D08: Transport and Storage Economics of CCS Networks in the Netherlands: Analysis of international CCS business cases around the North Sea (Phase 2)

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Applicable Documents

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

1 Executive Summary

Project Rationale, Objectives and Organisation

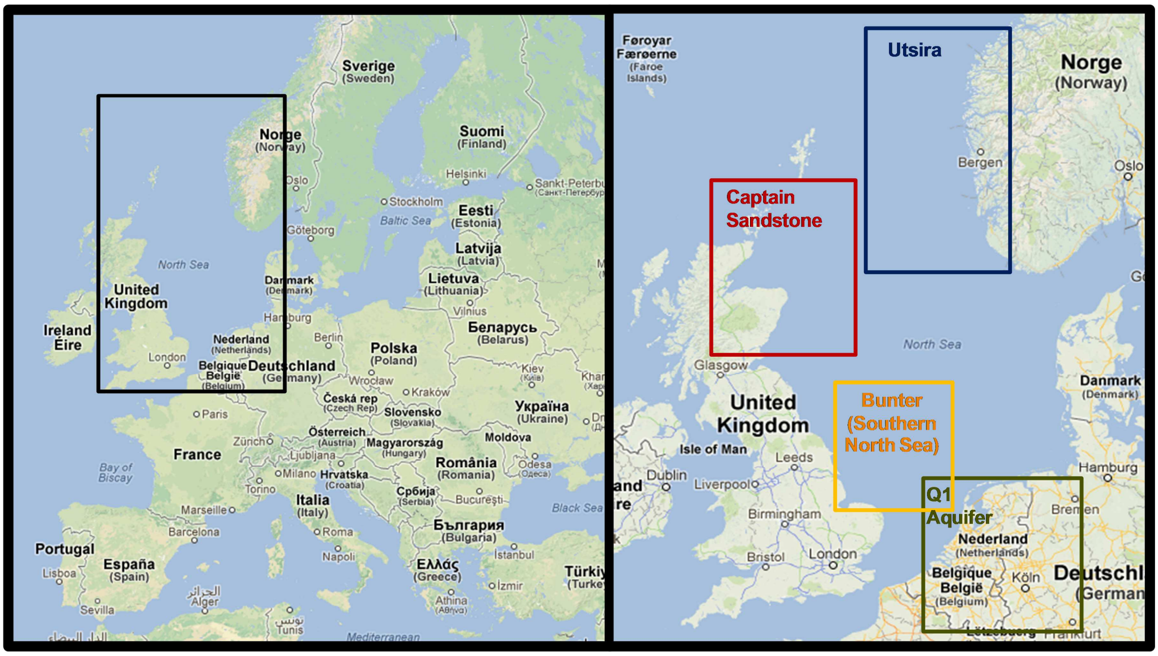
CCS has been identified as an important technology to achieve the ambitious emissions targets and low-carbon industrial growth plans in the Netherlands and the Flemish region in Belgium. The project landscape is taking shape and a number of large-scale demonstration projects and industry-led initiatives in the region are progressing towards a common user CO_2 transport and storage concept behind the belief that commercial deployment of CCS on a network basis would result in lower user costs, lower system redundancy and accelerated investment in capture facilities. These and other near term projects in other regions, however, are faced with urgent decisions on the design and technical specifications of their CO_2 offtake infrastructure. Given the incremental costs facing anchor projects in a network project relative to point to point solutions, there is significant potential for misalignment of projects currently under development relative to the requirement of future network systems.

A group of major emitters with the most advanced plans for CCS in the Netherlands and Belgium have formed a Steering Group to collectively evaluate and address common issues, including transport and storage. Following the completion of the Independent Storage Assessment in 2011, which identified the most appropriate CO2 offshore storage sites on the Dutch Continental Shelf, the Steering Group identified the need for an analytical framework to support the necessary strategic dialogue with one another, with transport and storage operators and public authorities on the costs and risks of pursuing alternative CO2 offtake pathways and the impact of near term technical design decisions on those issues. The resulting analysis was undertaken by a project team led by the Rotterdam Climate Initiative (RCI), consisting of the Clinton Climate Initiative (CCI), TNO Geosciences (TNO) and ECOFYS, between April and December 2012. The Steering Group provided regular input while certain transport and storage operators also provided guidance.

The primary objective was to provide members of the Steering Group with a planning tool, which would allow them to form a common view on the economics of alternative shared transport and storage options in the North Sea that could support large scale demonstration and early commercial projects in Rotterdam, Eemshaven and Antwerp on a network basis. This would also provide a basis for engaging with government and other key CCS stakeholders on the formulating regional and national plans to resolve current barriers to investment.

The project was completed in two phases, with the initial phase focused on offshore storage locations in the Dutch Continental Shelf and an EOR opportunity in Denmark most likely to support capture projects in the Netherlands in the short to medium term. Phase 2, which is the subject of this report, considered potential storage sites in the UK, Dutch and Norwegian North Sea in support of capture projects in the Netherlands and Antwerp in the medium to longer term.

Figure 1.1: Overview of Phase 2 Storage Locations



Phase 2 was organised in five key steps as follows:

1. *Definition of Transport & Storage Scenarios:* Determined the medium to long term CO_2 capture volumes from the Netherlands and Antwerp and identified four aquifer storage options in the North Sea likely to support these projects. Once the storage locations were identified, the project team developed possible transport routes, considering both shipping and pipeline transport modes.
2. *Data Collection:* Collected necessary technical input and basic cost assumptions for incorporation into a techno-economic model (ECCO tool) and calculated the capital and operating cost timeseries for each infrastructure component (e.g.: pipeline, ship, storage compartment). To the extent possible, the data was provided directly by the relevant project developers and complemented with publicly available information.
3. *Financial Modelling:* The financial valuation of each T&S scenario was done using a purpose-built financial model developed by CCI and incorporating the capital and operating cost timeseries produced by the ECCO tool as input. For each Transport & Storage scenario, the model provided total and unit costs, indicative tariffs charged to emitters for using the infrastructure and operator cash flows on an annual basis.
4. *Sensitivity Analysis:* Identified the most relevant cost drivers with a view to determine the lowest possible cost conditions within the existing set of T&S Scenarios. The cost drivers related primarily to CO_2 volumes/capture estimates and financing structure assumptions.
5. *Knowledge Sharing & Engagement:* The results of the modelling (base case and sensitivity analysis) were presented to the Steering Group over three Steering Group meetings between September and November 2012. In January 2013, the RCI organised a workshop to “hand over” the financial model to the Steering Group and determine the near term actions for the group, based on the conclusions, implications and strategic questions raised by the analysis.

Main Conclusions

In all, the analysis led to a better understanding of the relative costs and most important drivers of the offtake options modelled, including with regards to the choice of transport mode, the scale of infrastructure and the potential for under-utilisation, commercial and financing arrangements. The cost of the infrastructure and the range of tariffs on a per ton basis were also recognised by the Steering Group as broadly realistic. Furthermore, the financial model could serve as a starting point for a project application in the second round of the NER300 as it provides a benchmark on costs and could be adapted to reflect project specific assumptions.

The main conclusions of the project can be summarized as follows:

- Sharing transport and storage infrastructure is a cost effective approach for CCS
- Efficient utilisation of the infrastructure requires the coordination of earlier CO_2 capture projects and / or some visibility that a demo project can transition to full scale operations
- Storage costs are significantly reduced when CO_2 is injected close to the individual reservoir's maximum injectivity rates and therefore minimizing the operating period
- Assuming no existing infrastructure in place, the choice between a pipeline and a ship will depend on the required CO_2 throughput volumes and the transport distance
- While more favourable financing terms would lower the cost to individual user emitters, the proportionate impact differs by type of infrastructure, depending on the total CAPEX quantum (and associated debt service requirements) and the share of CAPEX in total costs

Next Steps

In January 2013, the RCI organised a Steering Group workshop to discuss the strategic issues raised by the analysis and determine possible near term actions to address them. One of the key points of the discussion related to the potential role of government and regulators to improve the currently challenging business case for CCS. Therefore it encourages Government to develop a plan and bring timing into the next steps. The Steering group suggests that Government should step in to the development of transport and storage with a vision. In short Government needs to give a signal: “CCS is going to grow. We lead and business has to follow”. Government should provide the missing investment signals by developing clear objectives for the technology in the national energy mix.

Specifically, the Steering Group highlighted a need for collaboration with government and other relevant authorities to:

- Ensure the transition from demonstration phase to commercial phase projects with appropriate planning of initial investments and oversized infrastructure
- Provide early mover projects with appropriate incentives to ensure the first projects are aligned to the future vision of CCS networks
- Develop the appropriate regulatory frameworks for transboundary transport and storage in the North Sea
- Mobilise other CCS stakeholders in the Netherlands with responsibilities to progress common user transport and storage

With regards to the key issues of ensuring storage and enabling shared transport, the Steering Group identified the following issues and next steps:

Ensuring Storage

- Progress CO_2 storage characterisation and feasibility studies for saline formations on the Dutch Continental Shelf to ensure a smooth transition from demonstration to commercial deployment of CCS
- Better understand the storage capacity elsewhere in the North Sea, based on work already done on mapping the storage potential in the UK and Norway
- Provide input into a review of the EU CCS Directive, particularly in relation to long term CO_2 containment and liability issues
- Develop an appropriate regulatory framework that will treat storage as an “asset”, including end of life policies for producing hydrocarbon field and “storage ready” certification
- Develop alternative business models for CO_2 storage, including for example public-private partnerships and service-based models

Enabling Shared Transport

- Issue of allocation of risk between early mover and future participants in a shared transport system
- Need to develop appropriate incentives for early mover projects as well as private public partnerships
- Issue of CO_2 specifications in shared transport networks
- Developing models for long term CO_2 transport regulation
- Enabling transboundary transport of CO_2, starting with the ratification of the London Protocol

Finally, the Steering Group recognised the scope and potential for further cooperation among CCS stakeholders in the Netherlands and the North Sea rim to develop a more coherent voice on critical issues and decided on the following next steps:

- Recommend the revival of the National Taskforce CCS in the Netherlands, a high level platform of public and private entities with a mandate to support Dutch CCS activities and accelerate the development of the technology
- Engage with potential transport and storage operators in the Netherlands and Belgium to further identify key issues and collaborate towards their resolution
- From a regional perspective, work more closely with the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) and the North Sea Basin Task Force (NSBTF)
- Strengthen formal dialogue with regional authorities in Rotterdam, the Eemshaven and Antwerp and support national level discussions with the European Commission

2 Introduction

From April to December 2012 a project team led by the Rotterdam Climate Initiative (RCI) and guided by a steering group of companies with the most advanced plans for Carbon Capture and Storage (CCS) in the Netherlands and Belgium, evaluated the economics of alternative transport and storage options in the North Sea on the basis of common user infrastructure.

This report outlines the project parameters, analytical approach, key findings and proposed next steps towards optimised, shared transport & storage infrastructure in the region.

2.1 Project Rationale

CCS has been identified as an important technology to achieve the ambitious emissions targets and low-carbon industrial growth plans in the Netherlands and more recently, by the Flemish Government and the Antwerp Port Authority[1].

A number of large-scale demonstration projects and industry-led initiatives in the region are advancing. With the support of the RCI, CCS demonstration projects in the Rotterdam area are progressing towards a common user CO_2 transport and storage concept that would see significant oversized infrastructure being developed as part of the solution. This is behind the belief that commercial deployment of CCS on a network basis would result in lower costs due to economies of scale, lower system redundancy and accelerated investment in capture facilities from the availability of established CO_2 offtake infrastructure.

These and other near term projects in other regions, however, are faced with urgent decisions on the design and technical specifications of their CO_2 offtake infrastructure. The key challenges for anchor projects in a network concept are the ability to reconcile the higher incremental investment costs in the short term with the operational benefits envisaged in the long term, as well as establishing appropriate commercial structures to support future users. There is, therefore, potential for misalignment of CCS projects currently under development relative to the requirement of future network systems.

The only way to address these challenges is through dialogue and cooperation between different stakeholders, including government and companies that may be natural competitors in their core business. In recognition of their shared interests in the development of CCS in the Netherlands and Belgium, a group of major emitters with the most progressed plans to pursue CCS in the near term have formed an emitter Steering Group with a view to collectively evaluate and address common issues. The Steering Group is comprised by E.ON, Electrabel, Air Liquide, Shell, Air Products, Essent (RWE) and the Antwerp Port Authority, coordinated by the RCI and supported by Stichting Borg (on behalf of the North Netherlands) and the Clinton Climate Initiative (CCI).

[1] The Rotterdam Climate Initiative aims to halve CO2 emissions by 2025, as compared to 1990 while the 2007 Energy Agreement in the North Netherlands foresees a reduction of up to 20MtCO2 per year by 2020. The Antwerp Port Authority aims to facilitate the development of the necessary CCUS infrastructure for transport and storage of CO2.

Over the course of 2010 and 2011, it participated in the Independent Storage Assessment (ISA) to identify appropriate CO_2 storage sites in the Dutch North Sea, resulting in a more comprehensive set of geological and technical cost data on depleted hydrocarbon fields and aquifers as well as detailed feasibility studies for the most promising near term sites. Building on the success of the ISA, the Steering Group has continued its collaboration to identify, articulate and evaluate the complex business case issues surrounding the development of a shared CO_2 transport and storage infrastructure in the medium and longer term. In early 2012, it identified the need for an analytical framework to support the necessary dialogue with one another, with transport and storage operators and government on the costs and risks of pursuing alternative CO_2 offtake pathways and the impact of near term technical and design decisions on those issues.

The resulting analysis was completed in two phases. Phase 1 focused on offshore storage locations in the Dutch Continental Shelf and an EOR opportunity in Denmark most likely to support capture projects in the Netherlands in the short to medium term. Phase 2, which is the subject of this report, considered potential storage sites in the UK, Dutch and Norwegian North Sea in support of capture projects in the Netherlands and Antwerp in the medium to longer term.

2.2 Project Objectives

The primary objective of this project is to provide the members of the Steering Group a “planning tool”, allowing them to form a common view of the economics and risks of a set of CO_2 transport and offshore storage initiatives supporting the first large-scale demonstration and early commercial scale projects in Rotterdam, Eemshaven and Antwerp on a shared basis, as well as possible financing structures for each. This will provide a basis for engaging with potential participants in a CCS network and with government and other key stakeholders on formulating a national or regional plan to address these complex issues.

Specific objectives are to:

- Produce commonly agreed costs for a set of CO_2 offtake scenarios in the North Sea and identify key cost drivers and their implications for development
- Support Steering Group members intending to apply for funding in the 2nd round of the NER300 by providing a benchmark on costs and help other members maintain positive forward momentum on potential medium-term capture plans
- Identify near term actions to ensure the feasibility and development of an optimal, shared transport and storage network for emitters in the Netherlands and Belgium
- Use the results of the analysis as a platform for dialogue with key stakeholders (including government and operators) as a means to quantify arguments independent of the interests of any single company
- Develop a publicly available financial model for use by other companies and regions considering CCS projects as a reference for possible tariff and financing structures, with their own cost data

2.3 Project Stakeholders, Responsibilities & Funding

The project required the coordinated engagement of a number of different parties and was organised on a similar basis to the Independent Storage Assessment. In short, the Project Team led by the RCI and consisting of CCI, TNO Geosciences (TNO) and ECOFYS, was responsible for developing the analytical framework and delivering the analysis. The Steering Group provided strategic direction and input on a continuous basis. In addition, the transport and storage operators relevant to the scenarios considered also provided guidance, primarily on technical specifications.

Through their participation in CATO-2, the Dutch scientific program for CCS, TNO and ECOFYS assembled and reviewed publicly available data on the technical parameters and costs for specific infrastructure components of each T&S scenario. The data was then inputted into ECCO (European Value Chain for CO_2), an excel-supported software developed in part by CATO-2 as a result of collaborative research under the EU 7th Framework Program (FP7) between 2009 and 2011. The ECCO tool integrates transport engineering and well / reservoir physics to estimate the post-tax economics and key performance indicators of CCS value chains, incorporating multiple CO_2 sources and sinks and macro-economic assumptions. For purposes of this project, the ECCO tool simply estimated the real, non-inflated capital and operating costs of individual chain units (pipelines, ships and storage compartments) over time for each transport and storage option.

CCI incorporated these cost estimates, as well as assumptions relating to project financing and tariff structures, into a purpose-built financial model to determine the overall costs and risk/reward profile for each T&S scenario. The key outputs of the model include unit costs, tariffs payable by each emitter and detailed operator cash flows and financial statements. In addition to the base case analysis, a set of sensitivities was also developed to evaluate the impact of specific parameters on cost, including the network build-out, utilization rates, financing mix and rates.

The members of the Steering Group and likely transport and storage operators, including the Port of Rotterdam and the CINTRA consortium, provided guidance on the scenario design, technical parameters and the ECCO tool cost estimates in one-to-one, confidential meetings.

The project was funded (partly in kind) by the RCI, Stichting Borg, Shell and CATO-2 in Phase 1, and by the RCI, the Global CCS Institute and the Antwerp Port Authority in Phase 2. An outline of the working partners and their responsibilities in this project are provided in
Table 2.1 below.

Table 2.1: Project Partners and Responsibilities

Name	Organisation & Rationale	Responsibilities

Project Team	▪ Deltalinqs, on behalf of the Rotterdam Climate Initiative (RCI) ▪ Clinton Climate Initiative (CCI), long standing advisor to the RCI ▪ TNO Geosciences (TNO) ▪ ECOFYS	▪ Overall Project coordination ▪ Compilation and delivery of Targeted Report and associated financial model ▪ Dissemination of key findings and coordination of knowledge sharing activities in collaboration with Global CCS Institute ▪ Data Collection and delivery of cost input to financial model ▪ Assistance in compilation of report and delivery of knowledge sharing workshops
Steering Group	▪ E.ON, Electrabel, Air Liquide, Shell, Air Products, Essent (RWE) ▪ Stichting Borg, representing the North Netherlands ▪ Antwerp Port Authority	▪ Rationale: The major emitters most committed to exploring the commercial implementation of CCS in the region and participants in ISA ▪ Input and strategic direction to the Delivery Team
Transport & Storage Operators (Participants)	▪ Port of Rotterdam, GdF Suez E&P, TAQA, CINTRA (VOPAK, Anthony Veder, Gasunie, Air Liquide), Chevron and Stedin	▪ Cost and technical data relating to transport and storage options under assessment ▪ Guidance on reasonable financial and contracting/commercial structure assumptions to be used in the model

More detailed information on the project partners and participants can be found in APPENDIX A: Project Team & Project Participants.

2.4 Key Steps in the Project

The project was organised in five key steps as follows:

1. *Definition of Transport & Storage Scenarios:* The Project Team, in close cooperation with the Steering Group, determined the medium to long term CO_2 capture volumes from the Netherlands and Antwerp and identified four aquifer storage options in the North Sea likely to support these projects (Phase 2). Once the storage locations were identified, the team developed possible transport routes, considering both shipping and pipeline transport modes. This resulted in 14 alternative CO_2 offtake options (Transport & Storage Scenarios or T&S Scenarios), reflecting different infrastructure configurations or CO_2 volumes and timing assumptions.

2. *Data Collection:* Once the T&S Scenarios were defined, the CATO-2 team collected the technical input and cost assumptions required by the ECCO tool for the calculation of the capital and operating cost timeseries for each infrastructure component (e.g.: pipeline, ship, storage compartment). To the extent possible, the data was provided directly by the relevant project developers and complemented with publicly available information.

3. *Financial Modelling:* The financial valuation of each T&S scenario was done using a purpose-built financial model developed by CCI and incorporating the capital and operating cost timeseries produced by the ECCO tool as input. This model provided the “base case” results for each T&S scenario, including total and unit costs, indicative transport and storage tariffs charged to emitters for using the infrastructure and operator cash flows on an annual basis.

4. Sensitivity Analysis: Building on the results of the financial modelling, the Project Team and Steering Group identified the most relevant cost drivers with a view to determine the lowest possible cost conditions within the existing set of T&S Scenarios. The cost drivers related primarily to CO_2 volumes/capture estimates and financing structure assumptions.

5. *Knowledge Sharing & Engagement:* The results of the modelling (base case and sensitivity analysis) were presented to the Steering Group over three Steering Group meetings between September and November 2012. In January 2013, the RCI organised a workshop to “hand over” the financial model to the Steering Group and determine the near term actions for the group, based on the conclusions, implications and strategic questions raised by the analysis.

2.5 Key Takeaways from Phase 1

As mentioned earlier, the initial phase of the analysis focused on a set of CO_2 transport and offshore storage initiatives that could realistically support capture projects in Rotterdam and the North Netherlands in the short (2015) to medium term (2020) on a shared basis. It included a total of 29 Transport & Storage scenarios relating to two offshore storage sites in the Dutch Continental Shelf (P18/P15 depleted gas field and Q1 aquifer) as well as an EOR opportunity in Denmark (Dan Oilfield).

These scenarios were designed to determine the relative cost impact of different development pathways for each storage option, focusing primarily on the issue of oversizing transport infrastructure and the timing of participation of different emitters in the network. Reassuringly, the results validated the expected relationship of cost drivers such as utilisation rates, injectivity, operating life and financing terms on user tariffs.

The broad conclusions of Phase 1 are that:

- Sharing transport and storage infrastructure is a cost effective approach for CCS in the Netherlands
- Efficient utilisation of the infrastructure requires the coordination of earlier CO_2 capture projects and/or some visibility that a demo project can transition to full scale project
  - For example, starting with an anchor demo project and a (5x) oversized offshore pipeline to the storage site we considered the gradual roll out of the onshore collection network as additional emitters come online. While the results were not necessarily linear, the analysis indicated that a 1.2x increase in average annual CO_2 throughput would lead to a ~70% reduction in pipeline costs and ~20% reduction in storage costs for the first anchor project.
- Storage costs can be significantly reduced by injecting CO_2 close to the individual reservoir’s maximum injectivity rates. This would also minimize the operating period and associated operating & maintenance costs.
  - However, it is important to note that as the volume stored in the reservoir nears the total capacity, the pressure in the reservoir will rise. This also has the effect of lowering reservoir injectivity. Therefore, making use of the available reservoir capacity at the least cost requires careful

coordination of the injection activity and the CO_2 volumes directed to the storage site.

- MMV costs during injection and for 20 years prior to complete abandonment (in accordance with the EU CCS Directive) can contribute between 4-13% of total costs to the emitters, depending on the project timeframe.
    - Extending the MMV period from the end of the injection operations to complete abandonment, would effectively delay abandonment (which can account for up to 50% total capital costs). The further into the future the end of injection operations, the lower the impact of MMV on total costs on a net present value basis.
- While more favourable financing terms would lower the cost to individual user emitters, the proportionate impact differs by type of infrastructure, depending on the total quantum of capital costs (and associated debt service requirements) and the share of CAPEX in total costs.
    - With regards to transport, offshore pipelines appear most sensitive, followed by onshore pipelines and shipping. Storage costs appears the least sensitive to changing construction financing terms as the majority are operating as opposed to capital costs.

3 Methodology

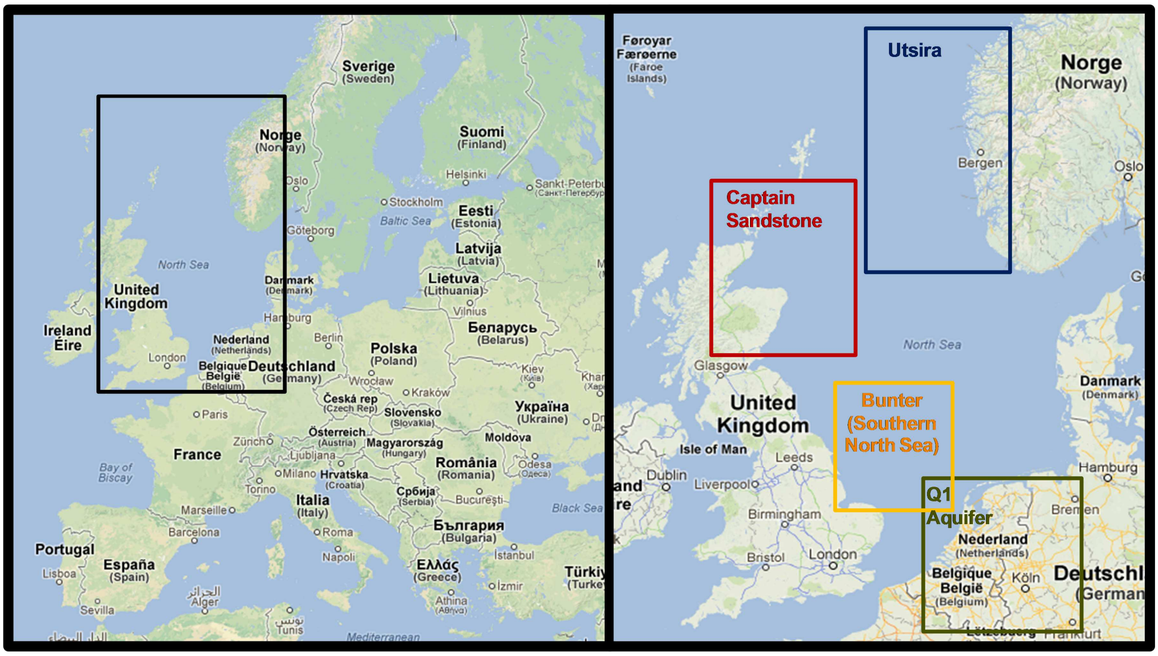
3.1 Scenario Definition

The scope of the analysis in both phases was limited to offshore storage locations and the selection of specific sites was driven both by current CCS project developments as well as the results of recent screening studies and detailed characterization work on offshore depleting hydrocarbon fields and saline formations in the North Sea.

As mentioned in the previous chapter, Phase 1 considered 29 Transport & Storage scenarios likely to support capture projects in the Rotterdam and the Eemshaven (North Netherlands) in the short (2015+) to medium term. These were based on two storage sites in the Dutch Continental Shelf (P18/P15 depleted gas field and Q1 aquifer) and an EOR opportunity in Denmark (Dan Oilfield).

In Phase 2, the focus shifted towards the medium (2020+) to long term capture projects in the Netherlands and Antwerp and the analysis considers four transboundary storage sites in the North Sea. These are the Bunter formation in the Southern North Sea (UK), the Captain Sandstone reservoir below Moray Firth (UK), the Utsira formation (Norway) and the Q1 aquifer (Netherlands).

Figure 3.1: Overview of Phase 2 Storage Locations



For each of the storage locations, the analysis incorporated a number of CO_2 capture scenarios for Rotterdam, Eemshaven and Antwerp, varying the total CO_2 volumes and timing of individual emitters' participation into the offtake system.
In contrast to previous studies, the growth curve of CO_2 available for storage was developed based on individual emitter members' medium term plans for CCS, rather than higher level emission reduction targets for each region. The CO_2 volumes from Antwerp are assumed to be either exported to the Netherlands via Rotterdam or

delivered directly to a storage location. In addition, the T&S scenarios relating to the Norwegian and UK storage sites consider the potential to share some of the CO_2 capacity in the onshore and offshore infrastructure with other emitters in the North Sea rim. For simplicity, there is only one measure of CO_2 volume, i.e.: no distinction was made between reserved capacity and throughput for individual emitters.

With regards to transport, the analysis considered a combination of onshore and offshore steel pipeline systems and shipping. The choice of transport mode was based primarily on knowledge of existing infrastructure and plans already underway in support of the first large scale demonstration projects in the Netherlands and the UK. In the case of the offshore routes not yet part of any specific project plans, TNO and ECOFYS performed a preliminary screening of the relative costs of pipeline vs. shipping to identify the most cost-effective alternative, given the CO_2 volumes, life of operations and transport distance. In some cases, where the assessment concluded that the cost differences were marginal, we chose to model both alternatives. Please refer to APPENDIX B: Analysis Supporting the Choice of Transport Mode for the UK Scenarios for a more detailed explanation.

In all, Phase 2 resulted in 14 Transport & Storage Scenarios, which are explained in more detail in the next chapter. Table 3.2 below provides an overview of all Phase 1 and Phase 2 scenarios.

Table 3.2: Overview of Phase 1 and Phase 2 Transport and Storage Scenarios

	Storage	Type & Capacity	Offshore Transport	CO_2 Sources	Rationale
Phase 1	P18 / P15 (NL)	Dep. Gas Field ~79MtCO_2	Pipeline	Rotterdam	Under consideration by the ROAD and Green Hydrogen projects in the Netherlands
Phase 1	Q1 (NL)	Aquifer ~200MtCO_2	Pipeline Shipping	Rotterdam Eemshaven	Most promising medium term site in the Dutch Continental Shelf as per ISA Phase 3 and EBN/ Gasunie
Phase 1	Dan Oilfield EOR (D)	Dep. Oil Field	Shipping	Rotterdam Eemshaven	Under consideration by the Green Hydrogen project in the Netherlands
Phase 2	Q1 (NL)	Aquifer ~200MtCO_2	Pipeline Shipping	Rotterdam FS Eemshaven Antwerp	Most promising medium term site in the Dutch Continental Shelf as per ISA Phase 3 and EBN/ Gasunie
Phase 2	South North Sea Aquifer (UK)	Aquifer [>2000MtCO2]	Pipeline Shipping	Rotterdam FS Antwerp	Likely storage option for future CCS projects in the Yorkshire & Humber area
Phase 2	Captain Sandstone Aquifer (UK)	Aquifer [>360MtCO_2]	Shipping Pipeline	Rotterdam FS Antwerp Eemshaven FS	Identified as one of the most promising CO_2 storage sites in the Northern North Sea by CCS stakeholders in Scotland
Phase 2	Utsira Sandstone (NO)	Aquifer [>20Gt]	Shipping	Eemshaven FS	Currently used for storage of CO_2 separated from natural gas produced at the Sleipner field

3.2 Cost Preparation Approach & Key Assumptions

With the T&S Scenarios in place, the TNO and ECOFYS collected the technical input and cost assumptions required by the ECCO tool and provided the capital and operating cost timeseries for each infrastructure component of the 14 Transport & Storage Scenarios. This included information on the geophysics of a specific storage site, the properties of any existing well or platform infrastructure, pipeline routes, compression requirements, ship terminals etc. The costs were broken down into capital costs for construction and abandonment as well as fixed and variable operating costs.

In addition to the proprietary information with the ECCO tool, the following public data sources were used:

- Phase 3 Independent CO_2 Storage Assessment (undertaken by TNO on behalf of the Steering Group in 2011. Public version of the report is also available on the Global CCS Institute website)
- Zero Emissions Platform (ZEP) report on storage cost items (summer 2011)
- TEBODIN, 2009, “Potential for CO_2 storage in depleted fields on the Dutch Continental Shelf” – cost estimate for offshore facilities
- EBN-Gasunie, 2010, “CO_2 transport-en opslagstrategie” (CO_2 transport and storage strategy)

The section that follows outlines the analytical approach and key assumptions by module – storage, pipelines and ships – as well as the general macro assumptions affecting all cost estimates.

3.2.1 ECCO Tool Assumptions Relating to Storage

To develop the cost timeseries for the storage modules, the CATO-2 team determined both the technical parameters of the storage site as well as the cost estimates, based on the CO_2 volumes injected in each T&S Scenario. Figure 3.3 below outlines the breakdown of technical inputs, capital and operating cost assumptions made for each scenario, while Table 3.4 provides a value for each.

Figure 3.3: ECCO tool Storage Module Structure (Inputs & Outputs)

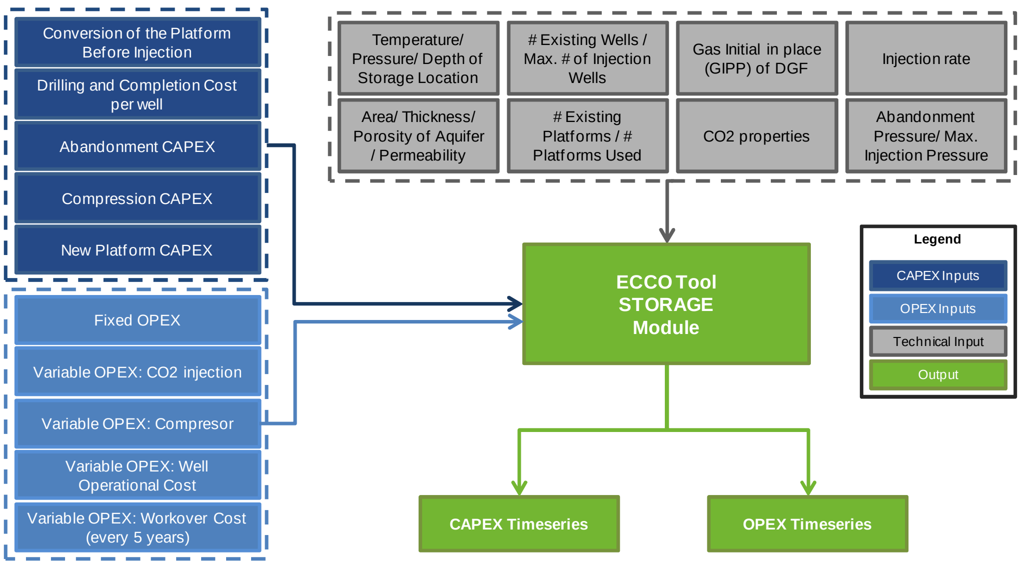


Table 3.4: ECCO tool Storage Module CAPEX and OPEX Assumptions

	Value	Reference
CAPEX		
Conversion of the platform before injection	10.6 €m	EBN/Gasunie report (2010) EBN/Tebodin report (2008)
Drilling and completion cost per well	18.53 €m	EBN/Gasunie report (2010)
Abandonment CAPEX (2 years after close in)	15.9 €m	RCI-ISA Phase 3 2012
Compressor CAPEX per unit (maximum 3 units)	1.0 €m	RCI-ISA Phase 3 2012
OPEX		
Fixed OPEX	10.6 €m	EBN/Gasunie report (2010) EBN/Tebodin report (2008)
Variable - CO_2 injection	€1.51/tCO_2	RCI-ISA Phase 3 2012
Variable – Compressor*	€0.07-0.13/tCO2	RCI-ISA Phase 3 2012
Variable - Well Operational Cost	0.3 €m/well/y	RCI-ISA Phase 3 2012
Variable - Workover Cost (every 5 years)	0.8 €m/well/y	RCI-ISA Phase 3 2012
Measurement, Monitoring & Verification (MMV)		
MMV during injection	2.83 €m/y	ZEP Report 2011
MMV post injection (Pre-Abandonment)	0.28 €m/y	ZEP Report 2011

* Variable compressor cost depends on the electricity price, which is given in Figure 3.9 and varies between €51-92/MWh.

In addition to the cost items mentioned above, the ECCO tool incorporated the following assumptions:

- CAPEX before injection consists of conversion of the platform (retrofitting of existing gas production platform). The value is based on the EBN/Gasunie report (2010). This report also refers to cost elements that are based on the EBN/Tebodin report (2008).
- The value of drillex (drilling expenditure, i.e. the cost of drilling a new well) is based on the EBN/Gasunie report (2010).
- In this study it is assumed that the oil production platforms of Q1 can be used for CO_2 injection. Mothballing of oil production platforms, from end of oil production until start of CO_2 injection, is not taken into account as a cost item. It is currently unknown when Q1 oil field will be at the end of their field life. Furthermore, it is very well possible that at the existing platforms tail-end oil will be produced simultaneously with CO_2 injection (i.e. oil production from a particular reservoir compartment, CO_2 injection into a different compartment or EOR), obviating the need for mothballing.
- The physical properties (which are listed in Figure 3.3) of the Q1 aquifer are based on an earlier TNO report (Vandeweijer et al, 2011). The storage potential of Q1 is about 200Mton and a permeability of approximately 1000mDarcy
- There are a number of gas fields and aquifers in the Bunter formation (Southern North Sea, UK) which could be used for CO_2 storage. The physical properties of the SNS aquifer in the Bunter sandstone are taken from the public available report (Bentham, 2006). The typical size of the aquifer is about 2000Mton with a permeability of approximately 700mDarcy.
- The Captain Sandstone formation has a permeability of approximately 2000 mDarcy and a storage capacity between 360Mton and 1700Mton depending on the injection strategy (Progressing Scotland's CO_2 storage opportunities report, 2011).

- The well design properties are mostly unknown and a default value of a maximum injection rate of 3.5Mton/y is used. However in the Captain Sandstone formation a maximum injection rate of 2.5Mton/y was used, which is consistent with previous ECCO tool modelling (Progressing Scotland's CO_2 storage opportunities report, 2011).

3.2.2 ECCO Tool Assumptions Relating to Transport (Pipelines and Ships)

With regards to transport costs, the main difference between the ship and pipeline modules lies in the split of costs between capital and operating expenditure. Typically, capital investments for the ship transport value chain are lower than for equivalent pipelines, while operational costs are higher. The two transport modes also perform differently depending on the transport distance and volume. Pipeline costs increase considerably with transport distance, while ship transport costs are less sensitive to this variable. Ships can be more cost efficient at long distances and shorter operational timeframes (e.g.: smaller storage reservoirs) or intermittent CO_2 supply.

Although these are general trends, the case specific costs of the infrastructure depend strongly on the cost assumptions. It is thus important to review these assumptions to allow for proper interpretation of the final results. In this section we present some general assumptions made for both transport modes, followed by a more detailed description of the cost assumptions for each module.

3.2.2.1 General Transport Module Assumptions

- All scenarios assume new built infrastructure only; no existing infrastructure is used for CO_2 transport
- Construction period assumed to be one year prior to operations
- CAPEX calculations are based on Reserved Capacity, while OPEX is based on throughput CO_2 volumes
- Compression of CO_2 from power plants is assumed to take place on site of the emitter
- For industrial emitters, compression is performed in a centralized "hub" (as part of transport, with costs shared across users)
- No additional compression is assumed to be needed at the liquefaction plant for the shipping option
- In shipping to storage, shipping costs include loading and unloading terminals and buffering
- Minimum capacity of a sea-going vessel is assumed to be 30,000m3 (approximately 4.5MtCO2/yr in the North Sea)

3.2.2.2 *Pipeline*

Pipeline transport costs are determined by the following key cost factors:

- Pipeline routing: determines the length of the pipeline and whether it is routed onshore or offshore;
- Diameter, material and wall thickness: depending on the volume to be transported and the required pressure the model calculates the optimal diameter and wall thickness to secure safe operation;
- Terrain covered by pipeline: Terrain factors are used to allow for cost inflation due to complex terrain conditions. Heavy industrialised and densely populated areas have typical higher capital investments for pipelines. Costs increase in heavily urbanized areas because of accessibility to construction and additional required safety measures. Complex terrain conditions like hilly areas and soggy or unstable soil may also increase the investment costs considerably;
- Art works, crossings and any umbilical control: specific cost factors are included for land fall and for art works if a pipeline crosses existing infrastructure. The amount and type of art works can be varied by the user. Costs for art works can go up to €4-8 million per artwork. Cost of land fall (onshore to offshore crossing or vice versa) also significantly adds to the total capital investments at about €7 million per crossing. The crossing of waterways/shipping lanes is also included.

Based on these variables the model calculates the capital investments and the annual operation and maintenance cost broken down into the following line items:

- Material costs (steel cost): the diameter and wall thickness determine the amount of steel used which together with a steel price yields steel costs;
- Labour cost (installation costs): a fixed per km price is assumed for the cost of labour;
- Construction costs (material/equipment costs and installation costs);
- Other costs: e.g. design and engineering, project management, regulatory filing fees, insurance costs, and right-of-way costs are assumed to be covered within a fixed cost factor per km pipeline;
- Art works, crossings and any umbilical control;
- Offshore capital includes specific requirements for offshore pipelines: capital costs cover platform tie in, shallow installation, heavy lift, dredging, marine survey, transportation, umbilicals and additional material requirements (coating/concrete). The costs are included as one cost factor amounting to €0.95m/km. An exception is the offshore platform tie-in which is specified as a length-independent capital investment of €16 million;
- Operation and maintenance costs (monitoring, operation, maintenance): the O&M costs are broken down into fixed costs and variable costs. The fixed costs are expressed as an annual % of capital investments (0.25%) which should be added to variable cost of €0.3/tCO_2.

Figure 3.5: ECCO tool Pipeline Module Structure (Inputs & Outputs)

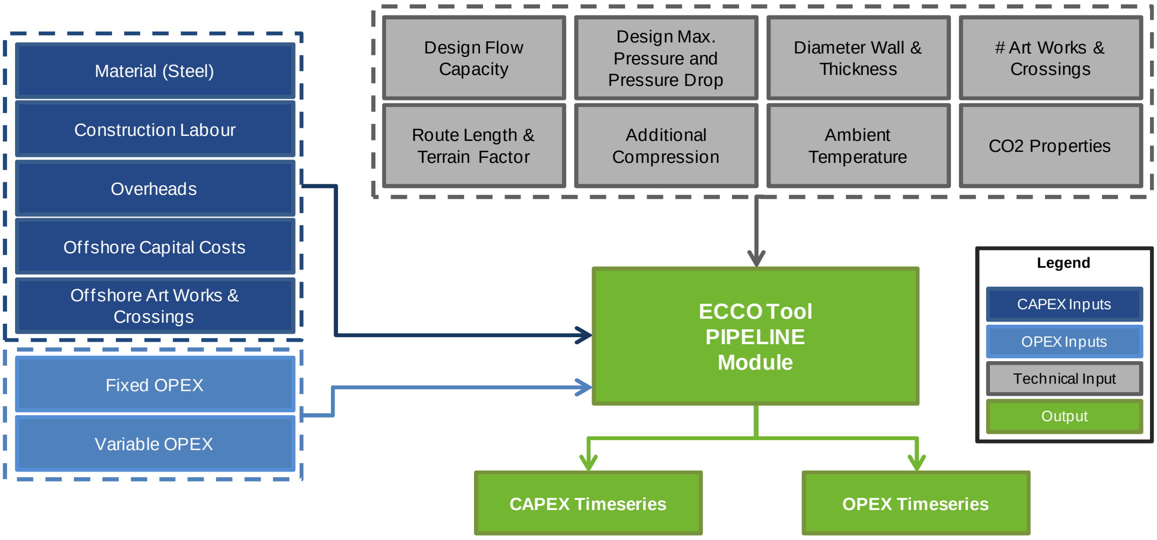


Table 3.6: ECCO tool Pipeline Module CAPEX and OPEX Assumptions

	Value	Reference
CAPEX		
Materials –steel	$\pi * L * t * (D - t) * \rho * Pr$	L=Length t=wall thickness D= pipeline diameter (outer) ρ = steel density (7850 kg/m^3) Pr =steel price (600 €/tCO_2)
Labour	0.120 €m /km	ECCO 2011
Overheads	0.102 €m /km	ECCO 2011
Offshore Capital	0.95 €m /km	ECCO 2011, adapted based on NOGEPA 2008/2009
Offshore infrastructure crossing	4-8 €m	NOGEPA 2008/2009
Offshore waterway crossing	11-16 €m	NOGEPA 2008/2009
Land fall	7 €m	NOGEPA 2008/2009
OPEX		
Fixed OPEX	0.25% of CAPEX	ZEP 2011;ECCO 2011
Variable OPEX	0.29 €/tCO_2	ZEP 2011; ECCO 2011

The model uses a terrain factor to inflate capital investments, as published in ECCO 2011. Special assumptions have been made for the onshore pipelines that route through the industrialized Rotterdam area. The terrain factor for the Rotterdam area has been adjusted to a 4, which results in cost inflation of the pipeline capital investments for labour and overheads by a factor of 4 (see Figure 3.5). Compression capital and energy costs are excluded.

The unit costs (€/tCO2) for pipeline transport as calculated by the ECCO tool were also independently validated using a model developed by the University of Utrecht. The differences between the two models were marginal and the ECCO tool figures are assumed to be reasonable.

3.2.2.3 Ship

Ship transport of CO_2 requires different infrastructure regarding the preparation (compression and liquefaction) loading and unloading (including intermediate storage) of CO2, relative to pipelines. As mentioned earlier, ship transport also has a different cost structure (capital and operating cost) compared to pipeline transport, with the most important elements of the ship value chain being liquefaction and gas conditioning, intermediate storage and loading, ship transport and offshore/onshore unloading (in- or excluding intermediate storage).

Costs of a ship based system comprise investment costs for liquefaction, intermediate storage, ship loading and unloading system. Further costs are for operation (e.g. labour, ship fuel costs, energy costs, harbour fees) and maintenance. Important variables that influence the specific transport cost are the distance from source (harbour) to sink (or harbour), site specific injection characteristics, transported volume & ship capacity. In this study, shipping economics are broken down into capital investments (liquefaction, loading and discharge terminal with optional intermediate storage) and operation and maintenance cost (ship lease cost, fixed and variable liquefaction cost, shipping fuel cost, port fees, CO_2 processing cost and fixed OPEX for loading, unloading and intermediate storage). The cost items are discussed in more detail in Table 3.8 below.

Figure 3.7: ECCO tool Ship Module Structure (Inputs & Outputs)

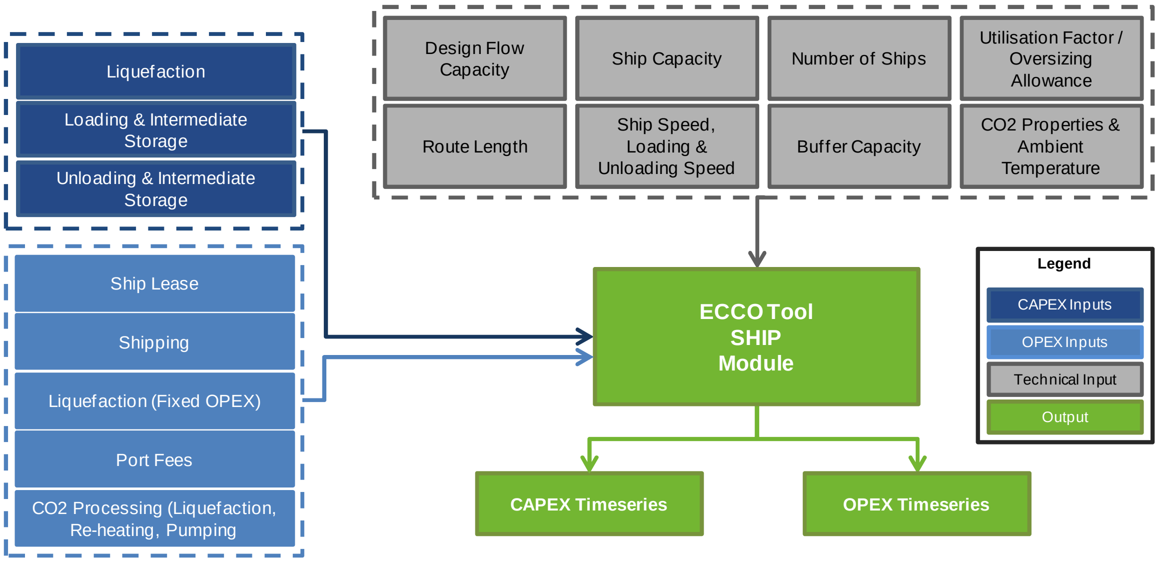


Table 3.8: ECCO tool Ship Module CAPEX and OPEX Assumptions

	Value	Reference
CAPEX		
Liquefaction (excl compression)	2-11 €m	ECCO 2011; updated based on SC 2012
Loading terminal	3-24 €m	ECCO 2011; updated based on SC 2012
Discharge terminal*	12-30 €m	ECCO 2011; updated based on SC 2012; Nardon 2010

Discharge intermediate storage	12 €m	SC 2012
OPEX		
Ship(s) lease: barge / see going vessel	5/15 €m/y	(6000 m^3 / 30000m^3) ECCO 2011 updated
Shipping fuel: barge / see going vessel**	53/97 MJ/ tCO_2 0.11-0.17 €/ tCO_2/ 0.20-0.31 €/ tCO_2	ECCO 2011 updated with Nardon 2011 and SC 2012
Liquefaction fixed O&M	5% of Cap. invest	ECCO 2011
Port fees	1.3 € /tCO_2	Nardon 2011
CO_2 processing (liquefaction, reheating, pumping)	162 MJ/tCO_2 0.34-0.53 €/ tCO_2	ECCO 2011

*Discharge terminal is only included in the case of inland transport and when transporting to Q1 storage reservoir.

**Assumes the energy content of Fuel oil is 41Gj and the price varies between €85.7-133.08 per ton

3.2.2.4 Liquefaction

The optimum CO_2 phase for shipping is found to be the liquid phase in which the density is sufficiently high and the transport conditions could be maintained constant without requiring too costly materials and insulations. The most likely options that remain are the fully pressurized vessels and the semi-pressurized/semi-refrigerated vessels in which the CO_2 is transported at approximately minus 55°C and 6.5 bars. Ship transport requires the energy intensive liquefaction of CO_2 which entails the compression, purification and cooling of the CO2. In the cost estimates the CO_2 is assumed to enter the liquefaction plant already pressurized. The cost of compression is thus not included in the presented estimates. The liquefaction cost estimates are presented in Table 3.8.

3.2.2.5 Loading and discharge terminal & intermediate storage

The capital investment for a loading terminal is based on cost estimates for a terminal that can handle 3 barges and one sea vessel. It is assumed that the terminal can accommodate various sizes of ships and barges ranging from 5kton to a seagoing vessel of 50kton, with a total simultaneous handling capacity of 65kton. The cost of the terminal is approximately €32 million, including loading system and infrastructure. In the case of port to port ship transport, the cost of the discharge terminal is assumed to be equivalent to the loading terminal. However, in the case of ship transport from port to offshore storage site, capital costs for the discharge terminal are assumed to be fixed at €30 million (Nardon, 2010).

A key stage of the shipping value chain is intermediate storage as the capture process of carbon dioxide is (semi)continuous whereas the cycle of ship transport is a discrete process. Multiple intermediate storage tanks would be required depending on the amount and capacity of ships utilized in the project or network. Typically the intermediate storage capacity needs to be one and one and half times the capacity of the used ship to allow for operational margins (Nardon, 2010).

The optimum capacity of intermediate storage tanks is determined by the cost of high tensile steel versus the capacity, as the wall thickness (and thus steel requirement) is proportional to the tank diameter and storage pressure. Here we assume a (configuration of) storage tank capacity of 10 kt with capital investments of approximately €12 million per tank (source: SC 2012).

3.2.2.6 Operation and Maintenance

Operation and maintenance cost are dominated by ship leasing cost. The ships leasing cost depends on the size of the vessel leased and the number of vessels leased. The number of vessels is determined by the distance, transport volume, ship size, utilization factor, load and discharge duration and the ship speed. For this project, ECCO tool estimates were adapted, based on feedback with certain project developers.

The cost of energy is calculated within the model and energy prices from the central scenario are used to calculate the annual OPEX based on actual transported volume. Compression capital and energy costs are excluded.

3.2.3 Key Macroeconomic Assumptions

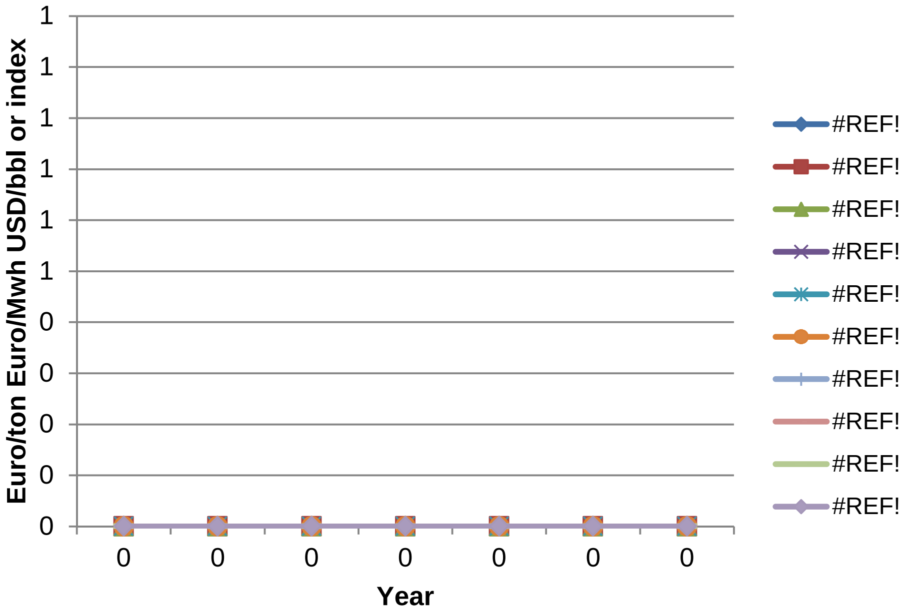
As part of the ECCO project, a number of macro-economic scenarios were developed to forecast future fuel prices, carbon prices, consumer price indices and other variables. These macro scenarios are based on assumptions relating to:

1. The degree of the influence of EU: the level of action set forth by EU regarding regulations for combating climate change.
2. The degree of globalization: the level of coordinated worldwide efforts against climate change.
3. Economic growth: global economic changes.
4. Fuel availability: a combined measure referring to high fuel consumption and low fuel price ('high' fuel availability means high fuel consumption and/or low fuel price; 'low' fuel availability means low fuel consumption and/or high fuel price).
5. The degree of environmental changes: level of CO_2 emissions, weather changes, pollution and smog, etc.

For each of the five drivers, the ECCO tool estimates the situation in 2040 as well as the pathway from 2010 and the particular combination of low or high degree of these drivers determines the overall macroeconomic scenario. There are 6 macroeconomic scenarios in total, named "Happy Planet", "EU Stands Alone", "Weak EU", "We Told You So", "Competition" and "New Energy Policy".

For purposes of this analysis, the 'Happy Planet' scenario was assumed, based on the CATO-2 team expectation of the future trends. The key indices are presented in Figure 3.9 below.

Figure 3.9: ECCO tool "Happy Planet" Macroeconomic Scenario Indices and Trends



Name	Description	Unit
OILCRUDE	Crude oil sales price (FOB)	USD/bbl
CO_2QUOTA	CO_2 Quota/CO_2 EU Allowance price	EUR/tonne
ELECWS	Wholesale Electricity price	EUR/MWh
GASNATURAL	Natural Gas sales price at wellhead	EUR/MWh
STEEL	Steel price	EUR/tonne
FUELOIL	Fuel oil price at fuel station	EUR/tonne
ELECCONS	Consumer Electricity price (at place of consumption)	EUR/MWh
FUELOILi	Fuel oil price index	index
MODi	Money-of-the-day / Nominal index	Index

More information on the ECCO modelling can be found in APPENDIX B: ADDITIONAL INFORMATION ON THE ECCO TOOL.

3.3 Financial Model

3.3.1 Basic Structure

The financial valuation of each scenario was done based on a Discounted Cash Flow (DCF) method, incorporating the capital and operating cost data provided by the ECCO tool along with assumptions on financing structures and some macroeconomic variables.

The model follows a "bottom up" structure in that it integrates the cost projections for each chain unit in a scenario, i.e. an individual pipeline, ship or storage compartment, and then aggregates the individual chain units into operators. This aggregation is largely a modelling simplification but was guided by the ownership arrangements most likely to develop in the Netherlands and the UK in the next five years.

The model then estimates the future cash flows of individual operators for the particular Transport & Storage scenario (i.e.: a particular set of user emitters, total CO_2 volumes, storage option and transport mode) on an annual basis, given the total costs and assumptions including the operator's capital structure, weighted average cost of capital (WACC), capital cost depreciation schedule and more general macroeconomic indicators.

Finally, using a modified IRR approach, discounting the operator cash flows at WACC, it solves for a price or emitter tariff applicable to each CO_2 emitter in the scenario. The model allows for two types of tariffs, reflecting the fee structure most likely to be applied to CO_2 transport and storage:

1. The "availability" tariff is a "take or pay" fee that ensures the capacity in the pipeline/ship/storage site for each emitter and should cover the operator's fixed costs. It is calculated based on each emitter's reserved capacity in each chain unit and would be payable regardless of whether any CO_2 is ultimately transported or stored

2. The "per tCO_2 transported/stored" tariff is calculated based on each emitter's CO_2 throughput (i.e.: CO_2 volume actually in the system) and is intended to cover the operator's variable costs, such as energy use, compression etc.

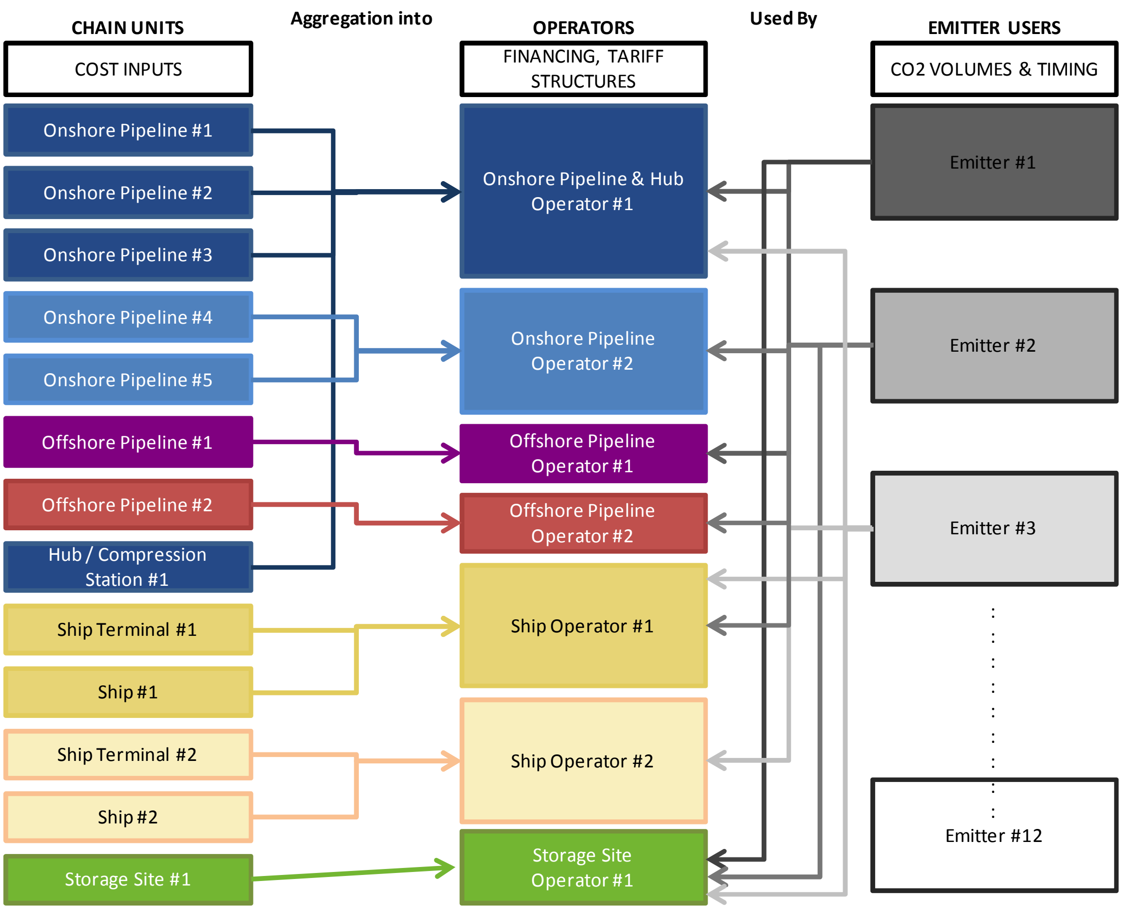
The model outputs consider three perspectives, appropriate for different users of the tool:

1. CO_2 Emitter: Summary of the tariffs payable by each emitter to each operator, given the CO_2 capture volumes and timing, total infrastructure costs and operator capital structure and target returns. Annual, total over the lifetime of the scenario and per ton of CO_2 reserved capacity or throughput tariffs.

2. Transport and Storage Operators: Separate detailed, financial statements (P&L and Cash Flow) for each of the storage, pipeline and shipping operators in the active scenario, showing the achieved rate of return. Capital structure assumptions are modelled at this level.

3. Scenario: Total CAPEX and OPEX for each scenario, presented also on a per ton of CO_2 transported or stored basis.

Figure 3.10: Basic Structure of the Financial Model



3.3.2 Key Assumptions

3.3.2.1 General

The model operates on a fully nominal basis and the cash flows are calculated annually. As mentioned earlier, the cash flows consider all costs, financial obligations (including debt servicing) and revenues for the specific transport and storage operator. The costs relating to CO_2 liabilities have not been considered in this analysis due to the uncertainties in their final regulation and pricing. Positive cash flows are available for distribution to equity investors (assumed to be the operator / owner) and therefore in this analysis, the IRR corresponds to the operator's project return on equity. The IRR is calculated using a "modified IRR" approach to take into account differences in the timing of the reinvestment periods between scenarios and the WACC relative to target returns.

In the base case, the model assumes a construction period of one year for all types of infrastructure (e.g.: pipeline, ship, storage site) and individual chain unit operating lifetimes as specified in each scenario by the timing of the user emitters. In the case of storage, the model also allows for Monitoring, Measurement and Verification (MMV) during the life of injection and for a user-specified, post injection period. Proper abandonment of the storage site post injection is assumed to take place over one year and the timing of abandonment is dependent on the post-injection (and pre-abandonment) MMV duration.

The model assumes a straight-line depreciation method for all capital costs and in the base case, full depreciation (i.e.: no salvage value) during the operating life of the specific operator level pipeline, ship or storage site. The tax calculation is based on (positive) EBIT and does not take consider any losses carried forward or other potential tax incentives. Along with the depreciation treatment, this is likely to prove a conservative assumption.

As explained in more detail in the previous chapter, the cost calculations within the ECCO tool take into account certain price forecasts, including fuel prices, based on a “happy planet” scenario. The basis for all costs is assumed to be year 2011 and all cash flows are inflated (in the financial model) at local Consumer Price Index (CPI). Other macro assumptions used in the analysis include the following:

Table 3.11: Summary Other Macro Assumptions

Inflation Rate	2.5%
Tax Rate	25%
Risk Free Rate	1.50% (10 yr Netherlands bond)

Source: www.tradingeconomics.com; www.taxrates.cc

3.3.2.2 *Financing Assumptions*

With regards to financing, the model allows users to optimize the cost of finance for each type of transport and storage, reflecting differences in individual business models and risk profiles. In the base case, it is assumed that there is no government funding and that transport operators are likely to secure higher leverage and more favourable overall financing terms than storage operators, as the lower risk nature of CO_2 transport make pipelines and ships a more conventional proposition for private sector investors. The assumptions relating to the amount of leverage each component of the chain would be able to source and the cost of capital were arrived at based on CCI’s discussions with a number of financial institutions and project sponsors on the conditions for private sector financing of large scale integrated CCS projects in Europe and Australia. For simplicity, the model does not take into consideration any transaction costs or fees relating to sourcing financing.

Any debt drawn during construction is assumed to be fully repaid within the tenor, with the first instalment due in the first year of operations. Finally, during the life of the operations, it is assumed that any negative net cash flows will be absorbed by the equity holders (operator owners).

Table 3.12: Base Case Financing Scenarios (All Chain Units)

	Pipelines	Shipping	Storage
Total Leverage	70%	70%	60%
Debt Rate	6.00%	6.00%	6.00%
Debt Tenor	15 years	15 years	15 years
Return on Equity (IRR)	10.00%	10.00%	13.00%
WACC	6.15%	6.15%	7.90%

Source: CCI analysis, based on discussions with financial institutions and project sponsors

3.3.2.3 *Areas of Flexibility*

One of the key objectives of this purpose-built model was to ensure the analysis can be adapted to specific projects, for example in support of second round NER300 funding applications, or other regions interested in developing a business plan for a CCS network.

To this end, the model has the flexibility to:

1. Define separate financing scenarios for each type of operator (i.e.: storage, pipeline, shipping), with a choice of financing instruments including debt, equity and government funding in the form of a capital grant. In each scenario, the model user can define the mix of financing instruments (% debt and equity), the cost of debt (risk free rate plus a premium or total rate), the debt tenor (or repayment period) and the target operator return on equity to reflect different risk / reward profiles

2. Set alternative tariff structures with fixed and variable elements to reflect different contractual arrangements between the operators and individual emitters or the timing of an emitter's participation in the network. Specifically, the model users have the capability to:
   a. Define the proportion of fixed costs intended to be covered by the "availability" tariff (in the base case, this is assumed to be 100% of CAPEX)
   b. Define how the reserved capacity is allocated among the emitter users by type of operator – either pro rata to each emitter's CO_2 volume contribution to the total reserved capacity in each year or over the life of the pipeline, ship or storage site's operations
   c. Determine potential differences in the tariffs applicable to the first mover relative to follow on projects

3. Change the allocation of specific chain units to different operators. For each scenario, the model can deliver output (financial statements) for up to two geological storage locations, five pipeline operators and three shipping operators.

4. Overwrite other pre-set, “base case” assumptions to reflect a specific project or regional differences, including the:
    a. Cost inputs (e.g.: total CAPEX and OPEX),
    b. Key macroeconomic assumptions (e.g.: CPI inflation rate, tax rate, sovereign risk free rate)
    c. Salvage value of each type of infrastructure (as a % of CAPEX) and the depreciation timeframe of the assets for purposes of the depreciation schedule
    d. Other timing assumptions relating to the cost basis, duration of the typical construction period for each type of infrastructure and the post-injection MMV period required by the storage operator prior to transferring the CO_2 liability to government.

3.3.3 The Public Model

The public financial model being delivered alongside this report has been built in a similar way to the restricted confidential model for use by the Steering Group and the overall structure, and flexibility in changing the inputs and setting financing scenarios is the same.

The key difference between the two models is of course the cost data sources. The public model incorporates generic, non-sensitive cost data available from the Institute’s Economic Assessment of Carbon Capture and Storage Technologies. Using headline cost figures (e.g.: overnight CAPEX, annual OPEX), the user is able to define the financing structure for transport and storage and the emitter tariff structure to produce user tariffs and operator cash flow details. More importantly, however, it is possible to adapt the generic cost inputs in the public model to specific projects for use in other regions.

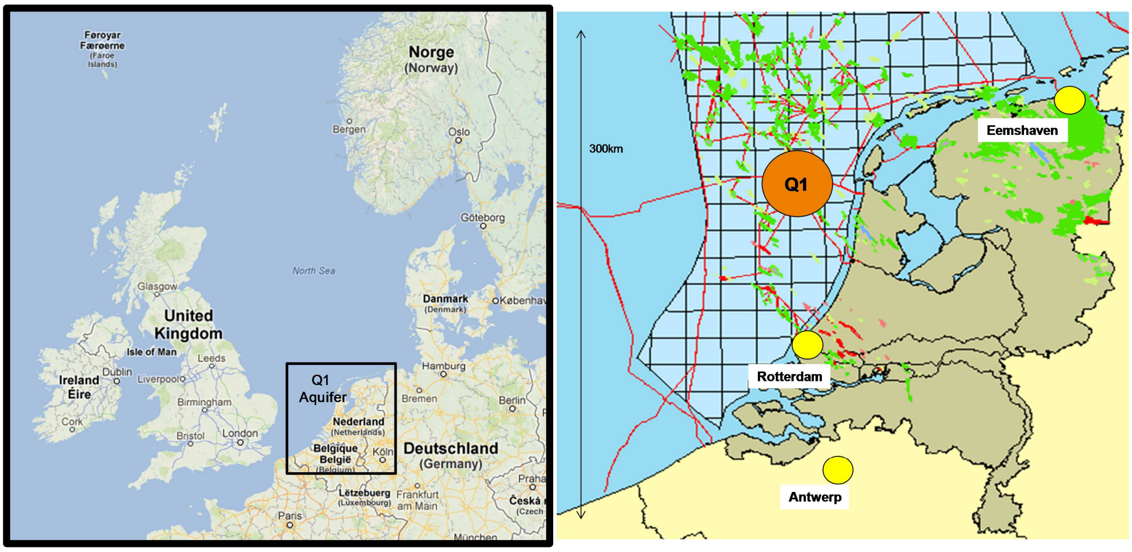
4 The International Offtake Case for the Netherlands & Belgium

The results of the 14 T&S scenarios that form the second phase of the analysis are presented in detail in the following four sections (4.1 to 4.4 inclusive). These sections are organised based on the ultimate storage location (section 4.1 on Q1, 4.2 on Southern North Sea, 4.3 on Captain Sandstone and 4.4 on Utsira) and by mode of transport and routing. The specific scenarios are described in a simplified schematic overview of the infrastructure as well as a table outlining the CO_2 volumes and timing parameters. Finally, the key cost figures (total CAPEX and OPEX) for each chain unit and the resulting “tariffs” per tCO_2 for the scenario are presented in a table at the end of each section. Section 4.5 provides an overview of the total transport and storage cost to emitters in the three regions in each scenario, while section 4.6 describes the sensitivities on the financing assumptions, including financing mix and the weighted average cost of capital.

4.1 Q1 Aquifer, NL

This is the most promising medium term storage site in the Dutch Continental Shelf, as identified by the Independent Storage Assessment as well as previous studies by EBN and Gasunie, with approximately $200MtCO_2$ total storage capacity. The analysis considers two transport concepts for a given CO_2 volume, sourced from full scale emitters in Rotterdam, demo and full scale emitters in Eemshaven and a demo scale emitters in Antwerp.

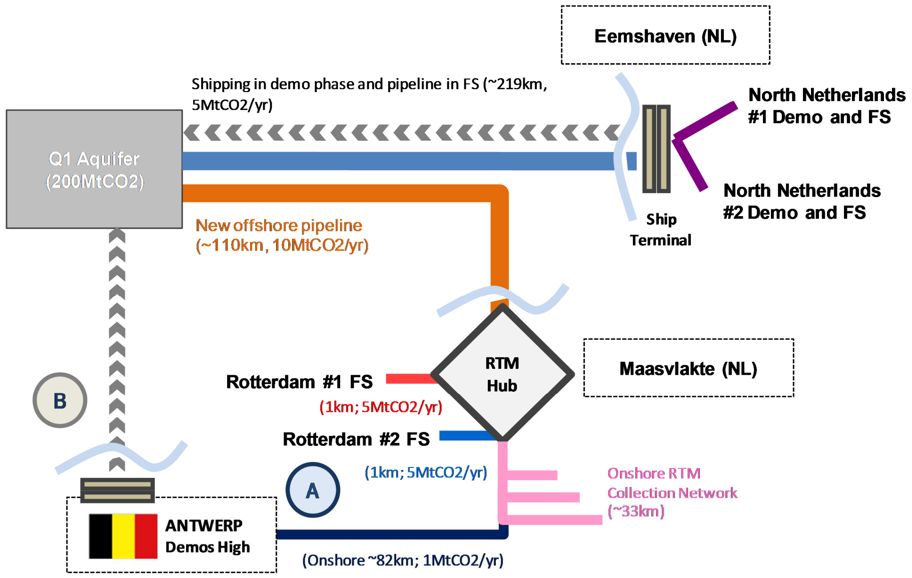
Figure 4.1: Geographical Location of Q1 Aquifer, Rotterdam, Antwerp and Eemshaven



4.1.1.1 Infrastructure Design and Simplified Schematic Overview

CO_2 volumes in the Maasvlakte area in the Port of Rotterdam are collected via two separate onshore pipelines, connecting to a new offshore pipeline from Maasvlakte to Q1 (~110km, 10MtCO2/yr max. capacity). In the North Netherlands, CO_2 is also collected via two separate onshore pipelines and transported offshore (~219km) via shipping in the initial demo phase (2020 to 2025) and via a new offshore pipeline (5MtCO2/yr max. capacity) once the volumes are scaled up (2025+). In the case of Antwerp, we model two transport alternatives – A) an onshore pipeline to the Rotterdam Hub, connecting with the new offshore pipeline from Maasvlakte to Q1 being used by the full scale Rotterdam emitters (scenario 1) or B) a direct shipping route from the Port of Antwerp to the aquifer (~256km) (scenario 2).

Figure 4.2: Simplified Schematic of Q1 T&S Scenarios



4.1.1.2 CO_2 Volumes and Timing

Table 4.3: Scenarios 1-2, Overview of Emitter CO_2 Volumes and Timing

Scenario				Offshore Transport				CO2 Volumes	
#	**Name**	**Emitter**	**Dest.**	**To Int. Hub**	**To Storage**	**Start**	**End**	**(MtCO2/yr)**	**Total (MtCO2)**
1	Q1, NL (A) -- ANT via RTM	Rotterdam FS #1	Q1, NL	--	Pipeline	Jan-20	Dec-35	4.5 MtCO2/yr	72.0 MtCO2
		North NL Demo #1	Q1, NL	--	Ship	Jan-20	Dec-24	0.5 MtCO2/yr	2.5 MtCO2
		North NL Demo #2	Q1, NL	--	Ship	Jan-20	Dec-22	0.5 MtCO2/yr	1.5 MtCO2
		Antwerp Demo (Low)	Q1, NL	Pipeline	Pipeline	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		North NL FS #2	Q1, NL	--	Pipeline	Jan-23	Dec-34	1.5 MtCO2/yr	18.0 MtCO2
		Rotterdam FS #2	Q1, NL	--	Pipeline	Jan-25	Dec-35	4.5 MtCO2/yr	49.5 MtCO2
		North NL FS #1	Q1, NL	--	Pipeline	Jan-25	Dec-34	4.5 MtCO2/yr	45.0 MtCO2
		Total				**Jan-20**	**Dec-35**		**198.5 MtCO2**

Scenario #	Scenario Name	Emitter	Dest.	Offshore Transport To Int. Hub	Offshore Transport To Storage	Start	End	CO2 Volumes (MtCO2/yr)	CO2 Volumes Total (MtCO2)
2	Q1, NL (B) -- ANT Direct	Rotterdam FS #1	Q1, NL	--	Pipeline	Jan-20	Dec-35	4.5 MtCO2/yr	72.0 MtCO2
		North NL Demo #1	Q1, NL	--	Ship	Jan-20	Dec-24	0.5 MtCO2/yr	2.5 MtCO2
		North NL Demo #2	Q1, NL	--	Ship	Jan-20	Dec-22	0.5 MtCO2/yr	1.5 MtCO2
		Antwerp Demo (Low)	Q1, NL	--	Ship	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		North NL FS #2	Q1, NL	--	Pipeline	Jan-23	Dec-34	1.5 MtCO2/yr	18.0 MtCO2
		Rotterdam FS #2	Q1, NL	--	Pipeline	Jan-25	Dec-35	4.5 MtCO2/yr	49.5 MtCO2
		North NL FS #1	Q1, NL	--	Pipeline	Jan-25	Dec-34	4.5 MtCO2/yr	45.0 MtCO2
		Total				**Jan-20**	**Dec-35**		**198.5 MtCO2**

4.1.1.3 *Key Cost Assumptions, Technical Parameters & Resulting Tariffs*

Table 4.4: Scenarios 1-2, Key Parameters & Cost of Transport & Storage Infrastructure

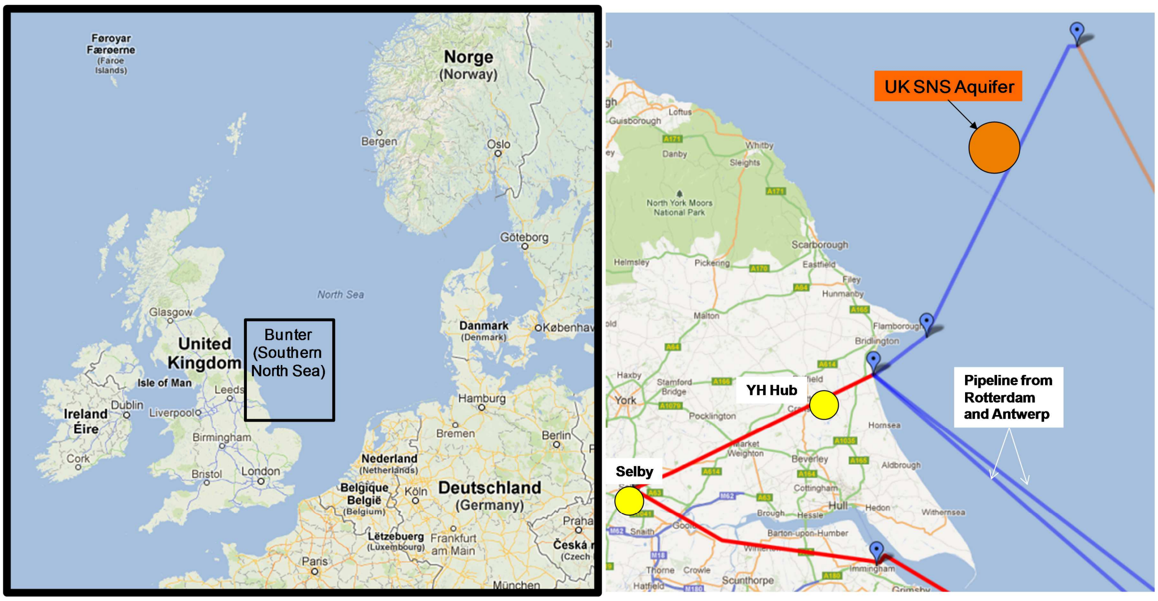
	IS1 # Users	Dist.	Max. Infra Capacity	IS1 Avg Annual T/Put	IS1 Total T/Put	IS1 Ops Life	IS1 Total Costs (2011 Basis) CAPEX	IS1 Total Costs (2011 Basis) OPEX	IS1 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	3	35 km	12.5 MtCO2/yr	8.2 MtCO2/yr	132 MtCO2	16	€63m	€39m	**€1.2 /tCO2**
ANT-RTM CN Onshore Pipe	1	82 km	1.0 MtCO2/yr	1.0 MtCO2/yr	10 MtCO2	10	€67m	€4m	**€11.2 /tCO2**
RTM-Q1 Offshore Pipe	3	110 km	10.0 MtCO2/yr	8.2 MtCO2/yr	132 MtCO2	16	€181m	€11m	**€2.6 /tCO2**
NNL Onshore CN Pipes	4	14 km	6.0 MtCO2/yr	4.5 MtCO2/yr	67 MtCO2	15	€14m	€7m	**€0.5 /tCO2**
NNL-Q1 Offshore Pipe	2	218 km	6.0 MtCO2/yr	6.0 MtCO2/yr	60 MtCO2	10	€290m	€10m	**€9.0 /tCO2**
Storage (Target RoE 13%)									
Q1 Storage	7		200 MtCO2	12.4 MtCO2/yr	199 MtCO2	16	€52m	€467m	**€2.8 /tCO2**
Ships (Target RoE 10%)									
NNL-Q1 Ship	3	219 km	4.5 MtCO2/yr	1.4 MtCO2/yr	7 MtCO2	5	€109m	€79m	**€35.8 /tCO2**

	IS2 # Users	Dist.	Max. Infra Capacity	IS2 Avg Annual T/Put	IS2 Total T/Put	IS2 Ops Life	IS2 Total Costs (2011 Basis) CAPEX	IS2 Total Costs (2011 Basis) OPEX	IS2 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	2	2 km	10.0 MtCO2/yr	7.6 MtCO2/yr	122 MtCO2	16	€6m	€7m	**€0.2 /tCO2**
RTM-Q1 Offshore Pipe	2	110 km	10.0 MtCO2/yr	7.6 MtCO2/yr	122 MtCO2	16	€181m	€11m	**€2.8 /tCO2**
NNL Onshore CN Pipes	4	14 km	6.0 MtCO2/yr	4.5 MtCO2/yr	67 MtCO2	15	€14m	€7m	**€0.5 /tCO2**
NNL-Q1 Offshore Pipe	2	218 km	6.0 MtCO2/yr	6.0 MtCO2/yr	60 MtCO2	10	€290m	€10m	**€9.0 /tCO2**
Storage (Target RoE 13%)									
Q1 Storage	7		200 MtCO2	12.4 MtCO2/yr	199 MtCO2	16	€52m	€467m	**€2.8 /tCO2**
Ships (Target RoE 10%)									
NNL-Q1 Ship	3	219 km	4.5 MtCO2/yr	1.4 MtCO2/yr	7 MtCO2	5	€109m	€79m	**€35.8 /tCO2**
ANT-Q1 NL Ship	1	256 km	4.5 MtCO2/yr	1.0 MtCO2/yr	10 MtCO2	10	€109m	€157m	**€33.3 /tCO2**

4.2 Southern North Sea Aquifer (SNS), UK

The Southern North Sea storage option was selected on the basis of its proximity to the Yorkshire & Humber (and Teeside) regions of the UK and its potential to accommodate longer term CO_2 volumes from initial projects planned in the region. The Triassic Bunter Sandstone formation is thought to have a theoretical estimated CO_2 capacity up to 14Gton (Benthem, 2009), based on recent studies undertaken in the UK and depending on the methodology applied.

Figure 4.5: Geographical Location of Southern North Sea Aquifer, Selby and Yorkshire & Humber Hub



The analysis considered CO_2 volumes sourced from full scale emitters in Rotterdam, demo and full scale emitters in Antwerp and makes an assumption in relation to volumes in the Yorkshire and Humber region in the UK. Given the high theoretical capacity of the Bunter formation, the total CO_2 volume was determined based on a 40 year operating life of a full scale capture plant.

With regards to transport, this set of scenarios focused on three routes from Antwerp and the Netherlands, differing by the use or not of the onshore transport hubs assumed to be in place in the Port of Rotterdam and Humber cluster: a) via Rotterdam and Yorkshire & Humber, b) via Yorkshire & Humber only and c) directly from Antwerp to storage.

4.2.1 Via Rotterdam and Yorkshire & Humber

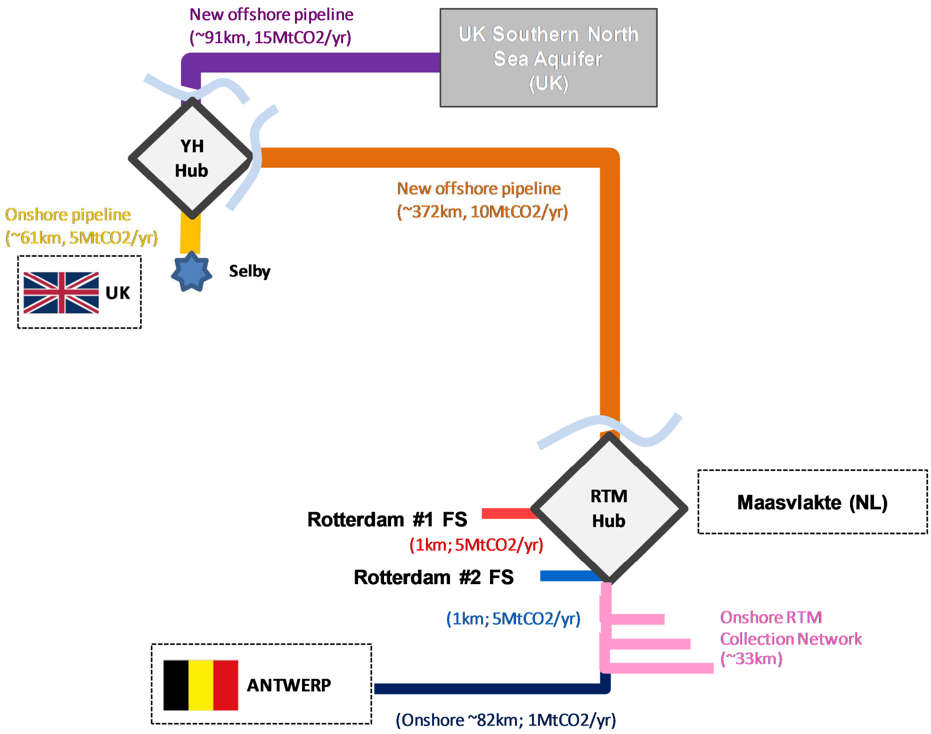
CO_2 volumes in the Maasvlakte area in the Port of Rotterdam are collected via two separate onshore pipelines, connecting at the Rotterdam Hub for onward transport via a new offshore pipeline to the Yorkshire & Humber Hub (assumed to be located at Barmston) (~372km, 10MtCO2/yr max. capacity). The choice of pipeline over shipping is supported by the relative costs analysis performed by CATO-2 (details in appendix B).

With the addition of Antwerp (scenarios 4 and 5), a new onshore pipeline from Antwerp to Rotterdam is developed (~82km, 1MtCO2/yr) to connect to the now extended

Rotterdam Collection Network. At the Yorkshire & Humber Hub, CO_2 volumes transported from the Rotterdam Hub are integrated with CO_2 volumes from UK emitters in the region for onward offshore transport via pipeline (~91km, 15MtCO2/yr max. capacity) to the Bunter formation in the Southern North Sea.

4.2.1.1 Infrastructure Design and Simplified Schematic Overview

Figure 4.6: Simplified Schematic of Southern North Sea via Rotterdam and Yorkshire & Humber T&S Scenarios



Note: Volumes indicate the maximum pipeline capacity assumptions

4.2.1.2 CO_2 Volumes and Timing

Table 4.7: Scenarios 3-5, Overview of Emitter CO_2 Volumes and Timing

Scenario			Offshore Transport					CO2 Volumes	
#	Name	Emitter	Dest.	To Int. Hub	To Storage	Start	End	(MtCO2/yr)	Total (MtCO2)
3	SNS, UK -- RTM via YH	Rotterdam FS #1	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Rotterdam FS #2	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**540.0 MtCO2**

Scenario #	Scenario Name	Emitter	Dest.	Offshore Transport To Int. Hub	Offshore Transport To Storage	Start	End	CO2 Volumes (MtCO2/yr)	CO2 Volumes Total (MtCO2)
4	SNS, UK -- ANT (Low Demo) via RTM and YH	Rotterdam FS #1	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Rotterdam FS #2	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Antwerp Demo (Low)	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-29	0.5 MtCO2/yr	5.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**545.0 MtCO2**
5	SNS, UK -- ANT (High Demo) via RTM and YH	Rotterdam FS #1	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Rotterdam FS #2	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Antwerp Demo (High)	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**550.0 MtCO2**

4.2.1.3 *Key Cost Assumptions, Technical Parameters & Resulting Operator Tariffs*

Table 4.8: Scenarios 3-5, Key Parameters & Cost of Transport & Storage Infrastructure

	IS3 # Users	Dist.	Max. Infra Capacity	IS3 Avg Annual T/Put	IS3 Total T/Put	IS3 Ops Life	IS3 Total Costs (2011 Basis) CAPEX	IS3 Total Costs (2011 Basis) OPEX	IS3 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	2	2 km	10.0 MtCO2/yr	9.0 MtCO2/yr	360 MtCO2	40	€6m	€22m	**€0.1 /tCO2**
RTM-YH Hub (UK) Offshore Pipe	2	373 km	10.0 MtCO2/yr	9.0 MtCO2/yr	360 MtCO2	40	€462m	€56m	**€4.5 /tCO2**
YH Hub (UK)-UK SNS Aq. Offshore Pipe	3	91 km	15.0 MtCO2/yr	13.5 MtCO2/yr	540 MtCO2	40	€161m	€26m	**€1.1 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	3		500 MtCO2	13.5 MtCO2/yr	540 MtCO2	40	€163m	€1,242m	**€3.5 /tCO2**

	IS4 # Users	Dist.	Max. Infra Capacity	IS4 Avg Annual T/Put	IS4 Total T/Put	IS4 Ops Life	IS4 Total Costs (2011 Basis) CAPEX	IS4 Total Costs (2011 Basis) OPEX	IS4 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	3	35 km	12.5 MtCO2/yr	9.1 MtCO2/yr	365 MtCO2	40	€63m	€42m	**€0.8 /tCO2**
ANT-RTM CN Onshore Pipe	1	82 km	1.0 MtCO2/yr	0.5 MtCO2/yr	5 MtCO2	10	€67m	€3m	**€22.2 /tCO2**
RTM-YH Hub (UK) Offshore Pipe	3	373 km	10.0 MtCO2/yr	9.1 MtCO2/yr	365 MtCO2	40	€462m	€56m	**€4.4 /tCO2**
YH Hub (UK)-UK SNS Aq. Offshore Pipe	4	91 km	15.0 MtCO2/yr	13.6 MtCO2/yr	545 MtCO2	40	€161m	€26m	**€1.0 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	4		500 MtCO2	13.6 MtCO2/yr	545 MtCO2	40	€163m	€1,251m	**€3.4 /tCO2**

	IS5 # Users	Dist.	Max. Infra Capacity	IS5 Avg Annual T/Put	IS5 Total T/Put	IS5 Ops Life	IS5 Total Costs (2011 Basis) CAPEX	IS5 Total Costs (2011 Basis) OPEX	IS5 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	3	35 km	10.0 MtCO2/yr	9.3 MtCO2/yr	370 MtCO2	40	€63m	€54m	**€0.8 /tCO2**
ANT-RTM CN Onshore Pipe	1	82 km	1.0 MtCO2/yr	1.0 MtCO2/yr	10 MtCO2	10	€67m	€4m	**€11.2 /tCO2**
RTM-YH Hub (UK) Offshore Pipe	3	373 km	10.0 MtCO2/yr	9.3 MtCO2/yr	370 MtCO2	40	€462m	€56m	**€4.3 /tCO2**
YH Hub (UK)-UK SNS Aq. Offshore Pipe	4	91 km	15.0 MtCO2/yr	13.8 MtCO2/yr	550 MtCO2	40	€161m	€27m	**€1.0 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	4		500 MtCO2	13.8 MtCO2/yr	550 MtCO2	40	€163m	€1,261m	**€3.4 /tCO2**

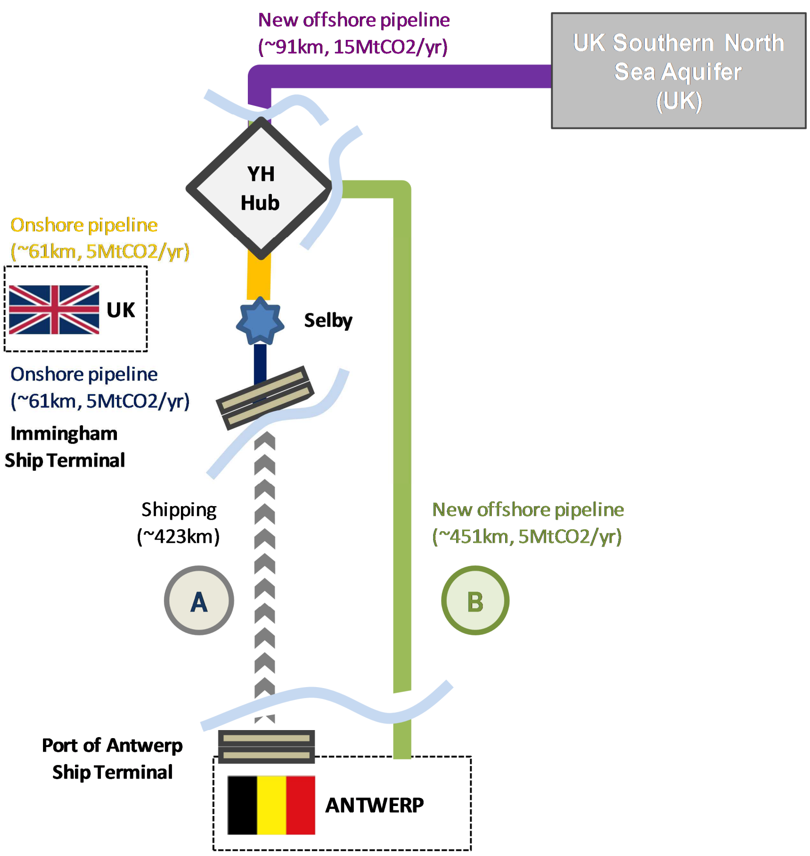
4.2.2 From Antwerp directly to Yorkshire & Humber

CO_2 volumes from Antwerp are transported directly to the Yorkshire & Humber region, connecting with CO_2 volumes from UK emitters in the region for onward offshore transport via pipeline (~91km, 15MtCO2/yr max. capacity) to the Bunter formation in the Southern North Sea. The design of offshore transport to the storage location is unchanged relative to scenarios 3-5, however storage capacity at the aquifer is now only shared between Antwerp and UK emitters, and the expected benefit of sharing infrastructure is lower.

For the offshore transport from the Antwerp port area to the UK, the analysis considers both pipeline and shipping alternatives -- a) shipping to the port of Immingham (~423km) and onward transport to the Hub via and onshore pipeline initially to Selby and then to Barmston (each approximately ~61km, 5MtCO2/yr) or b) via offshore pipeline directly to the Barmston compression station (~451km, 5MtCO2/yr max. capacity). The results of the relative cost modelling done by CATO-2 indicated that shipping would be more efficient for the demo phase (1MtCO2/yr volumes), but when the volumes transition to full scale (5MtCO2/yr), the difference is marginal, with the pipeline option becoming more affordable.

4.2.2.1 Infrastructure Design and Simplified Schematic Overview

Figure 4.9: Simplified Schematic of Southern North Sea via Yorkshire & Humber Only T&S Scenarios



Note: Volumes indicate the maximum pipeline capacity assumptions

4.2.2.2 CO_2 Volumes and Timing

Table 4.10: Scenarios 6-8, Overview of Emitter CO_2 Volumes and Timing

Scenario			Offshore Transport					CO2 Volumes	
#	**Name**	**Emitter**	**Dest.**	**To Int. Hub**	**To Storage**	**Start**	**End**	**(MtCO2/yr)**	**Total (MtCO2)**
6	**SNS, UK -- ANT (High Demo) via YH only (Ship)**	Antwerp Demo (High)	SNS, UK	Ship	Pipeline	Jan-20	Dec-59	1.0 MtCO2/yr	40.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**220.0 MtCO2**
7	**SNS, UK -- ANT (High Demo & FS) via YH only (Ship)**	Antwerp Demo (High)	SNS, UK	Ship	Pipeline	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		Antwerp FS	SNS, UK	Ship	Pipeline	Jan-30	Dec-59	5.0 MtCO2/yr	150.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**340.0 MtCO2**
8	**SNS, UK -- ANT (High Demo) via YH only (Pipe)**	Antwerp Demo (High)	SNS, UK	Pipeline	Pipeline	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		Antwerp FS	SNS, UK	Pipeline	Pipeline	Jan-30	Dec-59	5.0 MtCO2/yr	150.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**160.0 MtCO2**

4.2.2.3 Key Cost Assumptions, Technical Parameters & Resulting Operator Tariffs

Table 4.11: Scenarios 6-8, Key Parameters & Cost of Transport & Storage Infrastructure

							IS6 Total Costs (2011 Basis)		
	IS6 # Users	**Dist.**	**Max. Infra Capacity**	**IS6 Avg Annual T/Put**	**IS6 Total T/Put**	**IS6 Ops Life**	**CAPEX**	**OPEX**	**IS6 Cost per tCO2 T/Put**
Pipelines (Target RoE 10%)									
YH Hub (UK)-UK SNS Aq. Offshore Pipe	2	91 km	15.0 MtCO2/yr	5.5 MtCO2/yr	220 MtCO2	40	€161m	€20m	**€2.6 /tCO2**
Selby-YH Hub (UK) Onshore Pipe	2	61 km	10.0 MtCO2/yr	5.5 MtCO2/yr	220 MtCO2	40	€59m	€12m	**€1.0 /tCO2**
Immingham-Selby (UK) Onshore Pipe	1	61 km	5.0 MtCO2/yr	1.0 MtCO2/yr	40 MtCO2	40	€25m	€5m	**€2.2 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	2		500 MtCO2	5.5 MtCO2/yr	220 MtCO2	40	€161m	€701m	**€5.8 /tCO2**
Ships (Target RoE 10%)									
ANT-Immingham UK Ship	1	423 km	4.5 MtCO2/yr	1.0 MtCO2/yr	40 MtCO2	40	€109m	€636m	**€25.1 /tCO2**
							IS7 Total Costs (2011 Basis)		
	IS7 # Users	**Dist.**	**Max. Infra Capacity**	**IS7 Avg Annual T/Put**	**IS7 Total T/Put**	**IS7 Ops Life**	**CAPEX**	**OPEX**	**IS7 Cost per tCO2 T/Put**
Pipelines (Target RoE 10%)									
YH Hub (UK)-UK SNS Aq. Offshore Pipe	3	91 km	15.0 MtCO2/yr	8.5 MtCO2/yr	340 MtCO2	40	€161m	€22m	**€1.9 /tCO2**
Selby-YH Hub (UK) Onshore Pipe	3	61 km	10.0 MtCO2/yr	8.5 MtCO2/yr	340 MtCO2	40	€59m	€16m	**€0.7 /tCO2**
Immingham-Selby (UK) Onshore Pipe	2	61 km	5.0 MtCO2/yr	4.0 MtCO2/yr	160 MtCO2	40	€25m	€12m	**€0.8 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	3		500 MtCO2	8.5 MtCO2/yr	340 MtCO2	40	€162m	€895m	**€4.9 /tCO2**
Ships (Target RoE 10%)									
ANT-Immingham UK Ship	2	423 km	4.5 MtCO2/yr	4.0 MtCO2/yr	160 MtCO2	40	€123m	€1,176m	**€13.2 /tCO2**

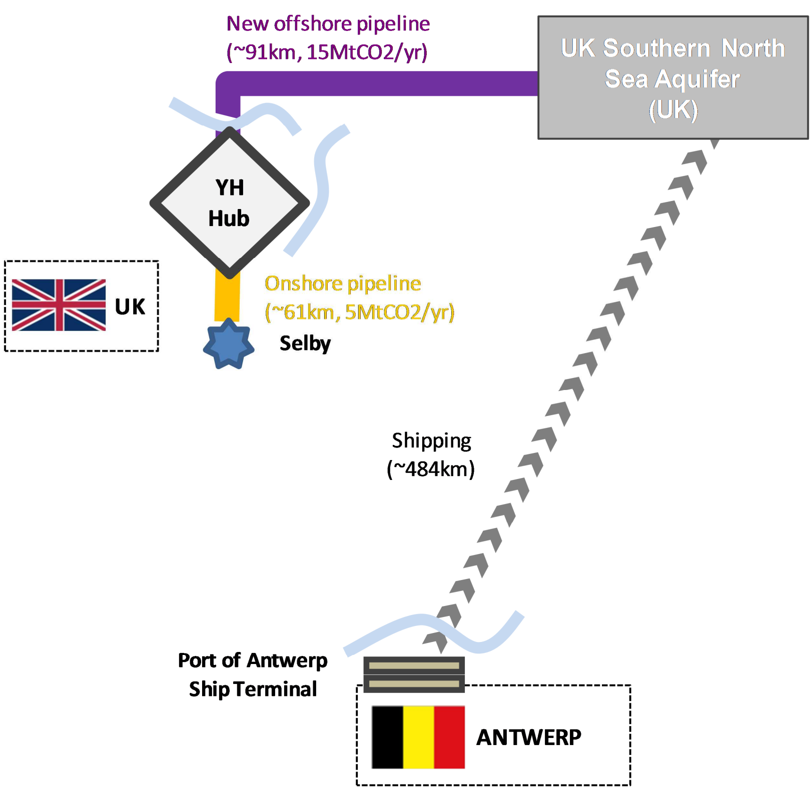
	IS8 # Users	Dist.	Max. Infra Capacity	IS8 Avg Annual T/Put	IS8 Total T/Put	IS8 Ops Life	IS8 Total Costs (2011 Basis) CAPEX	OPEX	IS8 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
YH Hub (UK)-UK SNS Aq. Offshore Pipe	3	91 km	15.0 MtCO2/yr	8.5 MtCO2/yr	340 MtCO2	40	€161m	€22m	**€1.9 /tCO2**
Selby-YH Hub (UK) Onshore Pipe	1	61 km	10.0 MtCO2/yr	4.5 MtCO2/yr	180 MtCO2	40	€59m	€11m	**€1.2 /tCO2**
ANT-YH Hub (UK) Offshore Pipe	2	451 km	5.0 MtCO2/yr	4.0 MtCO2/yr	160 MtCO2	40	€503m	€59m	**€15.5 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	3		500 MtCO2	8.5 MtCO2/yr	340 MtCO2	40	€162m	€895m	**€4.9 /tCO2**

4.2.3 Directly to Storage

In the case of Antwerp, shipping directly to the Bunter formation in the Southern North Sea and by-passing the onshore hubs in Rotterdam and Yorkshire & Humber appeared intuitively more straightforward and potentially more appealing than the previous scenarios. Scenarios 9 and 10, therefore, assume that the CO_2 volumes from Antwerp are shipped directly to the storage site (~484km), sharing capacity with UK emitters in the Yorkshire & Humber region. The UK volumes are assumed to be transported separately via offshore pipeline from the Barmston compression station, as in the previous scenarios (scenarios 3 to 8).

4.2.3.1 Infrastructure Design and Simplified Schematic Overview

Figure 4.12: Simplified Schematic of Southern North Sea Directly T&S Scenarios



Note: Volumes indicate the maximum pipeline capacity assumptions

4.2.3.2 CO_2 Volumes and Timing

Table 4.13: Scenarios 9-10, Overview of Emitter CO_2 Volumes and Timing

Scenario				Offshore Transport				CO2 Volumes	
#	Name	Emitter	Dest.	To Int. Hub	To Storage	Start	End	(MtCO2/yr)	Total (MtCO2)
9	SNS, UK -- ANT (LT High Demo) Direct	Antwerp Demo (High)	SNS, UK	--	Ship	Jan-20	Dec-59	1.0 MtCO2/yr	40.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**220.0 MtCO2**
10	SNS, UK -- ANT (High Demo & FS) Direct	Antwerp Demo (Low)	SNS, UK	--	Ship	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		Antwerp FS	SNS, UK	--	Ship	Jan-30	Dec-59	5.0 MtCO2/yr	150.0 MtCO2
		UK	SNS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**340.0 MtCO2**

4.2.3.3 Key Cost Assumptions, Technical Parameters & Resulting Operator Tariffs

Table 4.14: Scenarios 9-10, Key Parameters & Cost of Transport & Storage Infrastructure

	IS9 # Users	Dist.	Max. Infra Capacity	IS9 Avg Annual T/Put	IS9 Total T/Put	IS9 Ops Life	IS9 Total Costs (2011 Basis) CAPEX	OPEX	IS9 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
YH Hub (UK)-UK SNS Aq. Offshore Pipe	1	91 km	15.0 MtCO2/yr	4.5 MtCO2/yr	180 MtCO2	40	€161m	€19m	**€3.1 /tCO2**
Selby-YH Hub (UK) Onshore Pipe	1	61 km	10.0 MtCO2/yr	4.5 MtCO2/yr	180 MtCO2	40	€59m	€11m	**€1.2 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	2		500 MtCO2	5.5 MtCO2/yr	220 MtCO2	40	€161m	€701m	**€5.8 /tCO2**
Ships (Target RoE 10%)									
ANT-SNS Aq. UK Ship	1	484 km	4.5 MtCO2/yr	1.0 MtCO2/yr	40 MtCO2	40	€109m	€638m	**€25.1 /tCO2**

	IS10 # Users	Dist.	Max. Infra Capacity	IS10 Avg Annual T/Put	IS10 Total T/Put	IS10 Ops Life	IS10 Total Costs (2011 Basis) CAPEX	OPEX	IS10 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
YH Hub (UK)-UK SNS Aq. Offshore Pipe	1	91 km	15.0 MtCO2/yr	4.5 MtCO2/yr	180 MtCO2	40	€161m	€19m	**€3.1 /tCO2**
Selby-YH Hub (UK) Onshore Pipe	1	61 km	10.0 MtCO2/yr	4.5 MtCO2/yr	180 MtCO2	40	€59m	€11m	**€1.2 /tCO2**
Storage (Target RoE 13%)									
UK SNS Aq. Storage	3		500 MtCO2	8.5 MtCO2/yr	340 MtCO2	40	€162m	€895m	**€4.9 /tCO2**
Ships (Target RoE 10%)									
ANT-SNS Aq. UK Ship	2	484 km	4.5 MtCO2/yr	4.0 MtCO2/yr	160 MtCO2	40	€123m	€1,184m	**€13.3 /tCO2**

4.3 Captain Sandstone Aquifer (CS), UK

The second UK option considered in the analysis is the Captain Sandstone Aquifer located beneath the Moray Firth in the Central/Northern North Sea and with an estimated storage capacity of at least 360Mt and up to 1.7GtCO2. This is a potential longer term storage option for initial projects out of Scotland, including the Peterhead project under development by Shell and SSE.

Figure 4.15: Geographical Location of Captain Sandstone Aquifer, Golden Eye Aquifer (not used in this analysis) and Peterhead

The analysis considered CO_2 volumes sourced from full scale emitters in Rotterdam, demo emitters in Antwerp, demo and full scale emitters in the North Netherlands and makes an assumption in relation to volumes in Scotland. Similarly to the approach adopted for the Southern North Sea scenarios and given the range in the storage capacity estimate, the total CO_2 throughput volume was determined based on a 40 year operating life of a full scale capture plant.

With regards to transport, the relative cost modelling done by the CATO-2 team indicated that shipping would be more efficient than offshore pipelines, given the distance from the Netherlands and scenario volumes. We therefore explored two routes, via Rotterdam and from Eemshaven, to the compression station at St. Fergus for onward offshore transport via pipeline to the Captain Sandstone formation.

4.3.1 Via Rotterdam and St. Fergus

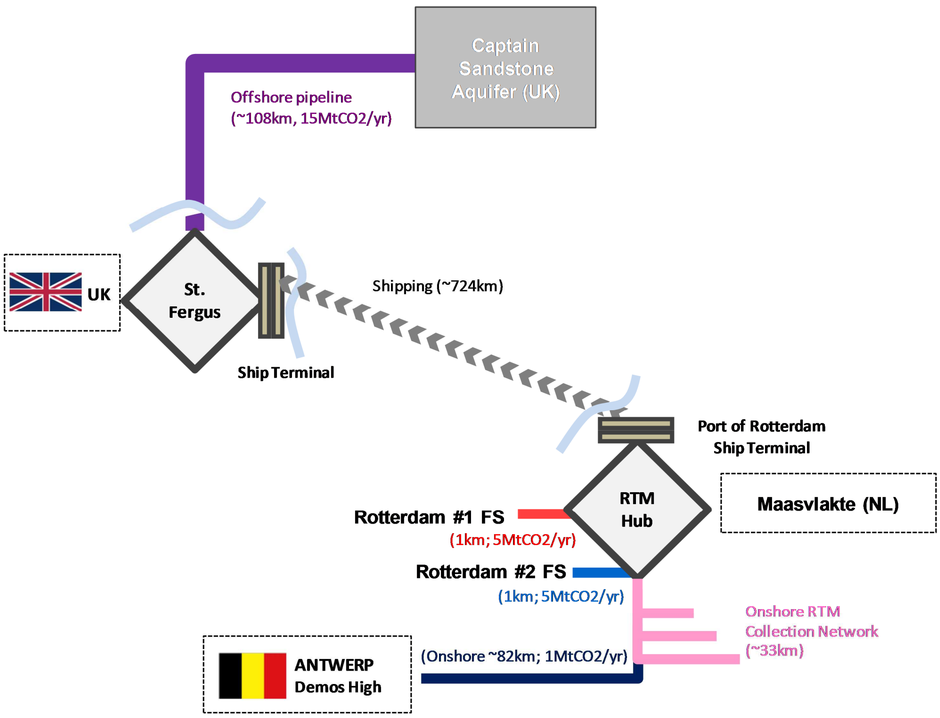
CO_2 volumes in the Maasvlakte area in the Port of Rotterdam are collected via two separate onshore pipelines, connecting at the Rotterdam Hub and adjacent ship terminal for onward transport via ship to St. Fergus on the Scottish coast (~724km).

With the addition of Antwerp (scenario 12), as in previous scenarios via Rotterdam, a new onshore pipeline from Antwerp to Rotterdam is developed (~82km, 1MtCO2/yr), connecting with the now extended Rotterdam Collection Network at Pernis. At St.Fergus, CO_2 volumes transported from the Rotterdam Hub are integrated with CO_2 volumes from

UK emitters in the region for onward transport via an offshore pipeline (~108km, 15MtCO2/yr max. capacity) to the Captain Sandstone aquifer.

4.3.1.1 Infrastructure Design and Simplified Schematic Overview

Figure 4.16: Simplified Schematic of Captain Sandstone via Rotterdam and St. Fergus T&S Scenarios



Note: Volumes indicate the maximum pipeline capacity assumptions

4.3.1.2 CO_2 Volumes and Timing

Table 4.17: Scenarios 11-12, Overview of Emitter CO_2 Volumes and Timing

Scenario				Offshore Transport				CO2 Volumes	
#	Name	Emitter	Dest.	To Int. Hub	To Storage	Start	End	(MtCO2/yr)	Total (MtCO2)
11	Captain Sandstone, UK -- RTM via St. Fergus	Rotterdam FS #1	CS, UK	Ship	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Rotterdam FS #2	CS, UK	Ship	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		UK	CS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**540.0 MtCO2**
12	Captain Sandstone, UK -- ANT via RTM and St. Fergus	Rotterdam FS #1	CS, UK	Ship	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Rotterdam FS #2	CS, UK	Ship	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Antwerp Demo (High)	CS, UK	Ship	Pipeline	Jan-20	Dec-29	1.0 MtCO2/yr	10.0 MtCO2
		UK	CS, UK	--	Pipeline	Jan-20	Dec-59	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-20**	**Dec-59**		**550.0 MtCO2**

4.3.1.3 Key Cost Assumptions, Technical Parameters & Resulting Operator Tariffs

Table 4.18: Scenarios 11-12, Key Parameters & Cost of Transport & Storage Infrastructure

	IS11 # Users	Dist.	Max. Infra Capacity	IS11 Avg Annual T/Put	IS11 Total T/Put	IS11 Ops Life	IS11 Total Costs (2011 Basis) CAPEX	OPEX	IS11 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	2	2 km	10.0 MtCO2/yr	9.0 MtCO2/yr	360 MtCO2	40	€6m	€22m	**€0.1 /tCO2**
St. Fergus-Captain Sands (UK) Offshore Pipe	3	108 km	15.0 MtCO2/yr	13.5 MtCO2/yr	540 MtCO2	40	€459m	€56m	**€3.0 /tCO2**
Storage (Target RoE 13%)									
Captain Sands Aq. Storage	3		500 MtCO2	13.5 MtCO2/yr	540 MtCO2	40	€290m	€1,265m	**€4.6 /tCO2**
Ships (Target RoE 10%)									
RTM-St.Fergus UK Ship	2	724 km	4.5 MtCO2/yr	9.0 MtCO2/yr	360 MtCO2	40	€109m	€2,710m	**€8.5 /tCO2**

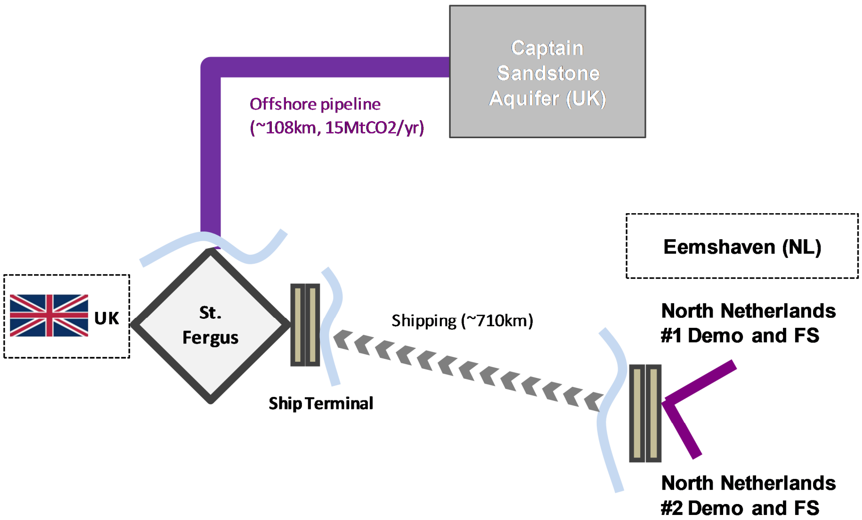
	IS12 # Users	Dist.	Max. Infra Capacity	IS12 Avg Annual T/Put	IS12 Total T/Put	IS12 Ops Life	IS12 Total Costs (2011 Basis) CAPEX	OPEX	IS12 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
RTM Onshore CN Pipes	3	35 km	12.5 MtCO2/yr	9.3 MtCO2/yr	370 MtCO2	40	€63m	€54m	**€0.8 /tCO2**
ANT-RTM CN Onshore Pipe	1	82 km	1.0 MtCO2/yr	1.0 MtCO2/yr	10 MtCO2	10	€67m	€4m	**€11.2 /tCO2**
St. Fergus-Captain Sands (UK) Offshore Pipe	4	108 km	15.0 MtCO2/yr	13.8 MtCO2/yr	550 MtCO2	40	€459m	€56m	**€2.9 /tCO2**
Storage (Target RoE 13%)									
Captain Sands Aq. Storage	4		500 MtCO2	13.8 MtCO2/yr	550 MtCO2	40	€290m	€1,280m	**€4.5 /tCO2**
Ships (Target RoE 10%)									
RTM-St.Fergus UK Ship	3	724 km	4.5 MtCO2/yr	9.3 MtCO2/yr	370 MtCO2	40	€109m	€2,717m	**€8.1 /tCO2**

4.3.2 North Netherlands via St. Fergus

In the case of the North Netherlands, similarly to the Q1 scenario, CO_2 is collected via two separate onshore pipelines, starting at each emitter and ending at a ship terminal in the Eemshaven. There, the CO_2 is liquefied and shipped to St. Fergus (~710km), where volumes are integrated with emissions from UK sources in the area. The offshore transport from St. Fergus to the Captain Sandstone aquifer is modelled as before (i.e.: offshore pipeline, ~108km, 15MtCO2/yr max. capacity).

4.3.2.1 Infrastructure Design and Simplified Schematic Overview

Figure 4.19: Simplified Schematic of Captain Sandstone North Netherlands via St. Fergus T&S Scenario



Note: Volumes indicate the maximum pipeline capacity assumptions

4.3.2.2 CO_2 Volumes and Timing

Table 4.20: Scenario 13, Overview of Emitter CO_2 Volumes and Timing

Scenario				Offshore Transport				CO2 Volumes	
#	Name	Emitter	Dest.	To Int. Hub	To Storage	Start	End	(MtCO2/yr)	Total (MtCO2)
13	Captain Sandstone, UK -- NNL via St. Fergus	North NL FS #1	CS, UK	Ship	Pipeline	Jan-30	Dec-69	4.5 MtCO2/yr	180.0 MtCO2
		North NL FS #2	CS, UK	Ship	Pipeline	Jan-30	Dec-69	1.5 MtCO2/yr	60.0 MtCO2
		UK	CS, UK	--	Pipeline	Jan-30	Dec-69	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-30**	**Dec-69**		**420.0 MtCO2**

4.3.2.3 Key Cost Assumptions, Technical Parameters & Resulting Operator Tariffs

Table 4.21: Scenario 13, Key Parameters & Cost of Transport & Storage Infrastructure

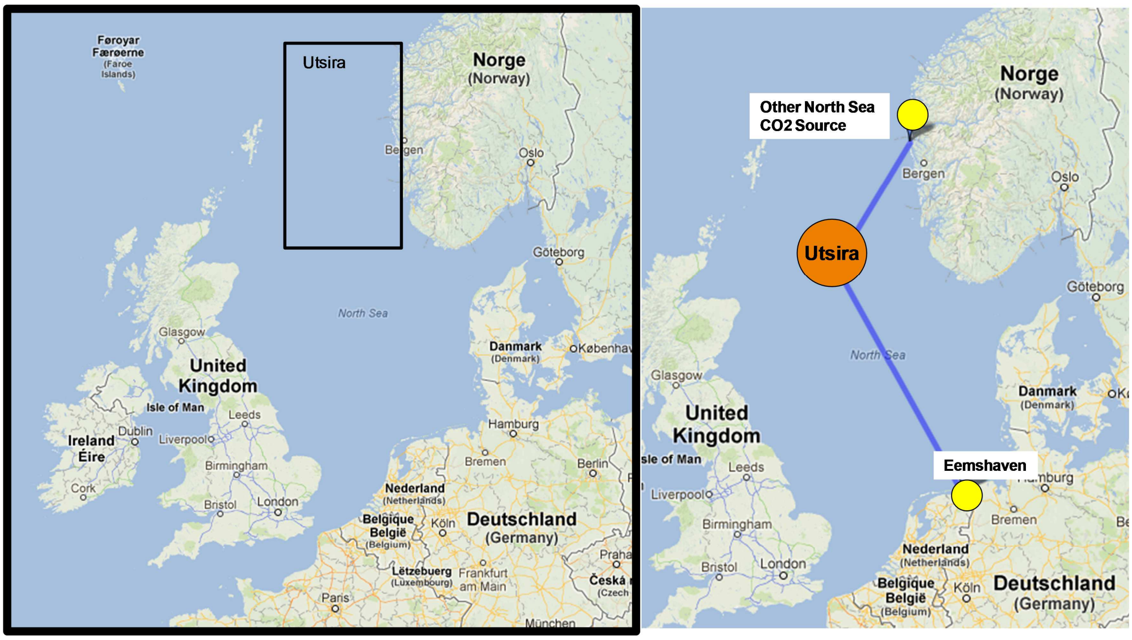
	IS13 # Users	Dist.	Max. Infra Capacity	IS13 Avg Annual T/Put	IS13 Total T/Put	IS13 Ops Life	IS13 Total Costs (2011 Basis) CAPEX	OPEX	IS13 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
St. Fergus-Captain Sands (UK) Offshore Pipe	3	108 km	15.0 MtCO2/yr	10.5 MtCO2/yr	420 MtCO2	40	€452m	€53m	**€4.5 /tCO2**
NNL Onshore CN Pipes	2	14 km	6.0 MtCO2/yr	6.0 MtCO2/yr	240 MtCO2	40	€14m	€25m	**€0.3 /tCO2**
Storage (Target RoE 13%)									
Captain Sands Aq. Storage	3		500 MtCO2	10.5 MtCO2/yr	420 MtCO2	40	€238m	€1,046m	**€5.7 /tCO2**
Ships (Target RoE 10%)									
NNL-St.Fergus UK Ship	2	709 km	4.5 MtCO2/yr	6.0 MtCO2/yr	240 MtCO2	40	€109m	€1,430m	**€7.8 /tCO2**

4.4 Utsira Aquifer (UTS), Norway

4.4.1.1 Infrastructure Design and Simplified Schematic Overview

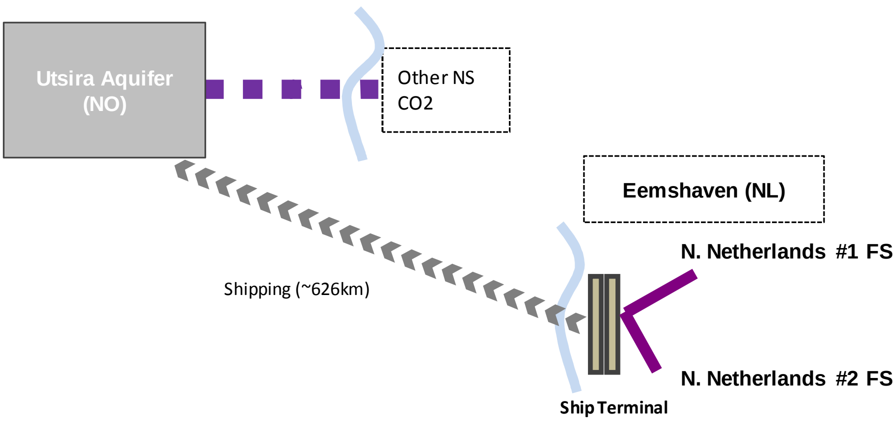
The final scenario relates to storage in the Utsira aquifer in the Norwegian North Sea and was designed as an additional reference point for full scale emitters in the North Netherlands. The formation is in the Utsira sands and has an estimated storage capacity of approximately 20Gton (Report for the FENCO ERO-NET project, 2010).

Figure 4.22: Geographical Location of the Utsira Aquifer



As in previous scenarios, CO_2 is collected via two separate onshore pipelines, starting at each emitter and ending at a ship terminal in the Eemshaven. There, it is liquefied and shipped using two vessels directly to the aquifer (~626km). Storage in the aquifer is assumed to be shared with CO_2 sourced from other North Sea locations, arriving at Utsira independently of the North Netherlands volumes.

Figure 4.23: Simplified Schematic Utsira T&S Scenario



4.4.1.2 CO_2 Volumes and Timing

Table 4.24: Scenario 14, Overview of Emitter CO_2 Volumes and Timing

Scenario				Offshore Transport				CO2 Volumes	
#	Name	Emitter	Dest.	To Int. Hub	To Storage	Start	End	(MtCO2/yr)	Total (MtCO2)
14	Utsira, NO -- NNL Direct	North NL FS #2	UTS, NO	--	Ship	Jan-30	Dec-69	1.5 MtCO2/yr	60.0 MtCO2
		North NL FS #1	UTS, NO	--	Ship	Jan-30	Dec-69	4.5 MtCO2/yr	180.0 MtCO2
		NO	UTS, NO	--	Pipeline	Jan-30	Dec-69	4.5 MtCO2/yr	180.0 MtCO2
		Total				**Jan-30**	**Dec-69**		**420.0 MtCO2**

4.4.1.3 Key Cost Assumptions, Technical Parameters & Resulting Operator Tariffs

Table 4.25: Scenario 14, Key Parameters & Cost of Transport & Storage Infrastructure

	IS14 # Users	Dist.	Max. Infra Capacity	IS14 Avg Annual T/Put	IS14 Total T/Put	IS14 Ops Life	IS14 Total Costs (2011 Basis) CAPEX	OPEX	IS14 Cost per tCO2 T/Put
Pipelines (Target RoE 10%)									
NNL Onshore CN Pipes	2	14 km	6.0 MtCO2/yr	6.0 MtCO2/yr	240 MtCO2	40	€13m	€25m	**€0.3 /tCO2**
Storage (Target RoE 13%)									
Utsira Aq. Storage	3		500 MtCO2	10.5 MtCO2/yr	420 MtCO2	40	€111m	€1,022m	**€3.8 /tCO2**
Ships (Target RoE 10%)									
NNL-Utsira Aq. NO Ship	2	625 km	4.5 MtCO2/yr	6.0 MtCO2/yr	240 MtCO2	40	€109m	€1,416m	**€7.7 /tCO2**

4.5 Summary Emitter Tariffs by Region

Having determined the technical and cost parameters of each of the 14 T&S scenarios, this section provides an overview of the total transport and storage cost to emitters in the three regions in each scenario. As explained in the previous chapter, the “tariffs” take into account the total infrastructure costs as well as the (base case) financing assumptions. All results are expressed in per ton of CO_2 throughput.

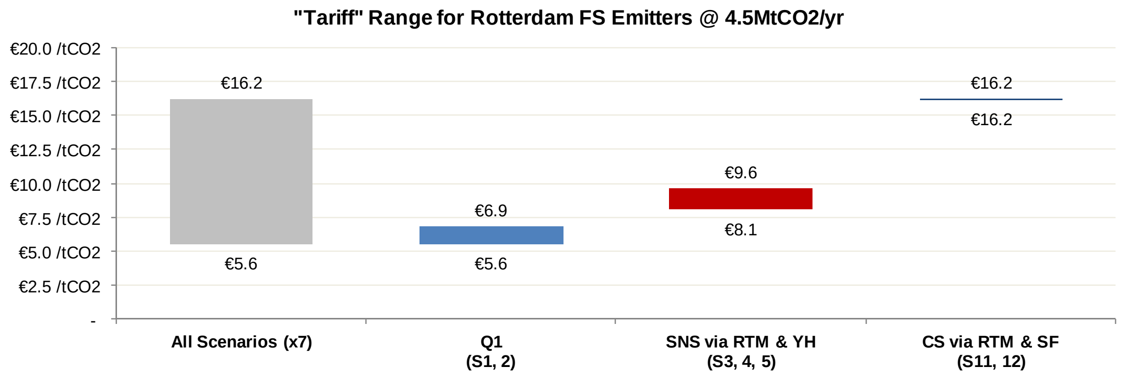
4.5.1 Rotterdam

The analysis considered 7 T&S scenarios for two full scale emitters (annual volumes of 4.5MtCO2/yr each) in the Rotterdam Port area relating to three storage options – Q1 aquifer in the Dutch Continental Shelf, Southern North Sea and Captain Sandstone aquifers in the UK North Sea.

The total transport and storage tariff across scenarios ranges between €5.6 and €16.2/tCO2. The lowest costs appear in the Q1 scenarios (scenarios 1, 2), primarily due to the proximity to Rotterdam (~110km relative to ~460km to the Southern North Sea aquifer and >800km to the Captain Sandstone aquifer) and more efficient sharing of infrastructure relative to other scenarios modelled. For example, the total transport cost attributable to Rotterdam emitters for this option is approximately €2.7-3.6/tCO2, relative to €5.7-6.2/tCO_2 for the Southern North Sea aquifer via Yorkshire & Humber and €11.6-11.8/tCO_2 for the Captain Sandstone aquifer via St. Fergus options. Similarly, the Q1 storage cost is approximately €2.9/tCO2, relative to approximately €3.4-3.5/tCO_2 for the Southern North Sea aquifer and approximately €4.5-4.6/tCO_2 for the Captain Sandstone aquifer options.

The different tariffs for the different formations are based on the difference in cost of each of the individual aquifers. Q1 is relatively cheap because of the assumption the platforms and production wells can be re-used, which is not the case for the SNS and CS sandstones. The injectivity is good for all aquifers but the captain sandstone aquifer uses a different maximum well injection rate. As a consequence more wells are needed for the same injection rate compared to the SNS or Q1 aquifers. More injection wells will results in higher CAPEX and high tariffs.

Figure 4.26: Summary Emitter Tariffs - Rotterdam



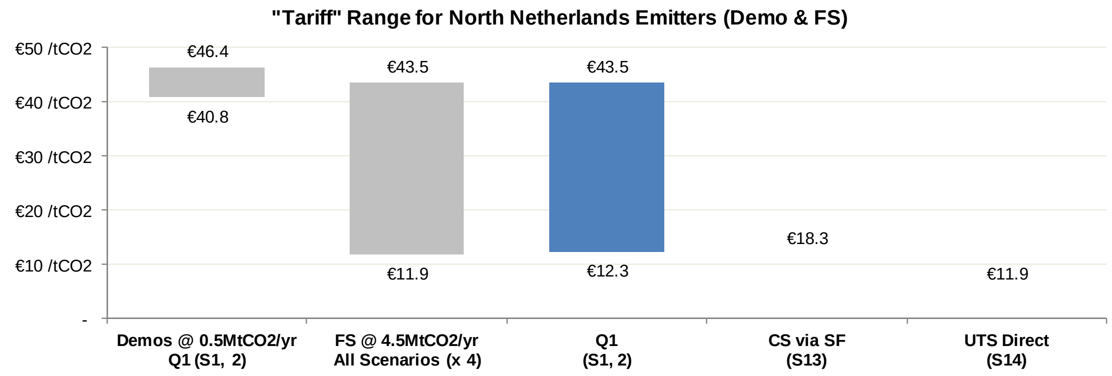
4.5.2 North Netherlands

In the case of the North Netherlands, the analysis focused on two emitters starting in either 2020 with a demo phase (annual volumes of 0.5MtCO2/yr each) and transitioning to full scale after 3 and 5 years (annual volumes of 4.5MtCO2/yr and 1.5 MtCO2/yr) (scenarios 1, 2) or in 2030 directly with full scale volumes (4.5MtCO2/yr and 1.5 MtCO2/yr) (scenarios 13, 14). The rationale for this was to examine both the short/medium and longer term options available to the North Netherlands.

The total transport and storage tariff for the demo phase in the Q1 scenarios is between €40.8/tCO_2 and €46.4/tCO_2, with the bulk of the costs attributed to transport, rather than storage which is shared with emitters from other regions already from 2020. To some extent this can be explained by the modelling approach to shipping and the assumption that operators can achieve their target returns within the life of the operations, however short that may be. In addition to the lease and operating costs, the costs also include 100% of the cost of loading and unloading terminals, as if all infrastructure is newly built for the exclusive use of CO_2 transport. The calculations are therefore rather conservative.

In the full scale phase, the tariff is between €11.9/tCO_2 and 43.5/tCO2. The range is wide, mainly because of the differences in timing (operating life) between the three storage options. In the case of Q1, the North Netherlands emitters are competing for limited storage capacity with Rotterdam and Antwerp, allowing them only up to 12 years of full scale operations. However, the results suggest that a cost of €12.3/tCO_2 can be achieved, if instead of prolonging the shipping operations from the demo phase, an offshore pipeline built once there is a transition to full scale volumes. With regards to the other two storage options, assuming a 40 year operating life for the North Netherlands capture plants and additional 4.5MtCO2/yr sourced from other North Sea emitters (UK, Norway), the results suggest that the Utsira option (scenario 14) would be the most cost effective for the region (€11.9/tCO2). The cost of storage for the Captain Sandstone aquifer (€5.7/tCO2) is higher than the Utsira aquifer (at €3.8/tCO2), driven primarily by lower maximum injectivity assumptions. In addition, the cost of transport directly to the Utsira aquifer by ship (~625km) is lower than in the Captain Sandstone scenario, where CO_2 is shipped initially to St. Fergus (~709km) and from there on to storage via offshore pipeline (~108km).

Figure 4.27: Summary Emitter Tariffs – North Netherlands



4.5.3 *Antwerp*

For Antwerp, the analysis focused on aggregate volumes in the Port area, simulating a demo phase from 2020 (at 1MtCO2/yr) and in some scenarios a transition to full scale (5MtCO2/yr) deployment from 2030. The rationale for this approach was to determine whether alternative transport options would be more appropriate at each phase and to quantify the expected savings relating to higher throughput volumes at full scale operations. The storage options considered are the same as for Rotterdam, however some additional routes were modelled in the case of Antwerp to evaluate the cost impact of by-passing onshore transport hubs in Rotterdam and the UK.

The total transport and storage tariff across scenarios is between €18.3/tCO_2 and €36.2/tCO_2 for the demo phase and €17.9-21.5/tCO_2 for full scale volumes.

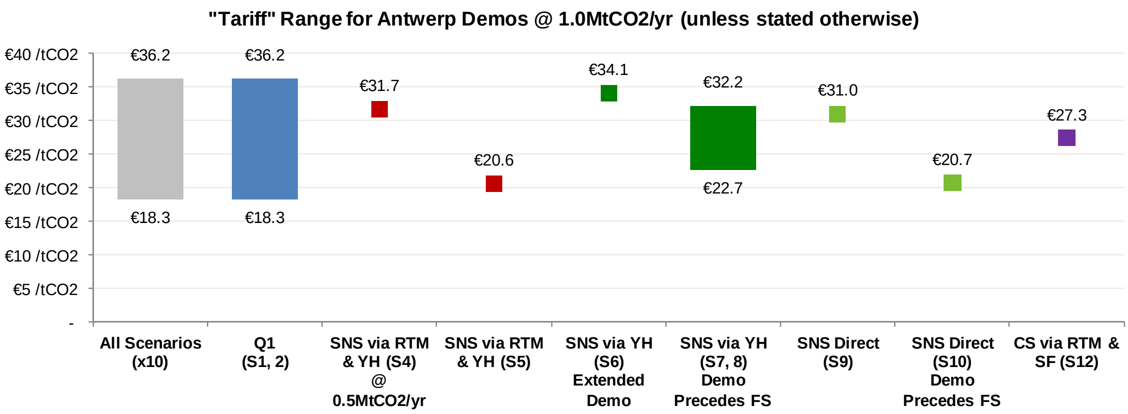
The Q1 results show the largest spread (€18.3-36.2/tCO2) and the cost differential between the two scenarios is driven by the choice of transport mode as the cost of storage remains the same in both scenarios at €3.0/tCO_2 (constant volumes and timing). The pipeline alternative (onshore pipeline connecting to the Rotterdam Collection Network and from there sharing capacity in the offshore pipeline from Maasvlakte to Q1 with the Rotterdam full scale emitters) is almost half the cost than a direct shipping route from the Port of Antwerp to the aquifer. As in the case of the North Netherlands demos, this differential may also be explained by the modelling approach (see detailed explanation in previous section on North Netherlands, 3.7.2)

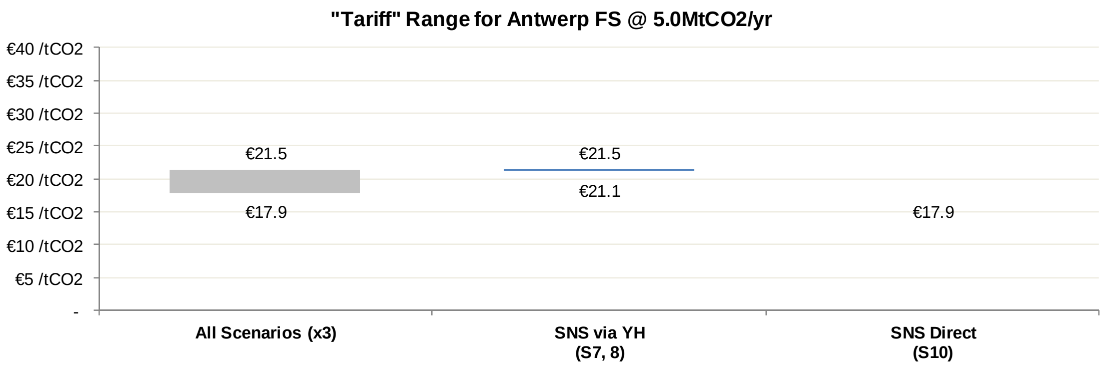
In the case of the UK aquifer options, the analysis considered three routes to the Southern North Sea aquifer – via Rotterdam and Yorkshire & Humber hubs (scenarios 4 and 5), via the Yorkshire & Humber hub only (scenarios 6, 7 and 8) and direct transport to the aquifer via ship (scenarios 9 and 10) – and one to the Captain Sandstone aquifer via Rotterdam (scenario 12).

For volumes of 1MtCO2/yr and no prospects of subsequent transition to full scale operations (S5, 6 and 9) the lowest cost appears in via Rotterdam route (scenario 5 at €20.6/tCO2). Interestingly, the analysis also considered a lower volume alternative for the same route (scenario 4 at 0.5MtCO2/yr) where the total cost increases by almost 54% due to the inefficient utilisation of the 1MtCO2/yr onshore pipeline connecting to the Rotterdam Collection Network. The Captain Sandstone option sits in the middle of the range at €27.4/tCO2.

Finally, for "demo" volumes that precede a transition to full scale operations (S7, 8 and 10) a direct route to the Southern North Sea aquifer would be the most cost efficient (€20.7/tCO_2 at 1MtCO2/yr for 10 years and €17.9/tCO_2 at 5MtCO2/yr for 30 years).

Figure 4.28: Summary Emitter Tariffs – Antwerp





4.6 Overview of Sensitivities

The analysis was completed with a set of sensitivities on the financing assumptions, including the financing mix and the weighted average cost of capital, reflecting potential support mechanisms and different risk/return assumptions. While it is not the intention of this study to take a view on financing terms, commercial negotiations or particular government incentives, the sensitivity analysis gives a reasonable indication of how the results could change, given different financing assumptions.

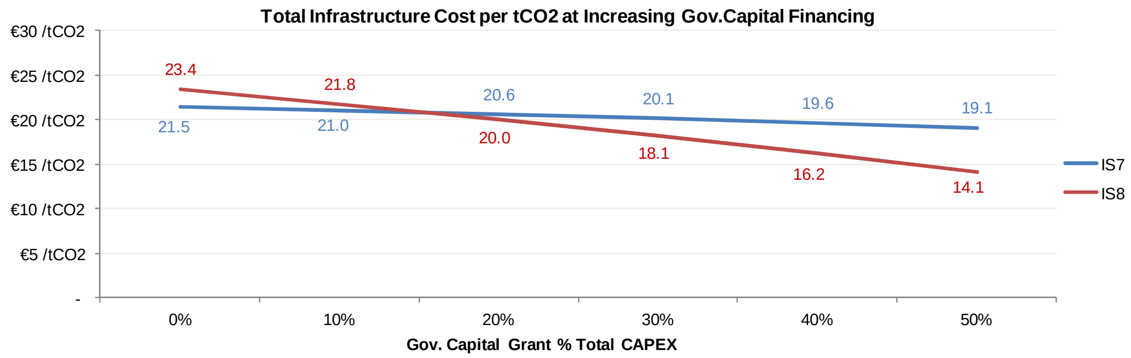
4.6.1 Financing Mix – Capital Grants

Capital grants have been the most common form of government support to CCS projects to date, as evidenced EU funding programs such as the EEPR and NER300. They are typically sized as a portion of capital expenditure, directly lowering the overall costs of the project and may be structured as preferred equity, requiring some form of repayment upon outperformance. They may be paid upfront or on a performance basis once the project is operational (e.g.: based on the volume of CO_2 verified to have been stored annually), or in some combination of the two.

As outlined in chapter 2, the base case financing assumptions do not involve any government funding – transport operations are financed 70% debt at 6% and 30% equity at 10% while storage is financed 60% debt at 6% and 40% equity at 13% return on equity. The sensitivity assumes that a portion of total infrastructure (transport and storage) CAPEX is now funded by a government capital grant which is paid up front but drawn on an “as needed” basis in line with the operators’ capital expenditure schedules. It is assumed that there are no repayment requirements and the cost to government has not been considered.

Figure 4.29 below shows the impact of increasing capital grants (as a % of total CAPEX) for two Southern North Sea via Yorkshire & Humber scenarios, which are identical in CO_2 volumes and timing but different in mode of transport from Antwerp to the Yorkshire Hub (ship in scenario 7 and pipeline in scenario 8). It is clear that increasing the contribution of a capital grant in the financing mix will lower the overall cost of the infrastructure by reducing the quantum of capital that needs to be raised and serviced by project proponents. The impact, however, varies between the two scenarios – a grant appears more effective in the case of pipelines (scenario 8) as it the CAPEX makes up a higher proportion of the total pipeline costs.

Figure 4.29: The Effect of a Capital Grant in the Financing Mix on the Total Emitter Cost

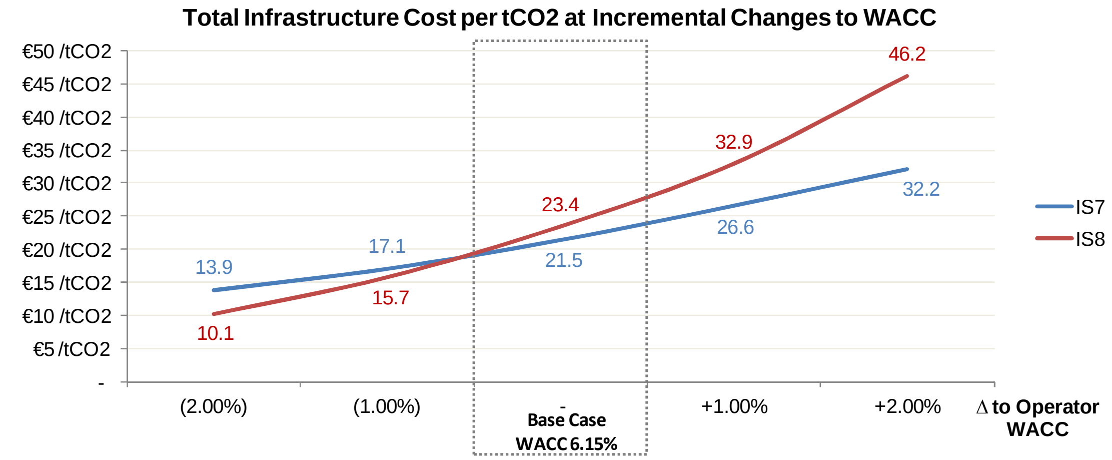


4.6.2 Weighted Average Cost of Capital

Finally, the analysis included a sensitivity on the Weighted Average Cost of Capital (WACC), which reflects the overall cost of financing of the project and different perceptions of risk and return. WACC is calculated as [Cost of Equity x (1-Debt fraction) + (After Tax Average Debt rate x Debt fraction)]. It is also the discount rate used in the calculation of the individual transport and storage operator cash flow Internal Rate of Return (IRR).

Assuming the base case financing mix of 70% Debt / 30% Equity for transport and 60% Debt / 40% Equity for storage and a constant after tax debt rate, changes to the WACC can be simulated applying different target equity returns. Figure 4.30 below shows the impact on total infrastructure cost of changes to WACC, for two Southern North Sea via Yorkshire & Humber scenarios, which are identical in CO_2 volumes and timing but different in mode of transport from Antwerp to the Yorkshire Hub (ship in scenario 7 and pipeline in scenario 8). As in the case of a capital grant, the impact of increasing or decreasing the WACC appears greatest in the case of pipelines (scenario 8) as it the CAPEX makes up a higher proportion of the total pipeline costs, resulting also in higher construction financing requirements. More generally, offshore pipelines appear most sensitive, followed by onshore pipelines and shipping. Storage costs are the least sensitive to changing financing cost assumptions as, unlike transport, operating costs make up the majority of costs.

Figure 4.30: Sensitivity of the WACC on the Total Emitter Cost



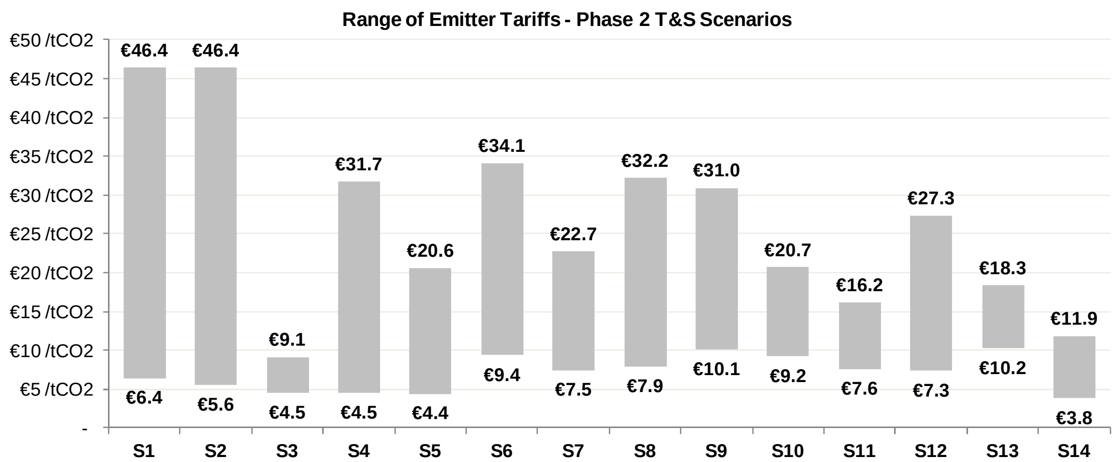
5 Steering Group Conclusions

5.1 Objectives & Results

The primary objective of this project was to provide the members of the Steering Group with a planning tool, which would allow them to form a common view of the costs and risks of alternative CO_2 offtake options in the North Sea that could support large-scale demonstration and early commercial projects in Rotterdam, Eemshaven and Antwerp on a network basis. The analysis is intended to inform discussions between operators and participants in a CCS network, relevant policymakers and other key stakeholders to address a series of complex issues related to the development of shared transport and storage infrastructure in the medium term.

The results of the analysis have been discussed with the Steering Group at three meetings between September and November 2012. Figure 5.1 below summarizes the total transport and storage tariff costs to the emitter users across all Phase 2 T&S Scenarios. The range in each scenario reflects differences in emitter CO_2 volume and timing assumptions. The lowest tariffs are typically achieved for emitters with the highest annual throughput volumes, using the least amount of infrastructure and when there is minimal excess capacity in the transport and storage system.

Figure 5.1: Summary Transport & Storage Tariffs across all Phase 2 Scenarios



In all, the analysis led to a better understanding of the economics and most important cost drivers of the different offtake options, including the choice of transport mode (pipeline vs. ship), the scale of the infrastructure and the potential for under-utilisation, commercial and financing arrangements. The cost of the infrastructure and the range of tariffs on a per ton basis were also broadly recognized as realistic. Furthermore, the financial model delivered to the Steering Group could serve as a starting point for a project application in the second round of the NER300 as it provides a benchmark on costs and could be adapted to reflect project specific assumptions (as described in Chapter 3).

More detailed information on the cost and tariff results can be found in APPENDIX A: Project Team & Project Participants

5.2 Main Conclusions

The main conclusions of the modelling were similar across the two phases and can be summarized as follows:

- Sharing transport and storage infrastructure is a cost effective approach for CCS
- Efficient utilisation of the infrastructure requires the coordination of earlier CO_2 capture projects and/or some visibility that a demo project can transition to full scale project
- Storage costs are significantly reduced when CO_2 is injected close to the individual reservoir's maximum injectivity rates and therefore minimizing the operating period
- Assuming no existing infrastructure in place, the choice between a pipeline and a ship will depend on the required CO_2 throughput volumes and the transport distance
- While more favourable financing terms would lower the cost to individual user emitters, the proportionate impact differs by type of infrastructure, depending on the total CAPEX quantum (and associated debt service requirements) and the share of CAPEX in total costs

5.3 Next Steps

With the modelling completed and the key conclusions drawn, in January 2013 the RCI organised a Steering Group workshop to discuss the strategic issues raised by the analysis and possible near term actions to address them.

5.3.1 Drive for Investment

One of the key points of the discussion was the recognition that the current macro environment and investment signals for CCS are very weak. The EU Emissions Trading System (ETS), for example, which was developed as a means to encourage the deployment of clean energy technologies and help Europe meet its Kyoto Protocol commitments has not stimulated the investment in low carbon technologies to the extent policymakers had originally hoped. Energy efficiency measures and reduced economic activity in the region has meant that emission targets have been met at relatively low cost, depressing the trading price of emission certificates. A relatively low certificate price outlook has also meant that private sector investors are unable to underwrite investment in large scale CCS projects.

Given this backdrop, the Steering Group discussed the role of government and regulators to improve the business case for CCS and provide the missing investment signals by developing clear objectives for the technology in the national energy mix. Plans for long term CO_2 transport and storage infrastructure would also accelerate investment in capture projects.

Specifically for the Netherlands and in light of the window of opportunity being created with the second round of the NER300 to realise further CCS projects in the region, the emitters highlighted the need for government and related government owned CCS stakeholders to work with industry in addressing the following issues:

- Ensuring the transition from demonstration phase to commercial phase projects with appropriate planning of initial investments and oversized infrastructure
- Providing early mover projects with appropriate incentives to ensure the first projects are aligned to the future vision of CCS networks
- Developing the appropriate regulatory frameworks for transboundary transport and storage
- Mobilising other CCS stakeholders in the Netherlands, such as EBN, with responsibilities to progress common user transport and storage

5.3.2 *Ensuring CO_2 Storage*

Addressing the complex issues relating to CO_2 storage remains high on the list of the Steering Group's priorities. The Independent CO_2 Storage Assessment completed in 2011 identified the most promising long term storage sites on the Dutch Continental Shelf and highlighted a need for further feasibility work to verify the capacity and ensure the availability of these sites.

The Steering Group discussed the inconsistencies for potential storage operators between hydrocarbon extraction and the characterisation and development of CO_2 storage sites. Specifically, the group highlighted the need to engage potential operators and work with government to:

- Progress CO_2 storage characterisation and feasibility studies for saline formations on the Dutch Continental Shelf to ensure a smooth transition from demonstration to commercial deployment of CCS
- Better understand the storage capacity elsewhere in the North Sea, based on work already done on mapping the storage potential in the UK and Norway
- Provide input into a review of the EU CCS Directive, particularly in relation to long term CO_2 containment and liability issues
- Develop an appropriate regulatory framework that will treat storage as an "asset", including end of life policies for producing hydrocarbon field and "storage ready" certification
- Develop alternative business models for CO_2 storage, including for example public-private partnerships and service-based models

5.3.3 *Enabling Transport*

The analysis has helped articulate a clear rationale for shared transport infrastructure and quantify the risks associated with not realising the ambition of regional CCS networks. In the discussion, the Steering Group highlighted the challenge in reconciling the higher incremental investment costs and risks to the first mover projects in the short term with the operational benefits of oversizing expected in the long term. In fact, the group drew comparisons with the development of other public good infrastructure, such as bridges and highways, in previous decades and called for decisive government engagement to progress common user CO_2 transport in the Netherlands and Belgium
The key issues to be addressed include:

- Allocation of risk between early mover and future participants in a shared transport system
- Developing appropriate incentives for early mover projects as well as private public partnerships
- Issue of CO_2 specifications in shared transport networks

- Developing models for long term CO_2 transport regulation
- Enabling transboundary transport of CO_2, starting with the ratification of the London Protocol

5.3.4 National and Regional Cooperation

One of the key themes of the discussion within the Steering Group was the scope and potential for further cooperation among CCS stakeholders in the Netherlands and the North Sea rim, including emitters, transport and storage operators, government bodies and potential regulators, to develop a more coherent voice on critical issues relating to CCS deployment and commercialisation.

Specifically with regards to the Netherlands, the group highlighted the need to revive the National Taskforce CCS, which was dismantled in 2011. This was a high level platform of public and private entities established in 2008 with a mandate to support Dutch CCS activities and accelerate the development of the technology. There was also agreement for the Steering Group to engage with potential transport and storage operators in the Netherlands and Belgium to further identify key issues and collaborate towards their resolution.

With regards to broader regional cooperation, the Steering Group recognised the need to develop an engagement plan with working groups such as the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) and the North Sea Basin Task Force (NSBTF). Finally, the group will seek to strengthen the dialogue with regional level authorities in Rotterdam, the Eemshaven and Antwerp and support national level discussions with the European Commission.

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7 APPENDIX A: Project Team & Project Participants

- The Rotterdam Climate Initiative (RCI) was established in 2007 as collaboration between the City of Rotterdam, the Rotterdam Port Authority, the DCMR Environmental Protection Agency and Deltalinqs, with a mission to reduce CO_2 emissions to 50% of 1990 levels by 2025. The RCI has been a member of the Institute since 2010. Deltalinqs is a business organisation representing the common interests of more than 200 logistical and industrial companies in the Rotterdam area, and through it the RCI has acted as a strategic partner on a number of knowledge sharing projects, including the Independent CO_2 Storage Assessment (2010-2011), Rotterdam CCS Network Project Case Study (2011) and Lessons Learned from the Barendrecht Project (2010). The team seeks to build on this successful cooperation with the Institute and leverage the results of prior work.

- Stichting Borg was established to coordinate preparations for CCS in the North Netherlands and focuses primarily on CO_2 storage issues and ensuring dialogue with all stakeholders, under which Gasunie, NAM, Groningen Seaports, NOM, Energy Valley and EBN, while the provinces of Groningen and Drenthe also participate. Stichting Borg joined the enlarged ISA Steering Group in mid 2011 lending its support to the RCI's work and ensuring the collaboration between the two regions.

- Antwerp Port Authority is the owner of the industrial area in the Port of Antwerp and the representative of the companies in the port of Antwerp

- The Clinton Climate Initiative (CCI) is a Strategic Partner to the Institute since its foundation and has been acting as Strategic Advisor to the RCI since 2008. Key examples of this partnership include the Pre-Feasibility Study (2008), RCI Report (2009) and the Independent CO_2 Storage Assessment (2010-2011).

- TNO Geosciences (TNO) is the leading independent research organisation for applied science in the Netherlands and has been active in the area of CCS since 1989. TNO undertook the preliminary characterisation of several potential storage sites in the Dutch Continental Shelf for purposes of the ISA.

- ECOFYS is a leading Dutch consultancy in the field of climate change, with excellent knowledge of CO_2 transport by pipelines.

- CATO-2 is the Dutch scientific program on CCS, coordinated by TNO. TNO (on behalf of CATO) is one of the leading four partners in the ECCO (European Value Chain for CO2) project and has been responsible for building some key modules of the ECCO Tool. The CATO program incorporates expertise from a large number of organisations, including ECOFYS.

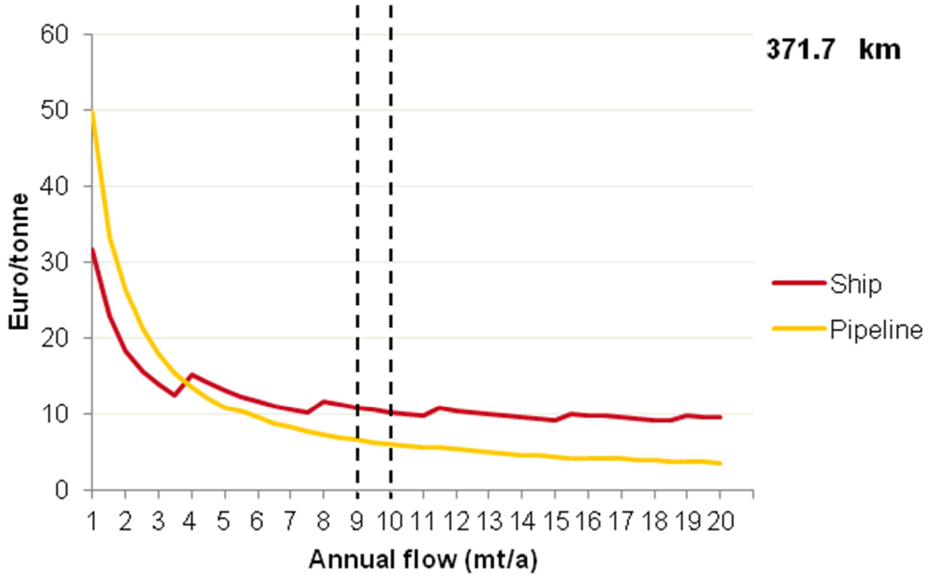
8 APPENDIX B: Analysis Supporting the Choice of Transport Mode for the UK Scenarios

As mentioned in Chapter 2, the analysis considered a combination of onshore and offshore steel pipeline systems and shipping for CO_2 transport. The choice of mode was based primarily on knowledge of existing infrastructure and plans already underway in support of the first large scale demonstration projects in the Netherlands and the UK.

However, in the case of the offshore routes not yet part of any specific project plans, TNO and ECOFYS used the ECCO tool to determine the relative costs of pipeline vs. shipping and identify the most cost-effective alternative. The assessment was done for each of the UK T&S Scenarios, based on assumptions relating to CO_2 volumes, life of operations and transport distance.

By way of example, we present the results of the screening for the Southern North Sea via Yorkshire & Humber scenarios (T&S Scenarios 3, 4 and 5). In these, there is between 9.0 and 10.0MtCO2/yr being transported from Rotterdam to the Yorkshire & Humber Hub over 40 years. The distance is approximately 372 km and as shown in Figure 8.1 below, given these criteria, an offshore pipeline (yellow line) appears more cost effective than shipping.

Figure 8.1: Unit Pipeline and Shipping CAPEX and OPEX for T&S Scenarios 3 – 5, (€/tCO_2)



9 APPENDIX C: ADDITIONAL INFORMATION ON THE ECCO TOOL

The ECCO tool simulates the flow physics of the chain in order to design the infrastructure under user-defined criteria, and to calculate which (incremental) investments the storage operator needs to do in order to (continue to) meet his contractual obligations. The physical phenomena simulated by the ECCO tool include: pipeline physics, compressor physics, CO_2 phase behaviour, flow through injection platform surface equipment, Vertical Flow Performance in injection wells (to calculate the pressure difference between wellhead and bottom of the well), semi-steady state inflow from the bottom of the well into the reservoir, and reservoir material balance to calculate the gradual build-up of the reservoir pressure and the resulting loss in injectivity (whence the need for incremental investments during the injection phase).

For reservoir physics, ECCO tool allows CO_2 injection into depleted gas fields (resulting in a mix of methane and CO2), injection into aquifers (with its specific pressure build-up characteristics), and injection into tail-end oil fields (resulting in Enhanced Oil Recovery, and re-circulation of CO2).

For transport, the ECCO tool allows both pipeline and ship transport, and assists the user to engineer the appropriate dimensions (pipeline diameter, compressors, ship capacities, terminal capacities) and to estimate the associated costs (CAPEX, OPEX).

The calculations of the physics determine both CAPEX (flow capacity) and OPEX (variable costs based on actual flow). The ECCO tool allows complex infrastructures and actor ownership structures to be defined: the tool is centred along hardware ownerships, hardware infrastructural relationships and inter-actor commercial contracts (rights and obligations, CO_2 flow rates, duration, volumes, tariffs etc.).

Finally, the ECCO tool allows various macro-economic scenarios to be defined, with consistent sets of time-series such as commodity prices (steel, electricity, fuel, crude oil, etc.), EUA (the ‘CO_2 price’), inflation rates, interest rates, indices / cost escalators for specific CAPEX and OPEX items, exchange rates, etc.

10 APPENDIX D: Results by Scenario

IS1 -- Q1, NL (A) -- ANT via RTM

Total Scenario User T&S Tariff	Min €6.4 /tCO2, Max €46.4 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes		8.2 MtCO2/yr	132 MtCO2	€63m	€39m	**€1.2 /tCO2**
ANT-RTM CN Onshore Pipe		1.0 MtCO2/yr	10 MtCO2	€67m	€4m	**€11.2 /tCO2**
RTM-Q1 Offshore Pipe		8.2 MtCO2/yr	132 MtCO2	€181m	€11m	**€2.6 /tCO2**
NNL Onshore CN Pipes		4.5 MtCO2/yr	67 MtCO2	€14m	€7m	**€0.5 /tCO2**
NNL-Q1 Offshore Pipe		6.0 MtCO2/yr	60 MtCO2	€290m	€10m	**€9.0 /tCO2**
Q1 Storage		12.4 MtCO2/yr	199 MtCO2	€52m	€467m	**€2.8 /tCO2**
NNL-Q1 Ship		1.4 MtCO2/yr	7 MtCO2	€109m	€79m	**€35.8 /tCO2**

IS2 -- Q1, NL (B) -- ANT via RTM

Total Scenario User T&S Tariff	Min €5.6 /tCO2, Max €46.4 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes		7.6 MtCO2/yr	122 MtCO2	€6m	€7m	**€0.2 /tCO2**
RTM-Q1 Offshore Pipe		7.6 MtCO2/yr	122 MtCO2	€181m	€11m	**€2.8 /tCO2**
NNL Onshore CN Pipes		4.5 MtCO2/yr	67 MtCO2	€14m	€7m	**€0.5 /tCO2**
NNL-Q1 Offshore Pipe		6.0 MtCO2/yr	60 MtCO2	€290m	€10m	**€9.0 /tCO2**
Q1 Storage		12.4 MtCO2/yr	199 MtCO2	€52m	€467m	**€2.8 /tCO2**
NNL-Q1 Ship		1.4 MtCO2/yr	7 MtCO2	€109m	€79m	**€35.8 /tCO2**
ANT-Q1 NL Ship		1.0 MtCO2/yr	10 MtCO2	€109m	€157m	**€33.3 /tCO2**

IS3 -- SNS, UK -- RTM via YH

Total Scenario User T&S Tariff	Min €4.5 /tCO2, Max €9.1 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes		9.0 MtCO2/yr	360 MtCO2	€6m	€22m	**€0.1 /tCO2**
RTM-YH Hub (UK) Offshore Pipe		9.0 MtCO2/yr	360 MtCO2	€462m	€56m	**€4.5 /tCO2**
YH Hub (UK)-UK SNS Aq. Offshore Pipe		13.5 MtCO2/yr	540 MtCO2	€161m	€26m	**€1.1 /tCO2**
UK SNS Aq. Storage		13.5 MtCO2/yr	540 MtCO2	€163m	€1,242m	**€3.5 /tCO2**

IS4 -- SNS, UK -- ANT (Low Demo) via RTM and YH

Total Scenario User T&S Tariff	Min €4.5 /tCO2, Max €31.7 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes		9.1 MtCO2/yr	365 MtCO2	€63m	€42m	**€0.8 /tCO2**
ANT-RTM CN Onshore Pipe		0.5 MtCO2/yr	5 MtCO2	€67m	€3m	**€22.2 /tCO2**
RTM-YH Hub (UK) Offshore Pipe		9.1 MtCO2/yr	365 MtCO2	€462m	€56m	**€4.4 /tCO2**
YH Hub (UK)-UK SNS Aq. Offshore Pipe		13.6 MtCO2/yr	545 MtCO2	€161m	€26m	**€1.0 /tCO2**
UK SNS Aq. Storage		13.6 MtCO2/yr	545 MtCO2	€163m	€1,251m	**€3.4 /tCO2**

IS5 -- SNS, UK -- ANT (High Demo) via RTM and YH						
Total Scenario User T&S Tariff	Min €4.4 /tCO2 Max €20.6 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes		9.3 MtCO2/yr	370 MtCO2	€63m	€54m	**€0.8 /tCO2**
ANT-RTM CN Onshore Pipe		1.0 MtCO2/yr	10 MtCO2	€67m	€4m	**€11.2 /tCO2**
RTM-YH Hub (UK) Offshore Pipe		9.3 MtCO2/yr	370 MtCO2	€462m	€56m	**€4.3 /tCO2**
YH Hub (UK)-UK SNS Aq. Offshore Pipe		13.8 MtCO2/yr	550 MtCO2	€161m	€27m	**€1.0 /tCO2**
UK SNS Aq. Storage		13.8 MtCO2/yr	550 MtCO2	€163m	€1,261m	**€3.4 /tCO2**

IS6 -- SNS, UK -- ANT (High Demo) via YH only (Ship)						
Total Scenario User T&S Tariff	Min €9.4 /tCO2 Max €34.1 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
YH Hub (UK)-UK SNS Aq. Offshore Pipe		5.5 MtCO2/yr	220 MtCO2	€161m	€20m	**€2.6 /tCO2**
Selby-YH Hub (UK) Onshore Pipe		5.5 MtCO2/yr	220 MtCO2	€59m	€12m	**€1.0 /tCO2**
Immingham-Selby (UK) Onshore Pipe		1.0 MtCO2/yr	40 MtCO2	€25m	€5m	**€2.2 /tCO2**
UK SNS Aq. Storage		5.5 MtCO2/yr	220 MtCO2	€161m	€701m	**€5.8 /tCO2**
ANT-Immingham UK Ship		1.0 MtCO2/yr	40 MtCO2	€109m	€636m	**€25.1 /tCO2**

IS7 -- SNS, UK -- ANT (High Demo & FS) via YH only (Ship)						
Total Scenario User T&S Tariff	Min €7.5 /tCO2 Max €22.7 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
YH Hub (UK)-UK SNS Aq. Offshore Pipe		8.5 MtCO2/yr	340 MtCO2	€161m	€22m	**€1.9 /tCO2**
Selby-YH Hub (UK) Onshore Pipe		8.5 MtCO2/yr	340 MtCO2	€59m	€16m	**€0.7 /tCO2**
Immingham-Selby (UK) Onshore Pipe		4.0 MtCO2/yr	160 MtCO2	€25m	€12m	**€0.8 /tCO2**
UK SNS Aq. Storage		8.5 MtCO2/yr	340 MtCO2	€162m	€895m	**€4.9 /tCO2**
ANT-Immingham UK Ship		4.0 MtCO2/yr	160 MtCO2	€123m	€1,176m	**€13.2 /tCO2**

IS8 -- SNS, UK -- ANT (High Demo) via YH only (Pipe)						
Total Scenario User T&S Tariff	Min €7.9 /tCO2 Max €32.2 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
YH Hub (UK)-UK SNS Aq. Offshore Pipe		8.5 MtCO2/yr	340 MtCO2	€161m	€22m	**€1.9 /tCO2**
Selby-YH Hub (UK) Onshore Pipe		4.5 MtCO2/yr	180 MtCO2	€59m	€11m	**€1.2 /tCO2**
ANT-YH Hub (UK) Offshore Pipe		4.0 MtCO2/yr	160 MtCO2	€503m	€59m	**€15.5 /tCO2**
UK SNS Aq. Storage		8.5 MtCO2/yr	340 MtCO2	€162m	€895m	**€4.9 /tCO2**

IS9 -- SNS, UK -- ANT (LT High Demo) Direct						
Total Scenario User T&S Tariff	Min €10.1 /tCO2 Max €31.0 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
YH Hub (UK)-UK SNS Aq. Offshore Pipe		4.5 MtCO2/yr	180 MtCO2	€161m	€19m	**€3.1 /tCO2**
Selby-YH Hub (UK) Onshore Pipe		4.5 MtCO2/yr	180 MtCO2	€59m	€11m	**€1.2 /tCO2**
UK SNS Aq. Storage		5.5 MtCO2/yr	220 MtCO2	€161m	€701m	**€5.8 /tCO2**
ANT-SNS Aq. UK Ship		1.0 MtCO2/yr	40 MtCO2	€109m	€638m	**€25.1 /tCO2**

IS10 -- SNS, UK -- ANT (High Demo & FS) Direct						
Total Scenario User T&S Tariff — Min €9.2 /tCO2; Max €20.7 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
YH Hub (UK)-UK SNS Aq. Offshore Pipe	4.5 MtCO2/yr	180 MtCO2	€161m	€19m	**€3.1 /tCO2**
Selby-YH Hub (UK) Onshore Pipe	4.5 MtCO2/yr	180 MtCO2	€59m	€11m	**€1.2 /tCO2**
UK SNS Aq. Storage	8.5 MtCO2/yr	340 MtCO2	€162m	€895m	**€4.9 /tCO2**
ANT-SNS Aq. UK Ship	4.0 MtCO2/yr	160 MtCO2	€123m	€1,184m	**€13.3 /tCO2**

IS11 -- Captain Sandstone, UK -- RTM via St. Fergus					
Total Scenario User T&S Tariff — Min €7.6 /tCO2; Max €16.2 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes	9.0 MtCO2/yr	360 MtCO2	€6m	€22m	**€0.1 /tCO2**
St. Fergus-Captain Sands (UK) Offshore Pipe	13.5 MtCO2/yr	540 MtCO2	€459m	€56m	**€3.0 /tCO2**
Captain Sands Aq. Storage	13.5 MtCO2/yr	540 MtCO2	€290m	€1,265m	**€4.6 /tCO2**
RTM-St.Fergus UK Ship	9.0 MtCO2/yr	360 MtCO2	€109m	€2,710m	**€8.5 /tCO2**

IS12 -- Captain Sandstone, UK -- ANT via RTM and St. Fergus					
Total Scenario User T&S Tariff — Min €7.3 /tCO2; Max €27.3 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
RTM Onshore CN Pipes	9.3 MtCO2/yr	370 MtCO2	€63m	€54m	**€0.8 /tCO2**
ANT-RTM CN Onshore Pipe	1.0 MtCO2/yr	10 MtCO2	€67m	€4m	**€11.2 /tCO2**
St. Fergus-Captain Sands (UK) Offshore Pipe	13.8 MtCO2/yr	550 MtCO2	€459m	€56m	**€2.9 /tCO2**
Captain Sands Aq. Storage	13.8 MtCO2/yr	550 MtCO2	€290m	€1,280m	**€4.5 /tCO2**
RTM-St.Fergus UK Ship	9.3 MtCO2/yr	370 MtCO2	€109m	€2,717m	**€8.1 /tCO2**

IS13 -- Captain Sandstone, UK -- NNL via St. Fergus					
Total Scenario User T&S Tariff — Min €10.2 /tCO2; Max €18.3 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
St. Fergus-Captain Sands (UK) Offshore Pipe	10.5 MtCO2/yr	420 MtCO2	€452m	€53m	**€4.5 /tCO2**
NNL Onshore CN Pipes	6.0 MtCO2/yr	240 MtCO2	€14m	€25m	**€0.3 /tCO2**
Captain Sands Aq. Storage	10.5 MtCO2/yr	420 MtCO2	€238m	€1,046m	**€5.7 /tCO2**
NNL-St.Fergus UK Ship	6.0 MtCO2/yr	240 MtCO2	€109m	€1,430m	**€7.8 /tCO2**

IS14 -- Utsira, NO -- NNL Direct					
Total Scenario User T&S Tariff — Min €3.8 /tCO2; Max €11.9 /tCO2	Avg Annual T/Put	Total T/Put	Total Costs (2011 Basis) CAPEX	OPEX	Avg. Cost per tCO2 T/Put
NNL Onshore CN Pipes	6.0 MtCO2/yr	240 MtCO2	€13m	€25m	**€0.3 /tCO2**
Utsira Aq. Storage	10.5 MtCO2/yr	420 MtCO2	€111m	€1,022m	**€3.8 /tCO2**
NNL-Utsira Aq. NO Ship	6.0 MtCO2/yr	240 MtCO2	€109m	€1,416m	**€7.7 /tCO2**

11 Appendix E: List of Tables & Figures