met, RCI feels the development of a clustered CCS network in Rotterdam is can be realised. This will provide the Netherlands with a powerful measure to reduce its impact on global warming and will serve as an example to the world to effectively manage CO_2 emissions in a responsible way. It simultaneously provides the opportunity to immediately reduce emissions on a large scale, while at the same time enabling the Netherlands to effect the transition to a more sustainable economy.

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Deltalinqs

DCMR milieudienst Rijnmond