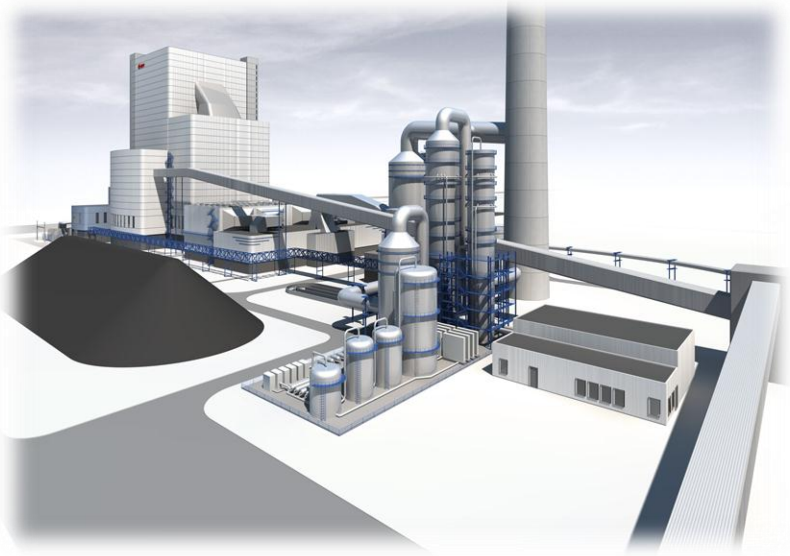
Lessons Learnt

ROAD

Special Report for the Global Carbon Capture and Storage Institute



ROAD | Maasvlakte CCS Project C.V.

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Executive Summary

Due to its 'first of a kind' nature, the ROAD project poses an array of challenges that can be considered uncommon to other utilities projects. This report outlines the major lessons learnt from the project development phase and is the last in a series of Special Reports that were part of the successful cooperation between ROAD and the Global CCS Institute.

Time, budget and space constraints have led to solutions that are not always fully optimized with respect to technical decisions and energy usage. For a new power plant with full scale carbon capture many technical concepts can lead to further performance improvement and savings in investment and operational costs. Considering the current market conditions and the expected plant operation modes for grid support, the steam pressure will fluctuate with load. ROAD has been limited in design optimization for off-design performance of the capture plant. One of the major questions ROAD will be able to answer when operating the demo-plant, is its reaction and behavior when lower steam pressure is available.

Independent process model validation using pilot plant data has been particularly valuable. It would be much riskier for a company to develop a post-combustion capture project without undertaking independent process model validation combined with access to pilot plant performance data. However, current pilot plants are not optimized for demonstrating low emission performance. Therefore care should be taken when interpreting the results especially when extrapolating them to full scale. Appropriate independent process modeling expertise using pilot plant data is valuable in reducing risks associated with extrapolation of pilot plant data. Using pilot plant data in process models is also a key risk mitigation strategy for estimation of operating costs (i.e. parasitic energy usage).

For transport and storage it is important to define the specifications for the CO_2 product. Parameters like oxygen, water and dust (amount and particle size distribution) are the most important. The CO_2 specifications differ widely for different capture technologies and due to a lack of experience, it is not exactly known what would be acceptable for the pipeline, well and reservoir. A significant insight that was gained from the flow assurance study was the conclusion that a two-phase flow will occur in the pipeline and in the well (at least the top of the well), during start-up. Transporting a fluid with two phases is a challenge; this can lead to severe slugging effects which will lead to vibrations and potential equipment damage. Also the design of the CO_2 compressor was a challenge. It seems there are only a few companies able to build a large CO_2 compressor combined with the demanded wide operational envelope. Furthermore, modifying a satellite platform with limited space provides challenges because limited space is available. Also the integrity of the existing platform is an attention point.

The project-team has also learned important lessons with regard to the integration of CCS and a power plant. Productive cooperation between the power plant and CCS teams is essential. A key learning point for the project in this regard was the importance of the utilities agreement between ROAD and the Maasvlakte Power Plant 3.

Support and involvement of local, regional and national governments throughout all project phases, as well as a positive public perception, are a prerequisite for creating the right circumstances for the successful implementation of a CCS project. Since CCS is a technology under development, a specific legal and regulatory framework on capture, transport and storage technologies is in many countries still missing or in development. This demands pro-activity, flexibility and close interaction with regulators and authorities. Managing expectations of stakeholders and developing a clear project vision are a prerequisite in that regard. One of the biggest threats is losing track of stakeholders' views and interests. Instead, CCS projects should develop an outside-in perspective, taking into account stakeholder expectations. By

developing a stakeholder dialogue they create two-way communication with stakeholders that are relevant to the implementation of the project. As a consequence of diverse technologies in the CCS chain, spread over different areas, multiple governments and authorities are involved in the project. This demands an integrated Stakeholder Management approach comprising functions such as regulatory affairs, permitting and public outreach.

The fact that the project is carried out in a joint venture has had a generally positive impact. Combining the knowledge and methodologies of the two parent companies, assumptions are challenged more rigorously, group thinking is avoided and decisions are taken more objectively. The existing knowledge within the parent companies is crucial in all aspects of the technical and commercial activities. Knowledge sharing between the project team and the parent companies is actively pursued. However, working in an innovative joint venture project also poses some challenges.

Introduction

In July 2009, Maasvlakte CCS Project C.V. ('MCP') submitted its project proposal to the European Commission, to apply for funding under the framework of the European Energy Programme for Recovery (EEPR). This marked the start of the 'ROAD project' ('Rotterdam Opslag en Afvang Demonstratieproject'; Rotterdam Storage and Capture Demonstration project).

Due to its 'first of a kind' nature, the ROAD project poses an array of challenges that can be considered uncommon to other utilities projects. This report outlines the major lessons learnt from the project development phase and is the last in a series of Special Reports that were part of the successful cooperation between ROAD and the Global CCS Institute.

The cooperation with the Global CCS Institute has proved to be instrumental in reaching the wider CCS community. ROAD has received valuable comments on draft Special Reports, all of which we believe today form an excellent bundle of practical information for setting-up a large scale CCS demonstration Project. ROAD is looking forward to continuing this cooperation in the future.

This report provides an overview of the project's highlights, outcomes and breakthroughs, difficulties encountered and lessons learnt. The report has been structured according to the project organisation, covering areas of project office and governance, capture, transport and storage and stakeholder management.

As the project approaches the key milestone of a decision on investment from its parent companies, an overview of upcoming milestones is also provided.

1. Project factsheet

1.1 Project Overview

ROAD is the **R**otterdam **O**pslag and **A**fvang **D**emonstratieproject (Rotterdam Capture and Storage Demonstration Project) and is one of the largest integrated Carbon Capture and Storage (CCS) demonstration projects in the world.

1.1.1 Project objectives

The main objective of ROAD is to demonstrate the technical and economic feasibility of a large-scale, integrated CCS-chain. In the power industry, to date, CCS has primarily been applied in small-scale test facilities. Large-scale demonstration projects are needed to show that CCS is an efficient and effective CO_2 abatement technology within the next 5 to 10 years. With the knowledge, experience and innovations developed by projects like ROAD, CCS could be deployed on a larger and broader scale: not only on power plants, but also within energy intensive industries. CCS is one of the transition technologies expected to make a substantial contribution to achieving climate objectives.

1.1.2 Partners

ROAD is a joint project initiated by E.ON Benelux N.V. and Electrabel Nederland N.V. (GDF SUEZ Group). Together they constitute the limited partnership Maasvlakte CCS Project C.V. The intended partners of ROAD are GDF SUEZ E&P Nederland B.V. for the CO_2 transport and TAQA Energy B.V. for the CO_2 injection and permanent storage. The ROAD-project is co-financed by the Government of the Netherlands, the European Commission within the framework of the European Energy Programme for Recovery (EEPR) and the Global CCS Institute.

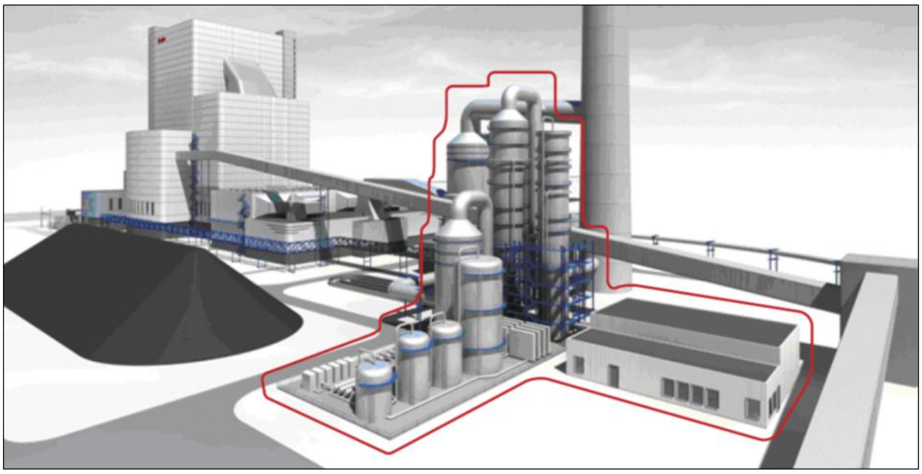
1.1.3 Project specifications

ROAD applies post combustion technology to capture the CO_2 from the flue gases of a new 1100 MWe coal-fired power plant (Maasvlakte Power Plant 3) in the Rotterdam port and industrial area. The capture unit has a capacity of 250 MWe equivalent and aims to capture 1.1 million tonnes of CO_2 per year. The capture installation is planned to be operational in 2015.

Location of ROAD CCS chain: Rotterdam port and industrial area and North Sea

Location of capture unit: Maasvlakte Power Plant 3 (photo: E.ON)

From the capture unit the CO_2 will be compressed and transported through a pipeline: 5 kilometres over land (buried pipeline) and 20 kilometres across the seabed to the P18-A platform in the North Sea. The pipeline has a planned transport capacity of 5 million tonnes per year. It is designed for a pressure of 140 bar and a maximum temperature of 80 °C.



250 MWe capture unit (post-combustion)

ROAD plans to store the captured CO_2 in depleted gas reservoirs under the North Sea. These gas reservoirs are located in block P18 (P18-6, P18-4 and P18-2) of the Dutch continental shelf, 20 kilometres off the coast. The depleted gas reservoirs are at a depth of 3500 meters under the seabed of the North Sea. The CO_2 will be injected from the platform into depleted gas reservoirs. The estimated storage capacity is 35 million tonnes.

1.1.4 Rationale for Rotterdam port and industrial area

The Rotterdam port and industrial area has a number of advantages creating favourable conditions to implement a CCS demonstration project like ROAD. The Rotterdam port and industrial area has many CO_2 point sources. Several new power stations prepared for the application of CCS (capture ready) are under construction. It is relatively close to a large number of (almost) depleted gas reservoirs on the continental shelf under the North Sea, allowing a small transport distance. These gas reservoirs meet the physical and geological properties for CO_2 storage and will become available in the next few years (from 2014 onwards). Furthermore, the Netherlands has a lot of knowledge and experience with both oil and gas extraction and storage of gas in aquifers and gas reservoirs. Finally, the complete CCS-chain (e.g. storage) is remote from inhabited areas. Stakeholders in the direct vicinity of the capture site and the onshore pipeline are other industries. Municipalities neighbouring this part of the port and industrial area are e.g. Westvoorne and Hoek van Holland.

P18-A platform at the North Sea (photo: TAQA)

1.1.5 Facts & Figures

Base installation: E.ON Maasvlakte Power Plant 3 (Rotterdam, The Netherlands)

- Net electrical output : 1069 MWe
- Efficiency : 46.3 % (LHV)
- Operational : 2013
- Capture ready : Carbon Capture Ready Certificate from TUV Nord

Capture Plant

- Technology : Post-combustion
- Solvent : MEA formulation
- Capacity : 250 MWe equivalent
- Capture rate : 90%
- CO_2 captured : Ca. 1.1 megatonnes / year
- Operational : 2015

Transport

- Pipeline transport
- Diameter : 16 inch
- Distance : 5 km onshore, 20km offshore
- Capacity : Gas phase : 1.5 megatonnes / year
  Dense phase : 5 megatonnes / year
- Design specifications : 140 bar, 80 °C

Storage

- Depleted gas reservoir : P18-4
- Operator : TAQA
- Depth : 3500 meters
- Estimated capacity : Ca. 8 megatonnes
- Available : 2014

1.1.6 Planning

The high level schedule of the ROAD project is as follows:

- 14 July 2009 : Application submitted for funding under EEPR
- September 2009 : Project selected for funding by European Commission
- May 2010 : Ministerial order Dutch funding published
  Grant Agreement signed by European Commission and ROAD
- September 2010 : Front-End Engineering Design studies Capture Plant completed
  Starting note Environmental Impact Assessment published
- June 2011 : Submitting EAI and permit applications
- 2nd quarter 2012 : Final Investment Decision
- 2012 : Start execution phase (procurement, construction, etc.)
- 2014 : CCS chain mechanically complete
- 2015 : Start of operation CCS chain
- 2015-2019 : Demonstration operation phase CCS chain
- 2020 : Start commercial operation CCS chain

1.2 Maasvlakte CCS Project C.V.

The initiating parties of the ROAD project are E.ON Benelux and Electrabel Nederland / GDF SUEZ Group. Together they constitute the limited partnership Maasvlakte CCS Project C.V.

1.2.1 E.ON Benelux

E.ON Benelux concentrates on the production and supply of electricity and gas to private customers and business customers in the Netherlands and Belgium. E.ON Benelux is primarily an electricity-generating company; the company can trade internationally and has its own professional sales organisation. The company was established in 1941 and since 2000 has been part of E.ON Energie AG. E.ON Benelux's power stations with a total capacity of 1850 MW are located in the province of South Holland, the economic heart of the Netherlands. The company has approximately 600 employees. E.ON Benelux is based in Rotterdam.

1.2.2 Electrabel Nederland

Electrabel Nederland is a leading player in the Dutch energy market and part of the GDF SUEZ Group. With six state-of-the-art production locations and a total capacity of 5103 MW Electrabel is the largest electricity producer in the Netherlands. Electrabel is a supplier of electricity and gas to both private and business customers. Electrabel Nederland has 1250 employees.

1.3 Intended Partners

Intended partners of Maasvlakte CCS Project C.V. are GDF SUEZ E&P Nederland for the CO_2 transport and TAQA Energy for the CO_2 injection and the permanent storage under the seabed of the North Sea.

1.3.1 TAQA Energy

TAQA Energy is part of the Abu Dhabi National Energy Company PJSC (TAQA), an energy company that has worldwide interests in power generation, combined heat and water, desalination, upstream oil & gas, pipelines, services and structured finance. TAQA has a workforce of 2800 employees and is located in Abu Dhabi, The Hague, Ann Arbor: Michigan, Aberdeen, Calgary and Amsterdam. In addition, TAQA has sustainable partnerships with companies in Africa, the Middle-East, Europe, North-America and India. TAQA is listed at the Abu Dhabi Securities Exchange (ADX).

In the Netherlands, TAQA Energy explores and produces gas and condensates from wells located onshore in the Alkmaar region and offshore in the Dutch North Sea. TAQA also operates a gas storage facility in Alkmaar and has interests in Dutch North Sea pipelines. 200 people work for TAQA directly and indirectly in the Netherlands both onshore and offshore.

1.3.2 GDF SUEZ E&P Nederland

GDF SUEZ E&P Nederland is one of the largest operators in the Dutch sector of the North Sea. With more than thirty production platforms and 300 employees, it is at the basis of the provision of energy to the Netherlands and several other countries.

Since its first successful drilling results in the Dutch North Sea, approximately forty years ago, GDF SUEZ E&P Nederland has grown into a leading operator. It has ample expertise and experience, always chooses the safest option and is continuously working towards the development of new techniques and improved methods. Continuity is ensured through exploration, takeovers and acquisition.

The company has also gained valuable experience through involvement in the K12-B CO_2 storage project. The project aims to investigate the possibilities of CO_2 storage and enhanced gas recovery at the K12-B gas field which is operated by GDF SUEZ E&P Nederland.

1.4 Financial contributors

The ROAD-project is co-financed by the European Commission within the framework of the European Energy Programme for Recovery (EEPR), the Government of the Netherlands and the Global CCS Institute.

In response to the economic crisis, the European Council and the European Parliament adopted the Commission proposal for an EEPR in July 2009. The EEPR funds projects in the field of gas and electricity infrastructure as well as offshore wind energy and CO_2 capture and storage (CCS). In total 12 CCS projects applied for assistance under the EEPR. In December 2009, the European Commission granted financial assistance to six projects that could make substantial progress with project development in 2010. These projects will receive overall funding of € 1 billion under the EEPR.

2. Project office and governance

2.1 Project organizational structure

The Limited Partnership Company, Maasvlakte CCS Project C.V. (MCP) is a joint venture between E.ON Benelux Holding B.V. (EBX) and Electrabel Nederland Project B.V. (EBL), the holding companies of which are E.ON AG and GDF SUEZ, respectively. ROAD is the name of the project executed by MCP. The ownership of MCP shares is 50% by EBX and 50% EBL. The limited partnership company (Commanditaire Vennootschap (C.V.) in Dutch) is a very common form for joint venture structures in the Netherlands. This structure has been chosen because of legal and fiscal transparency.

Given the joint ownership of the project, the MCP board of management is represented by two directors from E.ON and two from GDF SUEZ. The company's four directors are each head of a Project Team which comprise of the project's key focus areas:

- Capture;
- Transport and Storage;
- Stakeholder Management;
- Project Office and Governance.

The responsibilities for and within each of the four organizational pillars have been balanced on a 50/50 base between both parent companies. Furthermore each of the relevant work packages is explicitly represented in the organization.

The project aims to employee the skills of specialists from across both parent companies; however, strategic partners also play a role throughout the development and operational phases of the project. These third parties currently include GDF SUEZ E&P Nederland B.V. and TAQA Offshore B.V. for the CO_2 transport and CO_2 storage aspects, respectively.

Experiences and key lessons learned:

- The fact that the project is carried out in a joint venture has had a generally positive impact. Combining the knowledge and methodologies of two parent companies, assumptions are challenged more rigorously, group thinking is avoided and decisions are taken more objectively. The existing knowledge within the parent companies is crucial in all aspects of the technical and commercial activities. Knowledge sharing between the project team and the parent companies is crucial.
- However, working in an innovative joint venture project also poses some challenges. First, it can lead to inefficient double reviewing procedures. Trust is the key success factor to reduce the need for double reviews. Even in a project organization under development, trust can be achieved through dedicated team work and face to face contact. Second, given the uncertainty surrounding our project, it can be hard to get people to full-time dedicate themselves to the project. Therefore, keeping continuity of staffing is a key issue that needs to be addressed, for example by dedicating a specific budget to project development.
- The definition of an organisation structure with clear responsibilities from the start of the project is important and more complicated in the case of a joint venture. It would be best if the organisational structure and responsibilities are clear from the start.

2.2 Knowledge management

Experiences and key lessons learned:

Network meetings

ROAD actively participates in European and local networks to share experiences and learn from pilot and other CCS initiatives. While a very broad range of topics was being discussed during first meetings, the later ones focused more on specific topics. This has improved the applicability considerably.

Decision register for ROAD employees

ROAD initiated a decision register which is open for the ROAD employees. Significant decisions taken during board- or team-meetings are mentioned in the minutes and recorded in the decision register. The register is aimed to provide an overview of all major decisions taken and to make information more transparent and traceable.

Internal workshops

The lessons learnt presented in this report were mainly identified during workshops attended by a mixed group of people. The workshops contributed to the knowledge sharing between the project team members. Recently, another set of knowledge sharing activities were organized to extract the most important technical lessons from the experts working on the ROAD project. Three consecutive on-line chat sessions were organized of which the outcomes were valuable for the composition of this report:

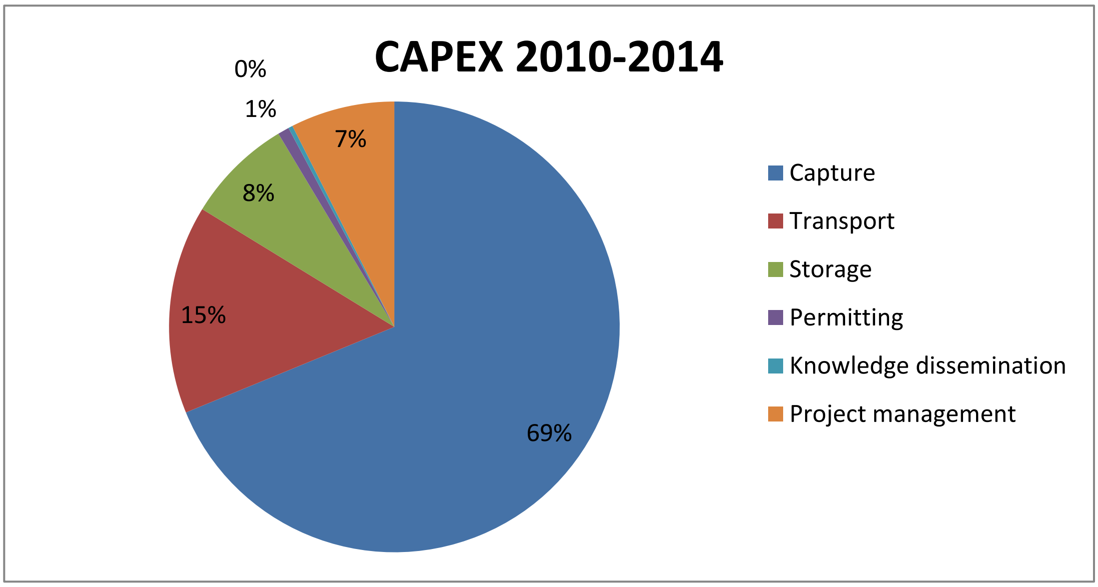
1. The first exercise was a brainstorming session to list as many insights with a significant impact to the ROAD project as possible;
2. The second session was an on-line voting process to select the most important statements with a considerable impact on the ROAD project and the main decisions of significant importance to discuss further;
3. The third and last session was an online discussion forum in which the most important issues, that were selected in session two, were elaborated upon.

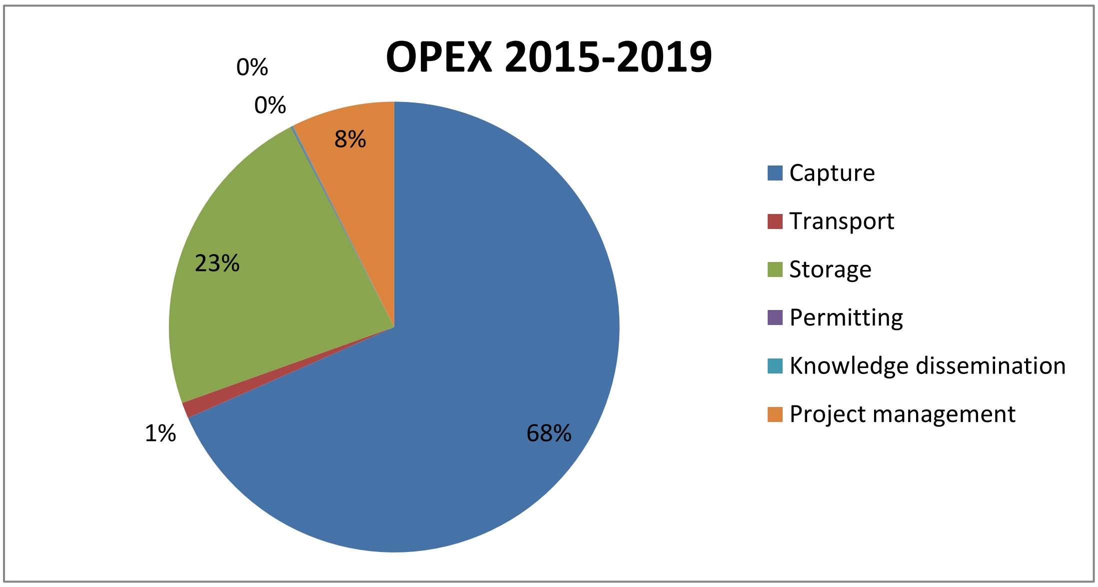
2.3 Finance and budget reconciliation

A complete study into the financial requirements of the project has been completed, in which the total CAPEX, OPEX and project Net Present Value (NPV) have been estimated through detailed financial modeling activities. The work presents a breakdown of costs in both CAPEX and OPEX phases, the cost assumptions, contingency that has been included in the budget and risk attribution. Furthermore several scenarios and their sensitivities were investigated; finally the expected cash flows were reviewed.

The project budget is governed by the company's organizational structure, with a budget divided between Project Office and Governance, Stakeholder Management, Capture and Transport and Storage. Budget is split over the life of the project into two phases; the design and construction phase (2010-2014) and the operational phase (2015-2019). Following the operational period, provisions have been made for plant decommissioning, and monitoring of the storage site. A work package breakdown has been used in compliance with the existing accounting and reporting structure in place at MCP. This structure revolves around a work package (WP) breakdown, subdivided by sub-work packages (used for reporting purposes) that are then built up to a projects oriented structure. Cost estimating has been performed on project level.

The total budget is 643 M€ (all values in this section are nominal values 2010). However, this includes both the anticipated utility costs (electricity and steam) and costs related to the transport contract injection fee that is coupled to the CO_2 price. The CO_2 price used in this base case budget is 27€/tonne on average.





The CAPEX budget, including contingencies, adds up to a total of 417 M€ (inflation of 2% is used). The OPEX budget adds up to a total of 226 M€, of which 19 M€ is budgeted for abandoning the offshore facilities (plugging the well and monitoring and handover). Using pilot plant data in process models provided further risk mitigation for operating cost estimates.

For budgeting purpose, actual CO_2 injection is assumed to cease at the end of 2019, but platform facilities will be kept alive for monitoring and plugging and abandonment purposes until end of 2023. In reality, the parent companies have the opportunity to continue operation after 2019 if this is then considered economically or strategically beneficial.

The total project contingency has been determined through a bottom-up approach indicating the maximum spread on each expense line item. The cost spread arbitrated on each expense line item represents the exposure due to:

- Market price exposure resulting in cost spread;
- Current state of engineering detail: concept design, basic design (pre-FEED), detailed design (FEED);
- Planning uncertainties (weather risk, mobilization of equipment);
- Other issues.

The external funding currently amounts to €334m and is distributed as follows:

- EU Grant – €180m disbursed for CAPEX phase milestones;
- NL Grant – €75m related to CAPEX phase milestones and €75m related to OPEX phase milestones (both will be received during the construction phase);
- GCCSI Grant – AUD$5m related to project front-end engineering design (FEED) related milestones (2011).

3. Capture, transport and storage

The technical highlights, outcomes and breakthroughs, difficulties encountered and lessons learnt with respect to the capture, transport and storage activities are described in this chapter.

3.1 Capture organization

3.1.1 Interfaces with the power plant

Time, budget and space constraints have led to solutions that are not fully optimized with respect to energy usage. For a new power plant with full scale carbon capture many technical concepts can lead to further performance improvement and savings in investment and operational costs. The combination of the absorber and power plant stack for example, or the design of a compressor directly coupled with the steam turbine can result in improvements. Briefly, one can state that for a high level of integration of the power plant and capture plant, and to reach highly efficient solutions, both plants have to be developed simultaneously.

Because of the changing market conditions (gas price volatility, growth in renewable generation), ROAD cannot be confident that MPP3 will operate at base load. With MPP3 load changes come pressure changes in the turbine, and therefore changes in the supply pressure of the steam to the capture plant. However, the reboiler operates at a stable temperature, so requires a stable steam supply. This can be managed by using different steam extraction points and transfering the steam supply between this points as the MPP3 load changes. ROAD has employed some technical innovations in their design to allow smooth control of the steam supply at maximum efficiency, given the available extraction points of the MPP3 turbine. A later special report is planned to describe these. An alternative solution would be to use more appropriate extraction points, available if the steam turbine and carbon capture plant were designed together.

One of the major questions ROAD will be able to answer when operating the demo-plant, is its reaction and behavior when lower steam pressure is available. To date, ROAD has been limited in extensive optimization of the off-design performance of the capture demo plant. Building an integrated model of the capture plant, power plant and steam cycle in a process simulator could aid in understanding the dynamic behavior and will be particular valuable for future full scale CCS plants.

Developing two projects that are so closely connected with two project teams is not the most efficient way for project execution. More optimal would be to combine the power- and capture-plant project teams. Transport and storage could be handled as a separated project because fewer interfaces have to be considered.

3.1.2 CO2 capture selection methodology

The ROAD project used an innovative strategy to select the capture plant EPC contractor. This strategy has been reported in a former report [1] and it helped in meeting the tight time schedule, effectively benchmarking of the suppliers, ensuring competition and consequently ending up with a better design.

The selection process requires decision-making at different levels within a tight time schedule. To achieve this, effective decision planning and discipline was needed. This clear and visible supplier selection strategy to drive forward suppliers was critical.

Especially (but not only) because of the extensive efforts invested by the bidding suppliers, it is important to manage relationships with the rejected suppliers for future projects. Lack of time and resources can easily drive the project team's attention towards suppliers that go on to the next selection phase instead of the suppliers that were not selected, which is a concern. To prevent this from happening, the project team organized feedback meetings for all suppliers that were rejected after the preliminary study phase.

3.1.3 Capture plant engineering and design

Experiences from pilot plants are of high importance for the success of ROAD. The pilot data has been particularly valuable in checking Fluor's design. It would be much riskier for a company to develop a post-combustion project without access to such pilots.

Corrosion is an issue known from experiences with the carbon capture pilot plants. Therefore it is recommended to carefully monitor the lifetime of the materials of the demonstration plant. Iron is expected as the most critical component with respect to corrosion.

The pilot plants also provide calibration for the modeling work, which does show a good match to Fluor's design data. Therefore they provide confidence in the Fluor design: the absorber size, energy consumption, pressures and water balance. The modeling gives confidence in the Fluor design and allows ROAD to accept weaker guarantees from Fluor (and therefore get a lower lump sum price). However, current pilot plants are not optimized for demonstrating low emission performance. Therefore care should be taken when interpreting the results especially if extrapolating to full scale.

Solvent management with respect to degradation and solvent reclaiming remain attention points for the design and operation of the ROAD demonstration plant. Reclaiming and solvent management have a very significant impact on the final energy consumption but reclaiming is not so simple to implement on smaller pilots, as it is too costly.

Ammonia was a critical item for the permits, since ROAD wants to build a carbon capture plant in an area where the N-deposition is already high. Strict standards and low emission rates have to be respected. Ammonia is formed as a degradation product of MEA[1]. The amount of ammonia therefore depends of MEA degradation and is mainly coming from the oxidative degradation of the MEA. This degradation is dependent on the O_2 level and the temperature. Besides, iron is causing degradation; this effect is already taken into account by Fluor (capture plant supplier). There are multiple counter-measures and degradation inhibitors available which can be implemented if it is required to further reduce the N-deposition.

ROAD is convinced the selection of the MEA solvent was the right choice for the ROAD context. MEA is the oldest known solvent available for carbon capture applications and therefore it is well known compared to other solvents. There are no confidentiality issues around MEA and more data is available. This makes permitting easier.

Dynamic modeling is under development and is considered necessary to support economic and operational project assumptions. Dynamic modeling suggests that the control of the water balance is complex during transient phases. This can lead to the use of high quantities of water and the production of waste streams. The temperature of the flue gas entering the process needs to be controlled. Too high flue gas temperatures result in significant quantities of water carrying over from the DCC[2] into the absorber and into the wash section. Too low flue gas temperatures result in a higher blowdown in the DCC. In order to close the water balance for

[1] Mono Ethanol Amine
[2] Direct Contact Cooler

the capture plant itself, the most important is to ensure that the temperature of the flue gases leaving the washing section is nearly equal to the temperature of the flue gas entering the absorber. Thus the cooling in the washing section also requires close control.

Nitrosamine emissions from a MEA based carbon capture process have been found so far not to have a significant environmental impact. When the nitrosamine issue was raised, it was treated as an emissions problem. Current power plant data suggests that nitrosamines are not volatile and therefore remain in the solution. However, the minimization principle for nitrosamines will continue to be strictly applied. In case needed, UV light equipment can be used at the wash section to destroy nitrosamines.

3.2 CO_2 transport and storage organization

Flow assurance (FA) needs a multidisciplinary approach. The knowledge to translate the FA study results to a design is hard to find. Software used during Flow Assurance Studies also is heavily monopolized by one or two software/simulator companies. It would be good to have third software for comparative purposes in order to boost the confidence in the results being generated to date.

The CO_2 specifications differ widely for different capture technologies and due to a lack of experience it is not exactly known what will be acceptable for pipeline, well and reservoir. Therefore ROAD has been very conservative in its specifications. Parameters like oxygen, water and dust (amount and particle size distribution) are the most important for transport and storage.

Compressor

It is important to start the flow assurance study at an early project stage by reverse calculation from storage. The compressor has a long lead time and therefore attention need to be paid need to order it on time.

The design of the CO_2 compressor was a challenge. It seems there are a few companies able to build a large CO_2 compressor combined with the demanded wide operational envelope. It was not easy for the sub-contractors to design a compressor for CO_2, first in a gaseous phase and then in the dense phase, at the required scale. ROAD found two companies to choose from.

Transport

A significant insight of the FA study was the conclusion that a two-phase flow will occur in the pipeline and in the well (at least the top of the well), during start-up. Transporting a fluid with two phases is a challenge; this can lead to severe slugging effects which will lead to vibrations. The FA study has also shown that the preliminary design to place a heater on the platform is not the right solution with respect to flow control problems. The reaction time of a suitable heater is too slow.

The ROAD concept of transporting warm CO_2 via an insulated pipeline and no heating on the platform is unique and has unique challenges. A prolonged shut-down can generate two-phase conditions in the pipeline. In case of a two-phase flow, there is no way to avoid slugging during startup. A detailed start-up and operation philosophy has to be worked out. This is still ongoing and under research due to its complexity. The flow assurance studies have given pretty good results. They can be used to give advice for the platform engineering. But the real problem with implementing results of FA studies is that real expertise of FA in combination with engineering is very unique. There is no practical experience available of the two phase flow of CO_2. To get information ROAD needs results from R&D projects. The solution of ROAD will be very valuable for future projects in the wider industry.

Platform

Modifying a satellite platform with limited space provides challenges because limited space is available. Also the integrity of the existing platform is an attention point.

Storage

Local Authorities created new procedures for storage permits; they had to discover how this would work in practice. ROAD had to wait until the CCS directive was implemented into Dutch law.

Also delivering the storage license requirements (i.e. building models, making plans, etc.) takes a long time and a lot of disciplines are involved. An early clarification of the storage facility and agreements with the owner are necessary in that regard. Furthermore the reservoir behavior determines all design and operation conditions of the complete CCS chain; the process is ruled by the reservoir.

4. Stakeholder Management

This chapter covers the main lessons learned concerning the stakeholder management efforts of the ROAD-project. In September 2011 the Special Report "Stakeholder Management ROAD" was published by the Global CCS Institute. In this chapter the main components of this report will be highlighted and complemented where needed. Please see the Special Report on Stakeholder Management for more detailed information.

To date, stakeholders have responded generally positively to information and activities undertaken by ROAD. A number of communication activities have to a certain extent been driven by stakeholder information needs and fine-tuned to specific stakeholder preferences. However, information provided to stakeholders can also raise new questions and increase their information needs. Overall a key learning has been that stakeholders appreciate being kept informed on new developments on a personal and direct basis.

The ROAD project organization has a dedicated team focusing on Stakeholder Management covering the following specialisms:

- Communications and Public Engagement;
- Regulatory Affairs;
- Permitting;
- Funding agreement management;
- Knowledge dissemination.

The key lesson learned concerning stakeholder management is the importance of the integration of stakeholder management and communication functions in the project management. The demonstration of large-scale CCS faces many technological challenges, but at this stage its success is for a large part dependent on many issues that are non-technical and depend on stakeholder perceptions and interests.

Support and involvement of local, regional and national governments throughout all project phases is a prerequisite for creating the right circumstances for the successful implementation of a CCS project. The stakeholder engagement and communication strategy of ROAD is aimed at gradually involving local communities in the project. In the initial phase (e.g. design and permitting phase) of the project communication activities have been generally aimed at informing stakeholders about the project (i.a. brochure, website).

From negative publicity concerning on-shore storage in The Netherlands, we learned right at the start of the project that public outreach and pro-active stakeholder management is critical for a successful CCS-project. At the same time however, we were working in uncertain conditions - most of the CCS-related legislation was not in place yet and related permits had never been awarded before. Moreover, in the current demonstration-phase, CCS-projects need public funding and in order to reach the goal of commercialising CCS, so knowledge sharing is essential. All-in-all, stakeholder management is a vital part of the CCS-chain that is no stronger than its weakest link.

4.1 Integration of stakeholder management in the project team

The Stakeholder Management team shares an open office space with other project teams. This cultivates bilateral and cross-functional contacts between teams. In addition, specialists of the Stakeholder Management team frequently participate in meetings and working groups of capture, transport and storage teams.

The team is responsible for identifying and assessing causes and effects of potential stakeholder and reputation risks. Furthermore, they are accountable for planning and managing mitigating and response measures. Ultimately, the Director Stakeholder Management and the Management Board of ROAD authorize whether stakeholder risks are deemed acceptable or unacceptable.

Integration of the Stakeholder Management into the project team strengthens the multidisciplinary perspective of the organization and creates cross-functional teams. For a technical project it helps taking non-technical aspects (e.g. stakeholder perceptions) into account in decision-making processes. However, such an approach also demands more co-ordination, planning and time management.

Experiences and key lessons learnt:

- The Stakeholder Management and communication function should be integrated in the project management since CCS projects have to deal with many issues that are non-technical and to large extent depend on stakeholder perceptions and interests. Ultimately Stakeholder Management is instrumental in creating necessary conditions for other project functions (e.g. capture, transport & storage).
- It´s not only about (technical) knowledge and information, but also about social skills and empathy of personnel of the project organisation. Technical experts received training in presentation, conversation and how to adequately cope with emotional situations. Stakeholder relations are not only determined by quality of information, but are to a large extent also by how (personal) relationships are being managed.

4.2 Public outreach plan

At the start of the implementation of its public outreach programme, ROAD defined a clear vision and mission statement for the project. This vision and mission statement drives all communication and corresponding key messages. It also clearly defined the position of ROAD vis-à-vis its parent companies on general energy issues. The vision and mission of ROAD is as follows:

- Vision: “In transition to a sustainable energy supply we will have to rely on various transition technologies in order to secure a reliable, efficient and clean energy supply.”
- Mission: “Demonstrating that a large-scale, integrated CCS-chain (offshore) can be applied in a reliable and efficient way within 10 years (2020) and can make a substantial contribution to the climate change objectives, and share knowledge and experiences with other industries and countries.”

Within the framework of the vision and mission statement ROAD formulated a number of positioning statements that should drive key communication messages: industrial, integrated CCS chain; offshore; reliability (safe); transition technology (reliable, efficient, clean); public engagement and dialogue; knowledge development and innovation; Rotterdam CCS network and sustainable economic development; and Dutch and European (financial) support.

One of the main strategies that were formulated was that the ROAD-project should primarily focus on local and regional stakeholders (this was particularly important following the projects in Barendrecht and the Northern provinces). The alignment of local and regional stakeholders was seen as a primary condition for the implementation of the ROAD-project. Furthermore, being an active partner of the envisaged Rotterdam CCS network would create a strong local value proposition for the ROAD-project: contributing to the sustainable economic development of the Rotterdam port and industrial area.

As the ROAD-project evolves, relationships with relevant stakeholder become more regular and intense. This should gradually build up a dialogue with local communities. In the long term the outreach strategy is focused on creating a structural platform via a so-called Community Advisory Panel (CAP) and building and securing mutual understanding and trust. The development of a CAP should also offer an on-going platform for an open, constructive dialogue between ROAD and its stakeholders and to monitor developments in public perceptions.

ROAD developed various basic communication materials to support its outreach strategy such as: project brochure with background information, website, exhibition materials and animations of how the CCS chain (capture, transport and storage) works. For public events like town hall meetings the technical specialists also used core samples in order to show what stones from the gas reservoirs look and feel like.

Experiences from the construction of the new coal-fired power plants have taught that local communities have worries about effects of industrial activities that impact the liveability of their direct environment (e.g. noise, air pollution, dust, traffic), beside external safety issues.

- In order to inform relevant stakeholders to the best of our abilities, technical experts received trainings in presentation, conversation and how to adequately cope with emotional situations. As such, effort was made to explain the CCS-rationale in technical detail but also in a clear and comprehensible manner. Besides (technical) knowledge and information, social skills and empathy of personnel of the project organisation has proven to be important to inform laymen about a complex project like ROAD. Again, stakeholder relations are not only determined by quality of information, but are to a large extent also about how (personal) relationships are being managed.
- A near neighbour is better than a distant cousin. It is important to structurally inform key stakeholders that can act as ambassador and advocate for the project.
- With a two-way communication strategy and getting an insight into expectations and mutual interests of stakeholders the project aims to secure public acceptance on the long term.
- It's also the economy,…! It is important not to only focus on climate change, but also on the economic benefits of CCS and local value propositions it can offer to local communities.
- CCS is technical and complex and for local communities it is easier to understand and experience images and tangibles than words and numbers; a picture is worth a thousand words.

ROAD's communication strategy has been explained in further detail in the Special Report on Stakeholder Management.

4.3 Permitting

ROAD has engaged with a broad range of permitting authorities from the various layers of government in the Netherlands: local (municipalities), regional (water authorities), regional (provinces), national (ministries and national advisors).

Just like other stakeholders, permitting authorities need to be informed on procedures and content, as early as possible. By convening with the permitting authorities at an early stage and discussing procedural and technical matters, ROAD has aimed to build mutual commitment and trust.

Internally, it has proven to be crucial to have a very clear definition of roles and responsibilities of the individuals involved in the permitting process. These roles and responsibilities obviously change during the project phases, but at any moment, these should be clearly communicated within the project team. Also, the permitting process should from the beginning be driven by a multidisciplinary team of employees out of all project pillars in order to communicate as effective as possible.

In engaging with permitting authorities the following lessons can be learned:

- The Ministry of Economic Affairs, Agriculture & Innovation, despite its initial reluctance, was essential in coordinating the permitting stakeholders and showing the (inter-)national relevance of the project via the State Coordination Scheme. Such a Scheme can be instrumental in improving quality and pace of permitting procedures involving multiple permitting authorities.
- Permitting stakeholders not only want to be informed on procedures, but also want to be educated on technical details of the project, as early as possible. Convene early with the permitting authorities to discuss matters as a) how many commentary rounds should be included in the permitting process; b) what points are relevant for them; c) who will be contact person and d) how information exchange will take place. This builds up mutual commitment and trust.
- Make sure contact persons at the permitting authorities are well-connected and committed to the project. Lack of sufficient resources (e.g. time, knowledge) can severely delay the project. Visibility and support from the management of permitting authorities can secure the necessary resources. The coordinating permitting authorities should actively manage the time schedule of the involved permitting procedure in order to prevent delays.
- For amine-based solvents it is important that the technology suppliers are open about the composition of the solvent. This is required to give regulators a pathway to permitting. An unknown solvent composition is a significant barrier with regard to permits and could be a key risk for the project.

4.4 Legal and regulatory framework

Just like in other parts of stakeholder management, close cooperation with authorities and regulators at an early stage of the project is essential due to the complexity of CCS regulation. CCS legislation is new and in The Netherlands, it had to be drawn from scratch. In addition;

- An open process between the applicant and the relevant authorities, in which the first findings are shared, is important to maintain the momentum of the (permitting) process.
- Without an open and flexible legislation (tailor made approach) it is very unlikely that CCS demonstration projects will be developed. Therefore, it is important that authorities and regulators are proactive and take their responsibilities regarding, for example, CO_2-storage. Issues should be addressed in a coordinated way, in order to avoid a big delay of the legislative and regulatory process.
- A prerequisite for the success of the project is that the authorities feel involved in the project.

4.5 Performance of external organisations

Dutch Government

The Ministry of Economic Affairs, Agriculture and Innovation has been of great help in coordinating the various permitting authorities and by explaining them why the project has (inter-)national relevance. In particular, the 'National Coordination Scheme' has been useful for coordinating the various permitting authorities and processes. Nevertheless, as initiator it is important for the project itself to stay involved in coordinating all permitting authorities.

NL Agency falls under the Dutch Ministry of Economic Affairs, Agriculture and Innovation and is concerned with the implementation of innovation and sustainability policy in the Netherlands. A regular contact with Agency NL exists and cooperation has been very fruitful to date.

European Commission

The cooperation with the European Commission has been excellent. The European Energy policy recognizes CCS as a key tool in mitigating climate change, and our open cooperation is based on the shared goal of realizing large-scale CCS demonstration projects across Europe.

Global CCS Institute

The cooperation with the Global CCS Institute has proven instrumental in reaching the wider CCS community. ROAD has received valuable comments on draft Special Reports, all of which we believe today form an excellent bundle of practical information for setting-up a large scale CCS demonstration Project. ROAD is looking forward to continuing this cooperation in the future.

4.6 Conclusions

For a CCS project, especially in the demonstration phase, it is important that authorities are proactive and take responsibility for storage risks. Issues should be addressed in a coordinated way to avoid letting concerns around uncertainties and/or the setting of precedents slow down the process.

Concerning Stakeholder Management, ROAD has formulated the following overall conclusions and recommendations:

- Often a specific legal and regulatory framework on capture, transport and storage technologies is missing or in development: this demands pro-activity, flexibility and close interaction with regulators and authorities. Managing expectations of stakeholders and developing a clear project vision are a prerequisite in that regard.
- CCS projects are driven by technology and can easily be caught up in technological tunnel vision. One of the biggest threats is losing track of stakeholders' views and interests. Instead CCS projects should develop an outside in perspective, taking into account stakeholder expectations. By developing a stakeholder dialogue they create two-way communication with stakeholders that are relevant to the implementation of the project.
- As a consequence of diverse technologies in the CCS chain, spread over different areas, multiple governments and authorities are involved in the projects. This demands an integrated Stakeholder Management approach comprising functions such as regulatory affairs, permitting and public outreach. Ultimately, Stakeholder Management is

instrumental in creating necessary conditions for other project functions (e.g. capture, transport & storage).

5. Project execution

5.1 Risk mitigation

Throughout the execution of the project, there has been an emphasised focus on the risks related to the nature of this 'first of a kind' project. Therefore, the risk mitigation strategy aimed to account for risks across all aspects of the project. These included risks associated with the implementation of new technologies on a scale never before demonstrated. The capture, transport and storage aspects of the CCS chain were individually assessed, along with their interfaces with each other and the host-power plant. In addition, risks of operating the full CCS chain were investigated. Further to this, non-technical risks associated with the regulatory framework, public-acceptance, and environmental permitting were also addressed by risk mitigation activities.

A key outcome of the work performed to date has been the impact of the transport and storage aspects on the overall risk of the project. The main risks of the project in various scenarios indicate that these demonstration projects must give particular attention to transport and storage. Commencement of the key engineering studies early in the project would prove beneficial in addressing and eliminating the risks observed. However, in addition to this, non-technical aspects of transport and storage such as permitting and regulatory issues must also be addressed early in the project.

An overview of the risk mitigation process has been reported in the Special Report to the Global CCS Institute on 'Mitigating Project Risks' [4].

5.2 Development of information during FEED in relation to permissions

A sensitive issue with amine-based post combustion capture technologies is the emission of the amine, its degradation products (in particular nitro-amines and nitrosamines) and ammonia. Because different process designs and different amines will result in different emission profiles, the impact of the technology (and thus solvent) selection could potentially have a high impact on permitting as well as public engagement.

The selected supplier eventually proposed the use of mono-ethanolamine (MEA) as solvent. MEA is the most extensively characterized solvent for post combustion capture applications. MEA degradation studies, identification of degradation products, liquid analysis of pilot plant samples and pilot plant emissions monitoring campaigns have been performed by a wide range of industrial technologists and academics all over the world. Also, the parent companies have experience with MEA as solvent on a pilot scale. Although the use of MEA does not avoid all emissions, the extensive knowledge base enables effective emission management. Countermeasures can be targeted at the expected degradation products in the expected quantities. Furthermore, this publicly available knowledge is a reliable source for the permitting authorities to base their permitting decision on.

Experiences and key lessons learned: Openness of product information is very important for a good agreement with the appropriate authority

5.3 Project schedule

It was found that a solid understanding of permitting procedures and scheduling can have a significant impact on timing and funding constraints. Anticipating delays in agreeing draft permits for public consultation, and building these delays into the project schedule would help avoid any delays in agreed milestones; for example, a final investment decision. The nature of this project as a technical demonstration of a new technology must be noted as having a unique impact on the permitting procedure that is likely to result in challenges through various aspects of the procedure, from permit application to public consultation. In addition to this, the impact of any project delay could have further consequences on funding that may be conditional on achieving certain milestones.

ROAD has very favourable storage conditions, an offshore site only 25 km away from the plant. Furthermore, it enjoys financial and political support from the EU Commission, the Dutch Government and the Rotterdam region. The fact that all of these conditions are favourable at the same moment of time is remarkable. Despite these encouraging circumstances the project development phase lasted longer than foreseen and the FID decisions for the ROAD project were postponed by ca. 1.5 year with respect to the initial schedule. The bottlenecks are linked to permitting, storage agreements and wider economic and political developments. The FID is currently foreseen by mid-2012 and is on the critical path of the ROAD project.

Nevertheless, the engineering and design works continue and the first operation date for the CCS chain remains unchanged. For future off-shore CCS projects in the Netherlands, ROAD recommends to incorporate a permitting delay in the planning of half a year. Specific for ROAD a set of new regulations were needed and Dutch laws have been adapted. For future off-shore CCS projects in the Netherlands the regulatory framework is now in place. Other countries may use ROAD's regulatory experience and the Dutch legislation as an example, but more delay should be incorporated for CCS projects in other countries, on-shore CCS projects and/or CCS projects for greenfield plants (mainly due to possible objections and appeals on construction of new power or industrial plants).

Better insights in the costs related to developing and operating the CCS chain and engineering details gained during the FEED study led the company to define a detailed work plan for the ROAD project. The general plan of approach for procurement and contracting is to outsource activities clustered in packages, to selected organisations within the GDF SUEZ and E.ON groups as well as to selected external business partners, creating responsibility sub-levels. Two different risk profiles for these outsourced packages have been identified:

- The capture plant is intended to be realized on a lump-sum basis after the Final Investment Decision (FID), including maximum risk (costs and timing) for the Engineering, Construction and Procurement (EPC) contractor.
- All other components are being contracted on a reimbursable basis, allocating the risk predominantly to ROAD, while, on the other hand, reducing costs due to a lower risk premium.

The timing of sub-activities is inherently included in the sub-level responsibilities. The contractors are responsible and are closely monitored by the ROAD organisation. A detailed view on the long lead items is important. The long lead items (requiring the longest engineering time) within the scope of the intended EPC capture contract are the main heat exchangers (direct contact cooler, wash water cooler, absorber intercooler, solvent cross heat exchanger and sea water coolers), the reboiler, the dehydration unit, the flue gas blower and the lean vapour compressor.

The schedule is driven by both the MPP3 construction schedule and cost minimization. In order to avoid MPP3 outage penalties, the tie-in works have to be executed on-track. Both drivers led to the specific construction plan and the clustering of heavy lift components. The heavy lifting activities of large vessels (direct contact cooler, absorber, stripper and lean vapor flash tank) and main compressor are on the critical path. Thanks to the clustering of heavy lift components the cost and project schedule can be squeezed significantly. After the lifting and placement of these major components the capture plant can be assembled. In a second phase the transport and storage works will become a point of attention.

5.4 Key implementation issues

This section aims to provide a high level overview of experiences with the key implementation issues of the project with a specific focus on health and safety, contracting and finance.

5.4.1 Management of health and safety

To establish good H&S practices during Design and Construction and to ensure that the design meets requirements (from ROAD, authorities and other stakeholders) the H&S execution must demonstrate full implementation and verification of the requirements (compliance).

The general plan of approach is to outsource activities, clustered in packages of which the contractor is responsible for compliance, ROAD MCP is accountable. Therefore ROAD MCP ensures by monitoring safety deliverables/milestones, attending meetings and reviewing specific safety activities and registrations of the contractors. H&S is not a separate item; it is integrated into regular project execution.

5.4.2 Working with various business partners

List of business partners:

MCP unit	Component	Business partner / contractor
Capture	Capture plant	Fluor (Netherlands/USA)
	MPP3/CCS interfaces construction	E.ON Benelux / MPP3
	Engineering and project management	MCP with combined team of experts from parent companies + externals
	Other costs (tendering process, etc.)	Various parties, mainly expensed in 2010
Transport & Storage	Transportation (pipeline)	GDF SUEZ E&P
	Storage (platform, well)	TAQA
Stakeholders, Project office & governance	Permitting	Royal Haskoning
	Other activities	Various parties

Table 1: List of business partners

These business partners (see table 1) in turn, source a significant part of the works from vendors and subcontractors.

5.4.3 Agreements with the power plant

The project has also been successful in cooperating productively with E.ON with regards to their MPP3 plant and the associated integration with the capture plant. It was found that a key learning point of the project is to consider the importance of the utilities agreement between

MCP and MPP3. Providing a clear agreement on how the power plant and capture plant will interact is an important factor in ensuring a strong relationship between the power plant and capture plant owners and operators. Such an agreement should be negotiated at an early stage. In ensuring minimal impact on MPP3 operation, this agreement between the two parties has demonstrated that strong cooperation between power and capture plant can be achieved. The basic principles of the Utility Agreement as the main contracts are:

- E.ON is allowed to operate MPP3 without being limited by the capture facility;
- Title and risk of utilities shall pass to MCP at the points of delivery;
- E.ON will use its best endeavours to install, own, maintain and operate a 10KV voltage line from E.ON's facility to the capture facility for the transportation of electricity. The consequences of MCP's choice not to have a direct connection to the public grid are entirely for MCP;
- Supply of all utilities is against market prices;
- Each party is responsible for its own permits and E.ON's permitting position must not be adversely effected by the capture facility.

5.5 Upcoming milestones and next steps for the project

As the project approaches the key milestone of a decision on investment from its parent companies, an overview of upcoming milestones is mentioned below:

- 2nd quarter 2012 : Final Investment Decision (FID);
- 2012 : Start execution phase (procurement, construction, etc.);
- 2014 : CCS chain mechanically complete;
- 2015 : Start of operation CCS chain;
- 2015-2019 : Demonstration operation phase CCS chain;
- 2020 : Start commercial operation CCS chain.

The FID currently is on the critical path of the ROAD project. The company currently foresees FID by mid-2012.

The schedule is driven by both the MPP3 construction schedule and cost minimization. In order to avoid MPP3 outage penalties, the tie-in works have to be executed on-track. Both drivers led to the specific construction plan and the clustering of heavy lift components. The heavy lifting activities of large vessels (direct contact cooler, absorber, stripper and lean vapor flash tank) and main compressor are on the critical path. Thanks to the clustering of heavy lift components the cost and project schedule can be squeezed significantly. After the lifting and placement of these major components the capture plant can be assembled. In a second phase the transport and storage works will become a point of attention.

6. Conclusion

Throughout this report a number of key learning points have been elaborated that will allow the project to continue successfully through future phases, and which may prove valuable for other CCS projects in the future.

It was found that a solid understanding of permitting procedures and scheduling can have a significant impact on timing and funding constraints. Anticipating delays in agreeing draft permits for public consultation, and building these delays into the project schedule would help avoid any delays in agreed milestones; for example, a final investment decision. The nature of this project as a technical demonstration of a new technology must be noted as having a unique impact on the permitting procedure that is likely to result in challenges through various aspects of the procedure, from permit application to public consultation. In addition to this, the impact of any project delay could have further consequences on funding that may be conditional on achieving certain milestones.

Time, budget and space constraints have led to solutions that are not fully optimized with respect to technical decisions and energy usage. For a new power plant with full scale carbon capture, many technical concepts can lead to further performance improvement and savings in investment and operational costs. Considering the current market conditions and the expected plant operation modes for grid support, the steam pressure will fluctuate with load. ROAD has been limited in design optimization for off-design performance of the capture plant. One of the major questions ROAD will be able to answer when operating the demo-plant, is its reaction and behavior when lower steam pressure is available.

Independent process model validation using pilot plant data has been particularly valuable. It would be much riskier for a company to develop a post-combustion capture project without undertaking independent process model validation combined with access to pilot plant performance data. However, current pilot plants are not optimized for demonstrating low emission performance. Therefore care should be taken when interpreting the results especially when extrapolating them to full scale. Appropriate independent process modeling expertise using pilot plant data is valuable in reducing risks associated with extrapolation of pilot plant data. Using pilot plant data in process models is also a key risk mitigation strategy for estimation of operating costs (i.e. parasitic energy usage).

For transport and storage it is important to define the specifications for the CO_2 product. Parameters like oxygen, water and dust (amount and particle size distribution) are the most important. The CO_2 specifications differ widely for different capture technologies and due to lack of experience it is not known what is acceptable for pipeline, well and reservoir. A significant insight of the flow assurance study was the conclusion that a two-phase flow will occur in the pipeline and in the well (at least the top of the well), during start-up. Transporting a fluid with two phases is a challenge; this can lead to severe slugging effects which will lead to vibrations. Also, the design of the CO_2 compressor was a challenge. It seems there are a few companies able to build a large CO_2 compressor combined with the demanded wide operational envelope. Furthermore, modifying a satellite platform with limited space provides challenges because limited space is available. Also the integrity of the existing platform is an attention point.

In addition, important lessons were learned with regard to the integration of CCS and a power plant. Productive cooperation between the power plant and CCS teams is essential. A key learning point for the project in this regard was the importance of the utilities agreement between MCP and MPP3.

Support and involvement of local, regional and national governments throughout all project phases, as well as a positive public perception, are a prerequisite for creating the right circumstances for the successful implementation of a CCS project. Since CCS is a technology under development, a specific legal and regulatory framework on capture, transport and storage technologies is in many countries still missing or in development. This demands pro-activity, flexibility and close interaction with regulators and authorities. Managing expectations of stakeholders and developing a clear project vision are a prerequisite in that regard. One of the biggest threats is losing track of stakeholders' views and interests. Instead CCS projects should develop an outside in perspective, taking into account stakeholder expectations. By developing a stakeholder dialogue they create two-way communication with stakeholders that are relevant to the implementation of the project. As a consequence of diverse technologies in the CCS chain, spread over different areas, multiple governments and authorities are involved in the projects. This demands an integrated Stakeholder Management approach comprising functions such as regulatory affairs, permitting and public outreach. Ultimately Stakeholder Management is instrumental in creating necessary conditions for other project functions (e.g. capture, transport & storage).

The fact that the project is carried out in a joint venture has had a generally positive impact. Combining the knowledge and methodologies of two parent companies, assumptions are challenged more rigorously, group thinking is avoided and decisions are taken more objectively. The existing knowledge within the parent companies is crucial in all aspects of the technical and commercial activities. Knowledge sharing between the project team and the parent companies is crucial. However, working in an innovative joint venture project also poses some challenges.

The ROAD construction schedule is driven by both the MPP3 construction schedule and cost minimization. In order to avoid MPP3 outage penalties, the tie-in works have to be executed on-track. Both drivers led to the specific construction plan and the clustering of heavy lift components. Thanks to the clustering of heavy lift components the cost and project schedule can be squeezed significantly. After the lifting and placement of these major components the capture plant can be assembled. In a second phase the transport and storage works will become a point of attention.

The cooperation with the Global CCS Institute has proven instrumental in reaching the wider CCS community. ROAD has received valuable comments on draft Special Reports, all of which we believe today form an excellent bundle of practical information for setting-up a large scale CCS demonstration Project. ROAD is looking forward to continuing this cooperation in the future.

7. Abbreviations and references

7.1 Abbreviations

CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
EA&I	Economic Affairs, Agriculture & Innovation
EBL	Electrabel Nederland Project B.V.
EBX	E.ON Bennelux B.V.
EC	European Commission
EEPR	European Energy Programme for Recovery
EIA	Environmental Impact Assessment
EPC	Engineering, Procurement and Construction
EU	European Union
FA	Flow Assurance
FEED	Front-end Engineering and Design
FID	Final Investment Decision
GDR	Group Decision Room
Global CCS Institute	Global Carbon Capture and Storage Institute
HSE	Health, Safety and Environment
Institute	Global Carbon Capture and Storage Institute
MCP	Maasvlakte CCS Project C.V.
MEA	Monoethanolamine
MPP3	Maasvlakte Power Plant unit3 (E.ON)
MPs	Members of Parliament
NGO	Non Governmental Organization
OPEX	Operational Expenditure
RFI	Request For Information
RFP	Request For Proposal
ROAD	Rotterdam Opslag en Afvang Demonstratieproject

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