KNOWLEDGE SHARING REPORT – CO_2 Liquid Logistics Shipping Concept Business Model

SUPPORTED BY

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Project: The Rotterdam CCS Network
Sub-Activity: CO_2 Liquid Logistics Shipping Concept (LLSC)

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Knowledge Sharing Report 10: CINTRA Business Model

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1 Introduction

Global warming has been widely recognized to be caused by the emission of anthropogenic carbon dioxide. In order to tackle this, the Rotterdam Climate Initiative was founded by the Port of Rotterdam, companies in the industrial port district, the municipality and the environmental protection agency Rijnmond (DCMR). RCI intends to achieve a 50% reduction in CO_2 emissions by 2025 as compared to the levels emitted in 1990. The following measures are envisaged:

- energy efficiency measures
- use of low-temperature industrial heat
- large-scale use of biomass
- CO_2 capture, transport, reuse and storage (i.e. CCS)

With the different CCS logistical chain components identified and the high number of emitters in the Rotterdam area, the companies Vopak, Anthony Veder, Air Liquide and Gasunie joined forces in a joint venture called Carbon In Transport (De Rotterdamse CINTRA Maatschappij BV, or “CINTRA”) to provide a fully integrated CCS transportation solution – for both emitters and storage providers. Their cooperation was made public upon the signing of an agreement with the Rotterdam Climate Initiative (RCI) on the 17th of March 2010 to jointly contribute to the RCI target setting regarding CO_2 emissions reduction.

Through CINTRA its partners offer CO_2 transportation services from a CO_2 capture unit’s exit flange all the way to the sink’s wellhead, whereby CINTRA concentrates on off shore sinks only. The means of transportation can be a mix of pipe, barge and ship solutions, whichever is preferred. The parties within CINTRA are able to provide all means of transportation except barging, for which CINTRA will partner with a suitable party like Chemgas as appropriate. For the Rotterdam case specifically Gasunie handed over the on shore pipeline scope to a consortium more suited to the job while maintaining its right to step into any future off shore pipeline system as the hub expands. Below the transport services per partner is listed for the CINTRA project:

- On shore compression, drying and pipeline: by a consortium consisting of Stedin, Port of Rotterdam and Air Liquide.
- CO_2 hub: liquefaction by Air Liquide, storage and terminal operations by Vopak
- Shipping: by Anthony Veder
- Sink operations: by Maersk Oil & Gas

Fig. 1 Parties involved in the Rotterdam launching scheme

Two of CINTRA's companies Vopak and Anthony Veder were granted a subsidy to detail out the Liquid Logistic Shipping Concept (LLSC); a part of the results of this study have been made public by the Global CCS Institute. In this final report, prepared under the subsidy scheme mentioned above, CINTRA's launching project scheme is elaborated upon. The topics addressed regarding this project scheme are its Rotterdam setting, i) the parties involved, ii) the CINTRA business principles and iii) the stakeholder management process being put into place. In addition the transportation costs for the various shipping and pipeline routes are compared and how the CINTRA business model will be rolled out further.

1.1 Rotterdam setting

As mentioned earlier the Rotterdam area has concentrated its counter climate change efforts in the RCI. The set emission reduction targets are given below in Figure 2.

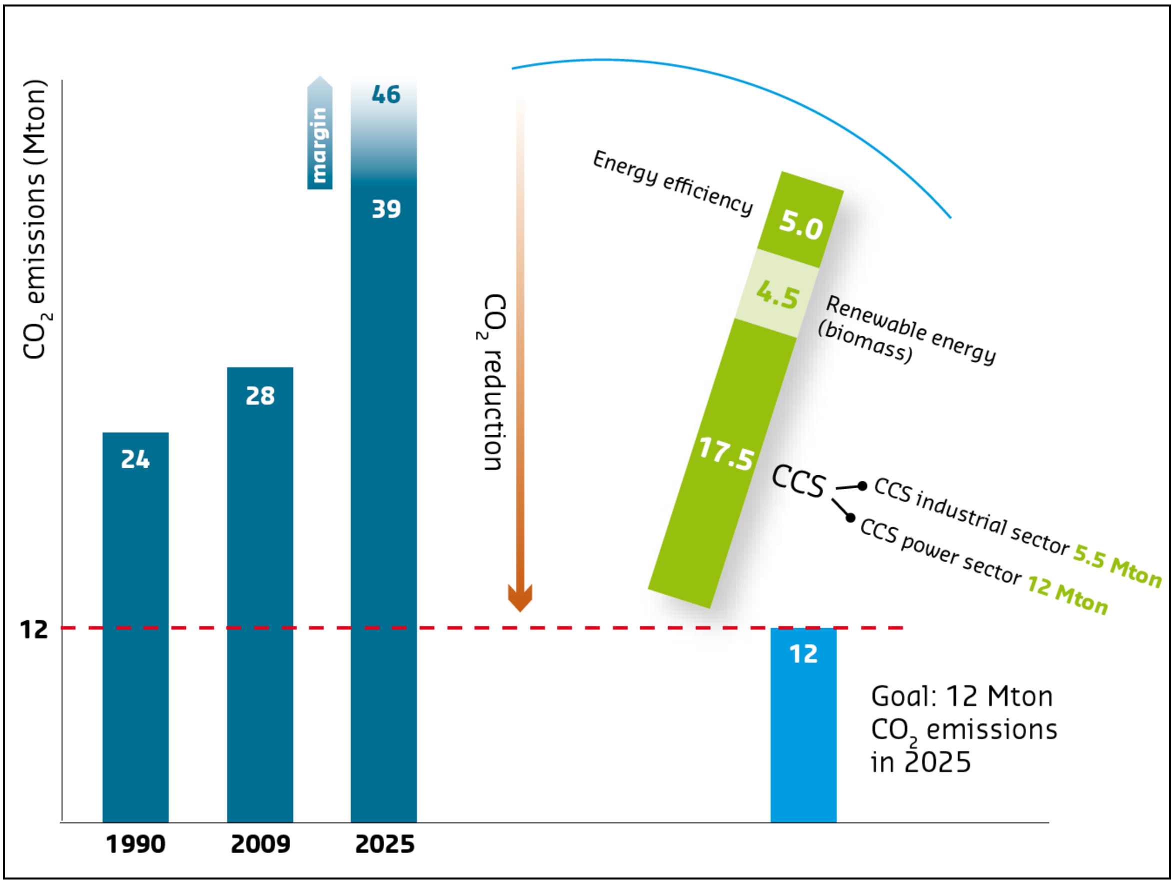

Fig.2 Rotterdam Climate Initiative CO_2 emission reduction targets *(source: RCI)*

The 1990 CO_2 emission levels are to be reduced 50% by 2025, with the foreseen growth scenario CO_2 emissions would be 46 million metric tons per annum (MTA) in 2025, therefore 26 MTA is to be avoided by then through 20 MTA of (a.o.) CCS driven CO_2 emission reductions. In other words, even a larger share than in the Blue scenario from the IEA in the contribution of the greenhouse gas emission reduction is to come from CCS, approximately 58%.

The Port of Rotterdam is the largest port in Europe, located in the city of Rotterdam, Netherlands. From 1962 until 2004 it was the world's busiest port, now overtaken by first Shanghai and then Singapore. In 2009, Rotterdam was the world's tenth-largest container port in terms of twenty-foot equivalent units (TEU) handled (2008: ninth, 2006: sixth). Covering 105 square kilometers (41 sq mi), the port of Rotterdam now stretches over a distance of 40 kilometers (25 mi). Most important for the port of Rotterdam are the petrochemical industry and general cargo transshipment handlings. The harbour functions as an important transit point for transport of bulk and other goods between the European continent and other parts of the world. From Rotterdam goods are transported by ship, river barge, train or road. Since 2000 the “Betuwe route”, a fast cargo railway from Rotterdam to Germany, has been under construction. The Dutch part of this railway has been opened in 2007. Large oil refineries are located west of the city. The river Meuse and Rhine also provide excellent access to the hinterland.

A number of emitters in the Rotterdam area have shown keen interest and commitment to develop CCS demonstration projects that may contribute to realization of this reduction target. The different types of emitters seen in the Rotterdam area are:

- power generation (coal and IGGC)
    - pre – combustion capture
    - post – combustion capture
- Industrial
    - refinery
    - hydrogen production

As a result, the Rotterdam area represents a large group of CO_2 emitters, with good connections to the industrial areas upstream the rivers Meuse and Rhine (the hinterland) where the German Ruhr area, being Germany's largest industrial area, is located just across the Dutch border. On top of this The North Sea's depleted oil and gas reservoirs represent a large CO_2 sink. This combination of a large emitter concentration and the availability of nearby sinks for CO_2 storage uniquely positions Rotterdam for launching of the CINTRA transportation concept.

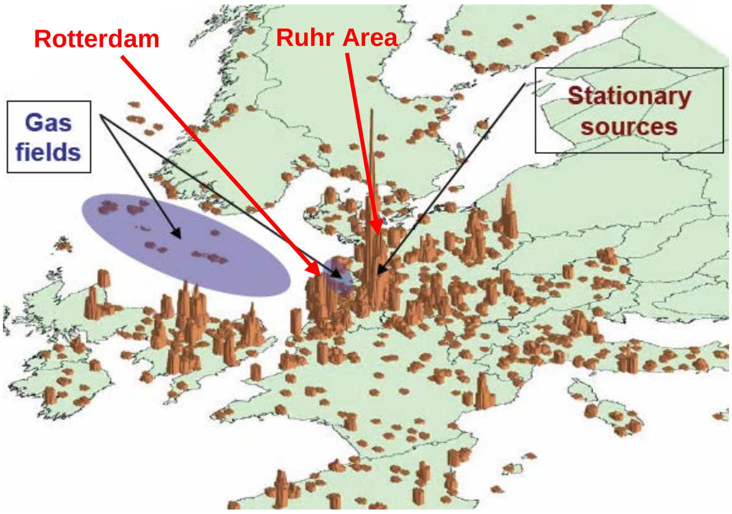

Fig. 3 Emitters and Storage clusters North West Europe

Zooming in on the Rotterdam port area, the CO_2 hub location is chosen according the following criteria:

- Safe distance from living areas and public facilities
- Safe handling of CO_2 vessels
- Safe sailing routes to harbour entrance and inland water ways
- Proximity to launching customers and pipeline right of way
- Terrain availability for future growth possibilities

PoR is in the process of completing the Maasvlakte II project which concerns the reclaim of 1,000 hectares new land to the west to extend its port facilities. In the figure below the potential CO_2 hub location is highlighted.

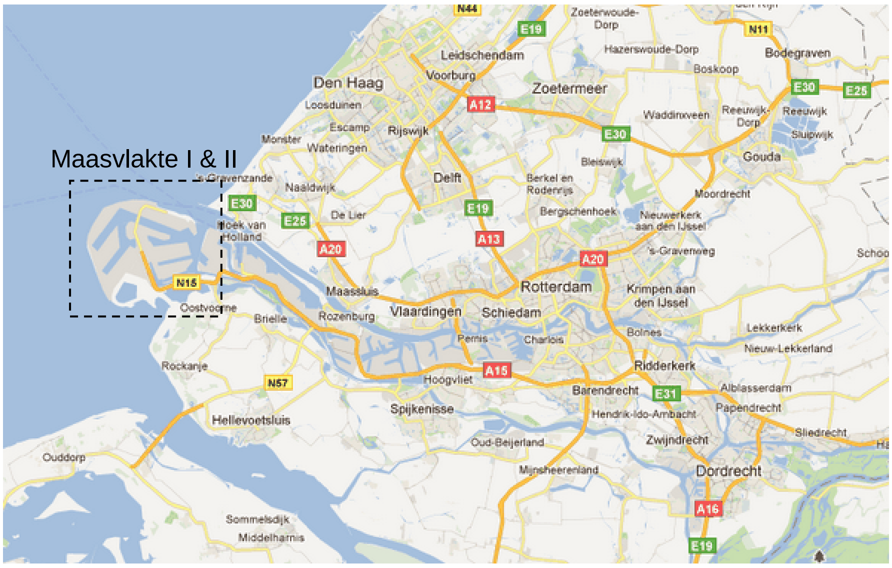

Fig. 4 Port of Rotterdam including Maasvlakte II extension

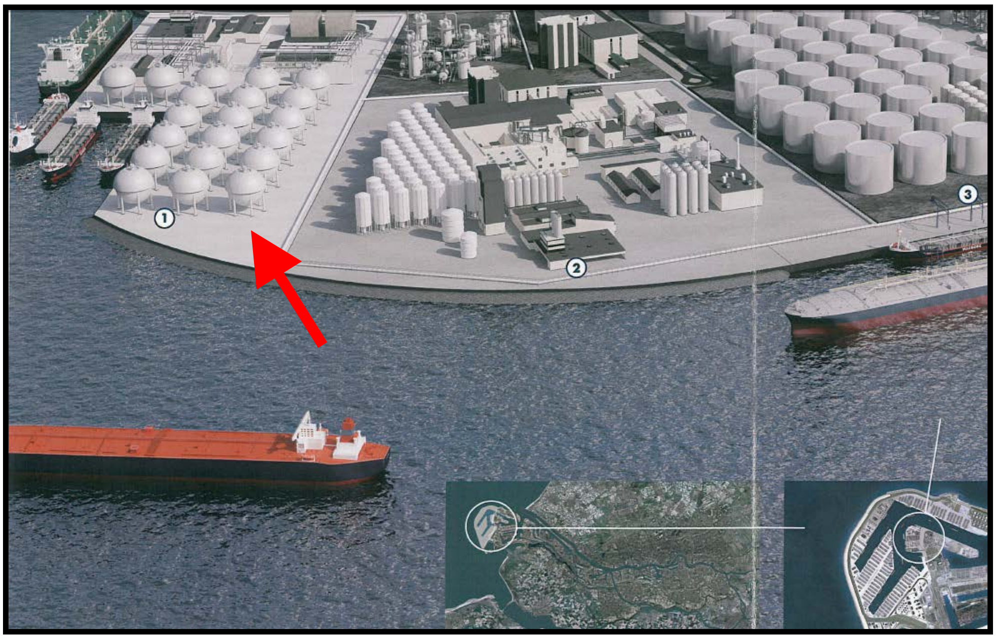

Fig. 5 CO_2 envisaged hub location on Maasvlakte II

1.2 Parties involved

The CO2 hub's launching scheme is envisaged to be set up by a group of eight companies. Below these companies, their relation and the respective scopes of work have been listed:

- On shore compression, drying and pipeline: by a consortium consisting of Stedin, Port of Rotterdam and Air Liquide.
- CO_2 hub: liquefaction by Air Liquide, storage and terminal operations by Vopak
- Shipping: by Anthony Veder
- Sink operations: by Maersk Oil & Gas

Fig. 6 Parties involved in the Rotterdam launching scheme

On shore pipeline:

Rotterdam has a pipeline network of 1,500 kilometers for liquid bulk, fast, safe and environmentally friendly transport within the port. More than 40% of land area in the harbor is used by the oil and chemical cluster. These companies are connected to this pipeline network at a specific point-to-point basis or through joint common carriers that provide access to third parties.

Stedin - as a network operator is responsible for the safe and reliable transport of electricity and gas. Stedin facilitates the transportation of gas and electricity in the Randstad (urban area of Amsterdam, Den Hague and Rotterdam) to nearly two million private, corporate and governmental clients. In addition, as an operator, Stedin is responsible for the construction, expansion and maintenance of the electricity transmission network. Stedin is a 100% subsidiary of Eneco Holding NV.

Port of Rotterdam - is the manager, operator and developer of the Rotterdam port and industrial area. As a public company it has two shareholders: the Dutch State and the City of Rotterdam. Its statutory objectives are the development, construction, management and operation of the port and industrial area in Rotterdam and to promote an effective, safe and efficient handling of shipping in the harbor and off coast. The Port Authority leases out - through long-term contracts - port sites for businesses, in particular for storage and transshipment activities, and the (petro) chemical industry, including energy producers.

Air Liquide - is the world leader in industrial and medical gases and related services with more than 40,000 employees in 75 countries. Air Liquide offers innovative solutions based on constantly enhanced technologies and produces air gases (oxygen, nitrogen, argon, rare gases etc) and many other gases including hydrogen.
The company contributes to the manufacturing of many everyday products, among which are: CO_2 for sparkling beverages, protective atmosphere for packed foods, oxygen for hospitals and homecare patients, ultra-pure gases for the semiconductor industry, hydrogen to desulphurized fuels. In addition to the above-mentioned activities Air Liquide designs, owns and operates gas purification technologies. Air Liquide´s company Lurgi, pioneer in gasification technologies, expanded the know-how of Air Liquide in this area. Among others, CO_2 Compression and Purification Units are being developed to liquefy and capture CO_2 through cryogenic rectification and/or liquefaction of CO_2“rich” streams coming from large localized CO_2 emission sources. These concern large tailor-made plants designed according specific customer needs regarding carbon capture and storage: type of emission source, size, CO_2 specification and transport and storage boundary conditions.

The CO_2 hub terminal:

Using its experience in the logistics field, Vopak and Anthony Veder developed the LLSC and joined forces with Gasunie (Dutch national gas grid operator) and Air Liquide (gas processing service provider) to set up the joint venture CINTRA (Carbon In Transport) to offer a one-stop shop for the LLSC’s envisaged customers.

Vopak – with its headquarters in Rotterdam, the Netherlands – is the world’s leading independent provider of conditioned storage facilities for bulk liquids. Operating in 31 countries worldwide, Vopak offers storage and transshipment solutions at 80 terminals, thereby connecting all continents through the world’s major shipping lanes. Vopak’s total storage capacity is 25.6 million cubic meters, which is dedicated to the storage of liquid and gaseous chemicals, oil products, petrochemicals, biofuels, liquefied gases and vegetable oils. In 2014 total storage capacity will reach nearly 33 million cubic meters. With almost 400 years of experience in storage and transshipment, Vopak is almost genetically dedicated to service. The company’s annual turnover is 1.1 billion euro (2010) Vopak’s shares are listed at the Amsterdam AMX-index. Vopak and its joint ventures employ an international workforce of more than 5,700 people.

Anthony Veder is one of the few tanker owners totally dedicated to the transport of liquefied gas. Established in 1937 and based in the Port of Rotterdam, Anthony Veder is involved in all aspects of gas transportation, including liquefied petroleum gas (LPG), liquefied natural gas (LNG), petrochemicals and Carbon Dioxide (CO_2). Innovation has always been at the heart of the company and they were the first tanker firm to introduce a purpose-built CO_2 vessel in 1999. They own one of the most modern and sophisticated gas tanker fleets (> 25 vessels) in the industry and this enables them to offer a reliable and flexible service. All aspects of Ship Management are present within the company, from chartering and operations, to technical ship management, crewing and business development, making it truly integrated ship owner. Next to handling the ship management of its own vessels they also do so for their pool partners and for third-party vessels. Currently they employ over the 600 people onshore and at sea.

Gasunie - Gasunie is a European gas infrastructure company. Their network ranks among the largest high pressure gas pipeline grids in Europe, consisting of over 15,000 kilometers of pipeline in the Netherlands and northern Germany, dozens of installations and approximately 1,300 gas receiving stations. The annual gas throughput totals approximately 125 billion cubic metres. They serve the public interest in the markets in which they are active and work to create value for our stakeholders. Gasunie is the first independent gas transport provider with a cross-border network in Europe and offers transport services via its subsidiaries Gas Transport Services B.V. (GTS) in the Netherlands and Gasunie Deutschland in Germany. They also offer other services in the gas infrastructure field, including gas storage and LNG. Due to the reliability and strategic location of our network in relation to expanding international gas flows, the Gasunie network forms the core of what is called the northwest European 'gas roundabout'.

With this joint venture, all the necessary skills and competencies for safe and reliable CO_2 handling and transportation are combined and provided for its partners.

2 CINTRA Business model

2.1 Business model principles

The objective of CINTRA is to provide emitters with a one stop shop for a complete logistical transportation solution for their captured CO_2 from their site to an offshore storage location.

CINTRA intends to take the captured CO_2 from the emitter to an intermediate storage site (i.e. CO_2 Hub or terminal in the Port of Rotterdam) via either barge (in liquefied phase) or pipeline (gaseous/dense phase). From this intermediate storage location the liquid CO_2 can be shipped by a seagoing vessel to the permanent offshore storage sites where the ship will discharge on a standalone basis via an offshore infrastructure (e.g. turret, submersed flexible hose or loading tower) that links the vessel to an injection platform or subsea completion/template. In addition compressed CO_2 is transferred from this CO_2 Hub to the storage sites by means of offshore pipelines. The CO_2 Hub will combine and link pipeline systems and barging/shipping routes, and will include functions like intermediate liquid storage, liquefaction of CO_2 and vaporization of liquid CO_2 as required. The concept will provide maximum flexibility and reliability to both emitters and storage locations, eventually leading to reduced cost of Carbon Capture and Storage (CCS). The concept is further illustrated below.

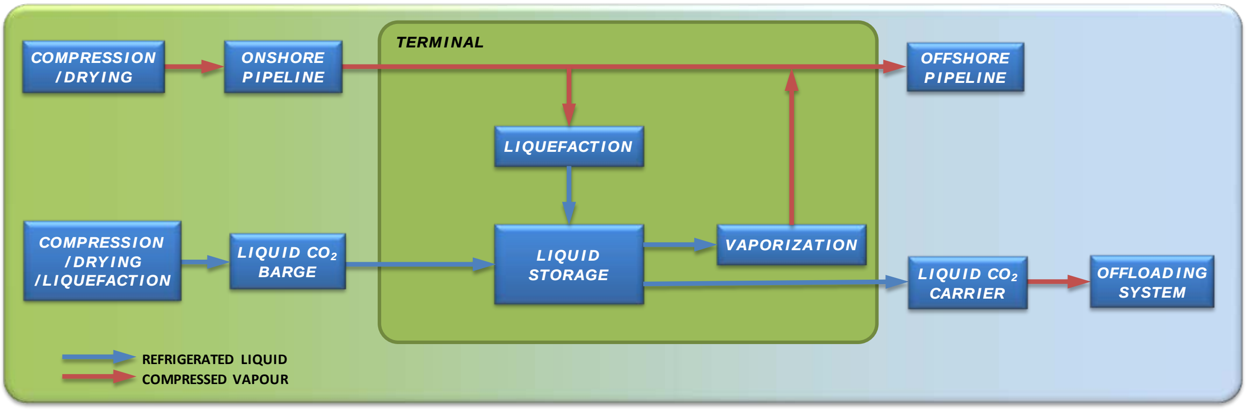

Fig. 7 CO_2 routes through the hub terminal

Technically this means that transforming the CO_2 from a gas to a liquid and back is a hub service as illustrated below.

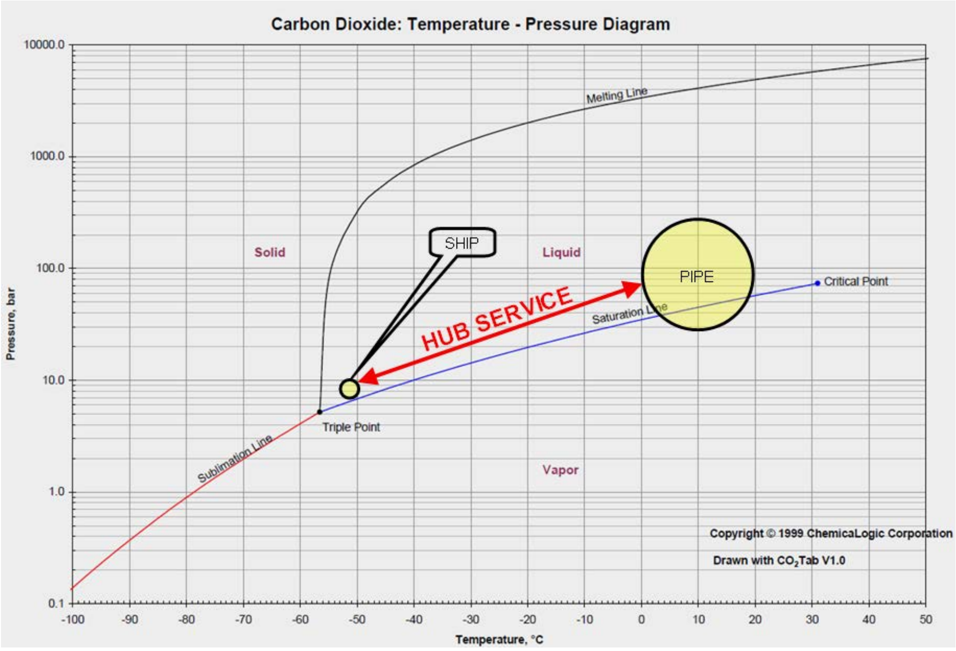

Fig. 8 Hub service: CO_2 phase transitions

CINTRA's main goals are listed below:

- Creating transportation economies of scale by combining multiple sources and sinks
- Enhancing reliability in a cost effective manner by creating a source/sink network which allows parties to act as each other's backup CO_2 supply and disposal route, thus creating CO_2 routing flexibility
- Accommodating cost effective organic growth of the logistic chain by expanding existing terminals, adding terminal tanks, vessels and pipelines and re-allocating ships to other routes (thus replacing them by pipelines on their original route) as the network grows.
- Creating a reliable CO_2 source for industrial purposes such as Enhanced Oil Recovery (EOR) - facilitating as such an economic incentive for CCS

To achieve these goals the following functionalities are to be provided by CINTRA:

- Accommodating an expanding group of emitters and storage providers
- Accommodating the unloading of barges coming from inland and the loading of ships going to offshore sinks
- Linking the pipeline and barge/ship system by providing CO_2 vaporization/liquefaction and intermediate CO_2 storage services at the hub (please see figure above to illustrate the technical implication)
- Provide independent custody transfer metering (for ETS or any other applicable carbon emission trading scheme)

As indicated above the terminal will be multi-customer, meaning that its operator will handle the CO_2 of various parties, both emitters and sink operators, in parallel. Therefore the operator's impartiality shall be beyond any doubt. Consequently the system operator shall not have any interest in whose CO_2 is processed first etc. Consequently the operator can not take title to the molecules himself.

2.2 Organization/Management structure

The need for an independent and complete transportation provider became apparent as soon as talks with emitters and sink operators kicked off. Ideally transportation through such a complex value chain is performed by one operator. To this end CINTRA acts as the chain's independent operator and is committed to treat all parties it deals with impartially.

As mentioned earlier the setup of CINTRA is such that essentially all links in the barge/shipping/piping transportation chain are covered by its partners. Per transport agreement the partners will provide services to CINTRA as needed.

The following activities are considered to be performed by CINTRA:

- Overall transportation Chain day-to-day technical operations: scheduling and nominating, i.e. chain traffic control
- Third part contracting
- Permitting
- Client interfacing
- Business development and sales

Activities to be performed by its partners:

- Building the chain's assets as per CINTRA's requirements
- Overall transportation Chain links' day-to day technical operations and maintenance

Since CINTRA does not have a running business yet at this point in time, its current status is such that the activities listed above are primarily performed by its partners. A managing director and financial controller have been appointed and among the selected representatives the roles have been divided as follows:

Account managers were elected for:

- Individual emitters, groups/clusters of emitters
- Sink/storage providers
- Political stakeholders

Supportive functions:

- Environmental, safety and permitting
- Technical
- Financial
- Legal
- Communication
- Risk management

Special attention to environmental and risk impact studies is given prior the start up of permitting procedures. Permitting has demonstrated itself in the past as being on the critical path of any project. By centrally coordinating the permit for the complete CINTRA chain, application inconsistencies will be avoided.

Technical: defining and optimizing the performance of the various links in the chain and subsequently setting their battery limit conditions such that the chain's overall costs are minimized whilst maintaining a robust, safe and reliable operation.

Financial: as the different chain components imply use of different assets, their associated cost models need to be aligned. An overall cash flow model has been set up to accommodate the different nature of the individual parties' cash flow models. This step was instrumental to create transparency among both the partners its clients.

Legal: for both the day to day operations of CINTRA in the development phase (in which Non Disclosure Agreements were signed, Memorandum of Understandings negotiated etc) and in the structuring of the Joint Venture, thorough legal advice and support was needed. In addition, the current commercial situation is requiring the negotiation of the transportation agreements (CINTRA – client level) and the Service Level Agreements (SLA's) on CINTRA – JV partner level.

Risk: regular risk assessments are primordial to generate a sound business case. Again here technical requirements of the chain have an impact on safety but also from an operational perspective requirements come forward. Questions on financial impact and uptime (both are inherently related) need to be assessed and dealt with to ascertain proper risk mitigation.

Stakeholder management is the number one priority in any CCS demonstration project due to the public's posture. It was shown in the past that if local population and environmental concerns aren't involved in the decision process and adequately handled, the project may not succeed.

2.3 Legal structure

The Joint Venture itself is incorporated in the Netherlands as a Besloten Vennootschap (B.V.), meaning that it is a legal entity that can operate under Dutch law and fiscal regime. This allows it to enter into legally binding contracts and agreements with other companies.

Its shareholders are the parties that are to provide the services required for the transportation chain through a service level agreement. Therefore no assets in CINTRA are needed which is also driven by the fact that the types of services as provided by its partners differ significantly in terms business model specifics.

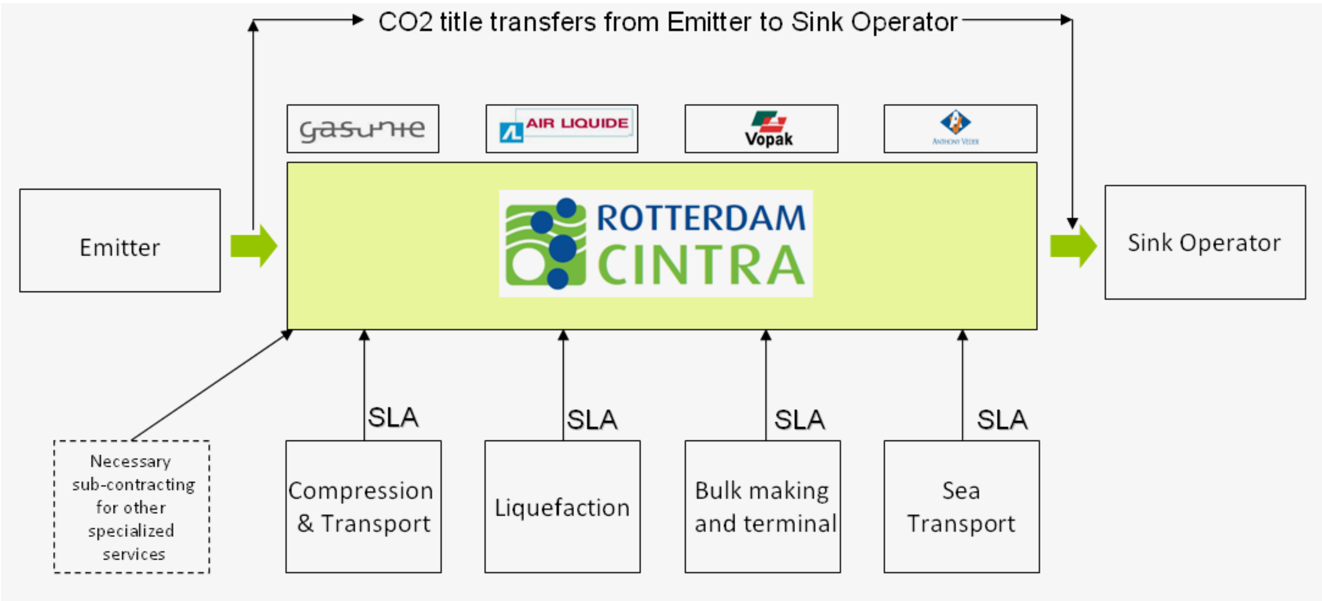

Fig. 9 CINTRA legal/contractual structure

2.4 Contractual framework

The basis for the Transport Agreements (TA's) CINTRA will enter into will be based on the following principles:

- In the base case the emitters are CINTRA's customers as it is the emitter who has to deal with its Carbon emission obligations/strategy
- ETS allowances generated trough CCS are for the sole benefit of the Emitter
- CINTRA will not take title to the CO_2. Custody transfer point will be mutually agreed upon between emitter, sink operator and CINTRA. As CINTRA parties are accustomed to offer transportation services this is in no event an issue
- CINTRA will not be involved in the offshore facilities costs and risks
- CINTRA TA's concern long term (+/- 20 years) take-or-pay contracts, meaning that emitters will need to book capacity in the transport system and will subsequently pay a fixed tariff for the associated investments and fixed costs regardless whether they use the transportation capacity or not.
- CINTRA has one TA with the emitter, backed up by one SLA per JV partners transferring rights and obligations from the TA to the JV partner
- TA's and SLA's are based on a standard template using a repeatable formula to enable transparency and economies of scale that are predictable and as such usable in commercial negotiations
- TA and SLA clauses aim for treating its customers in an impartial, fair and transparent manner with CINTRA as its independent operator.

Cash flows generated by the TA's flow to the partners via the SLA's after the deduction of minor CINTRA costs such as limited personnel and overhead etc.. No overall fee/profit is applicable to the CINTRA TA's: a partner not contributing to an emitter specific transportation solution is not entitled to any compensation whatsoever. Summarizing CINTRA only runs on a cost plus basis that allows for a pre-agreed project IRR.

Obviously every emitter and sink provider will have its specific project related implications on the contract framework but it is advisable to keep the CO_2 TA's as much in line with existing commodity flows and subsequent contract setups as possible.

For the Rotterdam launching scheme the on shore pipeline system operations is not a service that will be provided via CINTRA. Therefore emitters will need to establish their own transport agreement with the pipeline consortium although this originally was planned to be part of CINTRA's "one-stop-shop" solution. Pre-FID negotiations may still lead to streamlining this aspect.

3 Commercial

3.1 Transportation costs

To illustrate the impact of different variables like location, capacity and type of transport a high level cost estimation model was developed. The basis for the cost estimate is the LLSC as presented Figure 10. The transport by pipeline is assumed to be in the dense phase for all scenarios. The previously presented schematic was based on subcritical onshore pipeline transport. In this evaluation longer distances are reviewed for which subcritical transport is not recommended.

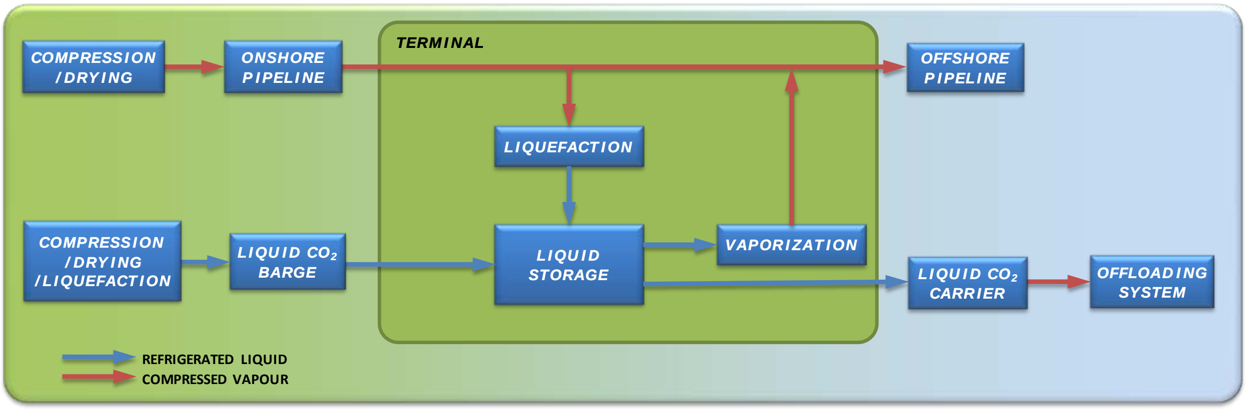

Fig. 10 Schematic representation of the LLSC

The different building blocks consist of different chain components. For these chain component a transportation tariff, expressed in an indexed cost per tonne of CO_2 transported, was defined based on component cost estimates and budget quotes. The limited time and available information at this stage of development for the concept required extrapolation of available data to provide a range of data suitable for different capacities and distances. It was assumed that only ship/barge costs and pipeline costs were influenced by both capacity and distance. Other component costs are only related to the capacity. The obtained costs include capital investment costs as well as operational costs. Indexed cost figures are used to analyze trends and development properties of the concept.

Cost estimate assumptions

For the study the main assumptions for the cost estimates are:

- Required IRR of 10%;
- Depreciation period for CAPEX of 20 years;
- Inflation at 2 %;
- Profit tax rate at 25.5 % of EBT;
- Termination value at book value;
- Liquefier at emitter inlet pressure 0,1 barg, 30 °C, wet;
- Drier regeneration by means of electric heat;
- Electricity @ 60 €/MWh;
- Liquefier Cooling water: 40 m^3/ton CO_2; provided by a closed cooling water circuit with a forced draft cooling water tower;
- Insurance + maintenance : 3 % of above;
- Personnel: 17 FTE for total terminal => 8,5 FTE for liquefier and 8,5 FTE for tanks;

- Barge tariffs hold until a sailing route of 700 km (R'dam <-> Karlsruhe);
- Liquefier at the hub: inlet pressure ±25 barg, 30 °C, 1 ppmv H_2O;
- Design capacity = 120 % of average; design capacity in MTA;
- Insurance + maintenance : 3 %;
- **ONSHORE HP COMPRESSOR/DRIER/PIPELINE**
  - All bull gear compressor plus Ti printed circuit heat exchangers, incl. stand alone CW towers;
  - Costs above uplifted by 10 % to come to clients costs (permitting, legal, project team etc.);
  - OPEX: 1 % insurance, 2 % maintenance, 1 operator in 5-shift system;
  - Electricity includes power for mole sieve regeneration;
  - No booster stations assumed: 220-120 bar pressure drop over pipe; diameter set accordingly as a function of length;
  - Pipeline CAPEX: 85 -90 €/inch*meter;
  - Compressor sizes considered 0,5, 1 & 1,5 MTA;
- **BARGE & HUB TERMINAL**
  - Hub terminal size set equal to 1,5 x ship size;
  - Barge terminal size set at 7500 m^3;
- **REGAS PLANT**
  - Assumed to consists of BOG blower, recondenser, LP+HP pumps ORV + backup SCV
  - No fuel consumption for backup SCV included (is negligible at the Rotterdam location);
  - Utilities such as NG supply to SCV and water system excluded: is already part of terminal utilities which contains a CW system whose costs should either cover the liquefier or the regas water system;
  - Design capacity at 120 % of annual average;
- **OFFSHORE HP COMPRESSOR/DRIER/PIPELINE**
  - All bull gear compressor plus Ti printed circuit heat exchangers, incl stand alone CW towers;
  - Costs above uplifted by 10 % to come to clients costs (permitting, legal, project team etc.);
  - OPEX: 1 % insurance, 2 % maintenance, 1 operator in 5-shift system;
  - No booster stations assumed: 100 bar pressure drop over pipe; diameter set accordingly as a function of length;
  - Pipeline CAPEX: 120 €/inch*meter;
- **SHIP**
  - HFO is used @ USD 550/mt;
  - Tonnage TAX regime;
  - 20 yr depreciation, 10 IRR, no offshore infrastructure included;
  - Voyage related spare 1.3 days;
  - Offloading system CAPEX and OPEX excluded;
  - Ship sizes considered: 6, 12, 20 & 30 x1000 m^3;
- **SHIP OFFLOADING SYSTEM**
  - Tariffs are valid for an off loading tower or an STL. For the STL the costs on the ship are included
  - Offloading system concerns one offloading point: no spare offloading system are foreseen;
  - Costs are assumed to be irrespective of flow.

Chain component costs are based on equipment, ship, barge and pipeline total installed cost provided by cost estimating software validated and supported by vendor quotation and input if required. All chain components are estimated for a design capacity of 120% of the yearly average capacity as presented. Operational cost for the chain components is included in the presented tariffs and include utilities cost, fuel, personnel, maintenance, insurance and land lease.

The assumption of a 20 year contract duration, as is considered appropriate for infra structural facilities such as the CCS transportation chain, is of paramount importance. To illustrate this below chart is given.

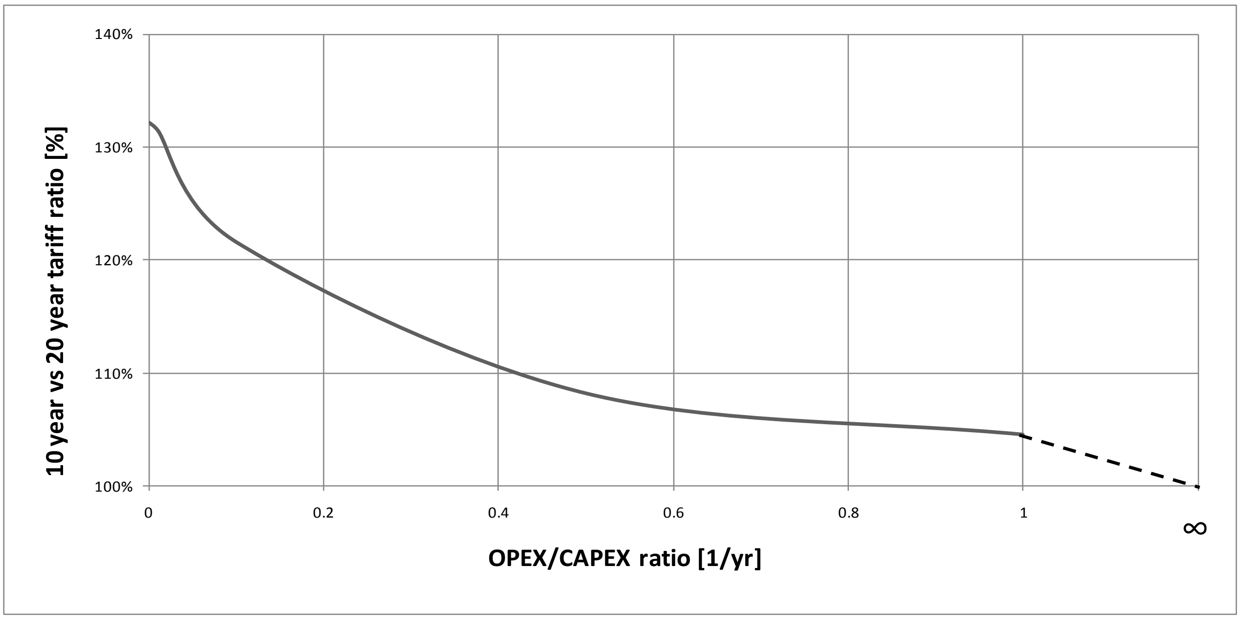

Fig. 11 10 year vs. 20 year tariff as a function of OPEX/CAPEX ratio

The CAPEX is the initial investment and OPEX is the annual operational costs of the facility. The chart implicates that when the contract duration would be decreased from 20 to 10 years for instance, the tariff increase would be around 20 %, depending on the OPEX/CAPEX ratio that applies for that specific part of the chain (see below). This demonstrates that CCS requires long term commitments from policy writers to emitters, sink operators and transporters alike to make CCS affordable for society.

Chain component	OPEX/CAPEX ratio
Barge/ship	0.15-0.20
Liquefier	0.10-0.15
Terminal	0.05-0.10
High pressure compressor	0.15-0.20
Pipelines	0.05
Vaporizer	0.05-0.10
Offshore off loading system	0.05

Table 1: Chain component OPEX/CAPEX ratios

One other noteworthy phenomenon is that, since shipping transportation concepts typically show a higher OPEX/CAPEX ratio than piping concepts, the tariff penalty for shorter contact durations will be slightly smaller for the former. Hence the LLSC has a financial advantage for any launching CCS scheme which share a tendency regarding shorter term contracts.

Chain component cost

The LLSC consists of four transportation sections and a central terminal. The tariff index for the four different transportation sections are presented below to illustrate the dependency of these four routes with regard to transportation distance and transport capacity.

Onshore pipeline CO_2 transport

The onshore pipeline transportation section costs is built up of two components, the installation and operational costs of the pipeline itself and the installation and operational cost of the installation at the emitter. The installation at the emitter involves all required cost to dehydrate and compress the CO_2 stream as delivered by the emitter to pipeline specification. The transportation is performed at supercritical conditions with a fixed pressure drop between emitter and terminal or sink for all cases.

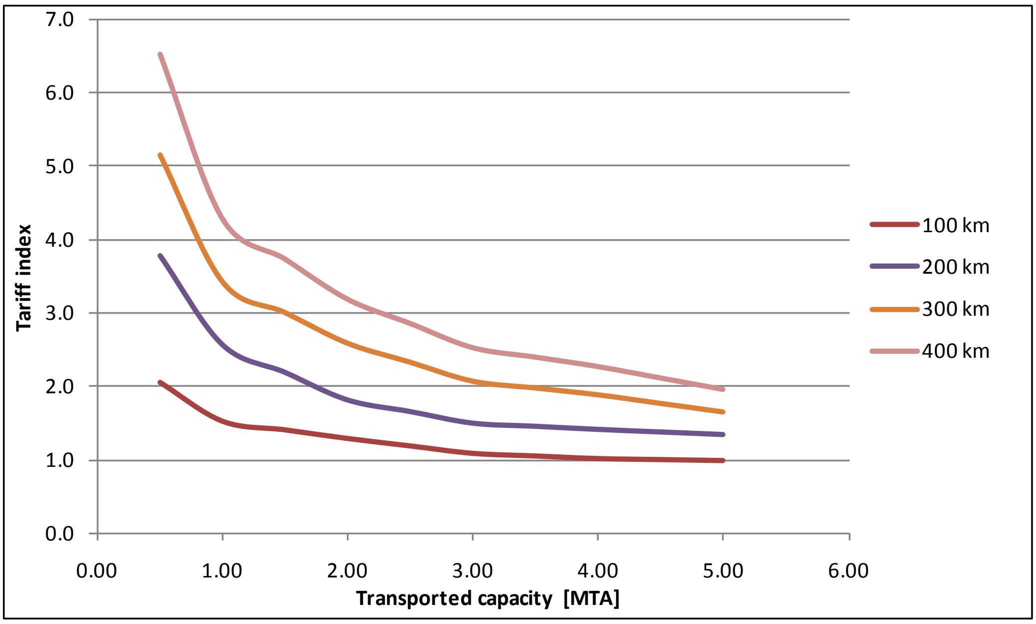

Fig. 12 : Onshore pipeline CO_2 transportation costs for various transportation distances

Transportation costs for an onshore pipeline and emitter installation depends both on capacity and distance. The results show the clear benefit of economy of scale, where the impact of distance on the costs per transported tonne of CO_2 also becomes less if total capacity is increased.

Onshore liquid CO_2 transport

Onshore transportation of liquid CO_2 is done by barges. The limited size of barges for inland transportation by waterways makes the transportation cost per tonne, only for the barging costs, almost independent of distance. This is valid up to a certain maximum distance, depending on barge capacity. The installation required at the emitter involves all assets to dehydrate, liquefy, store and transfer from the emitter to the barges. The cost for the combination of barging and emitter developments for different capacities and distances are presented in Figure 13.

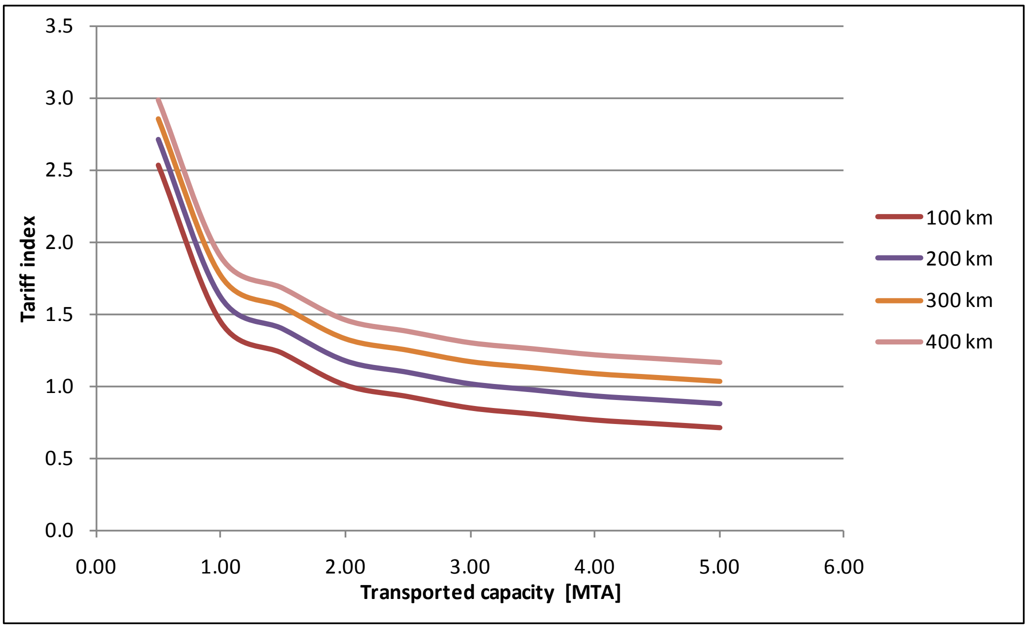

Fig 13 : Onshore liquid CO_2 transportation costs for various transportation distances

The transport cost of liquid CO_2 by barge is less depending on transportation distance compared to pipeline transport, especially for smaller quantities.

Offshore pipeline CO_2 transport

The offshore transport of CO_2 by pipeline only involves the installation and operational costs for the pipeline itself. The dependency on capacity and distance is presented Figure 14.

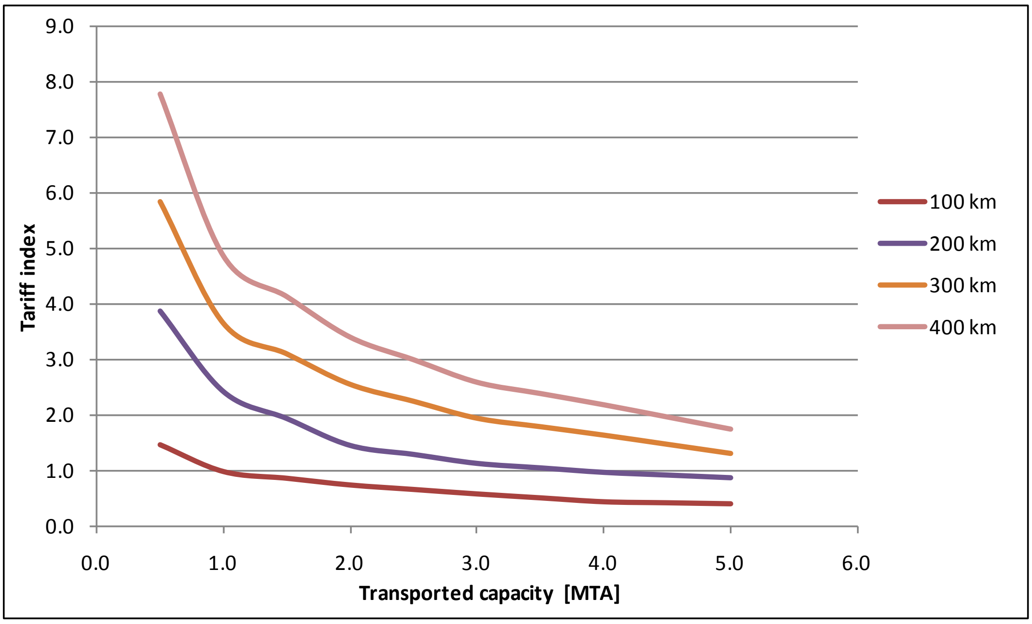

Fig. 14 Offshore pipeline CO_2 transportation costs for various transportation distances

The results show, as expected, a similar dependency on distance and capacity as for onshore pipeline transport. The absolute costs for offshore pipeline transport is higher compared to onshore transport.

Offshore liquid CO_2 transport

The cost for offshore liquid transport by ships includes besides the ship costs also the costs for the offloading facilities (tower or buoy) at the sink location.

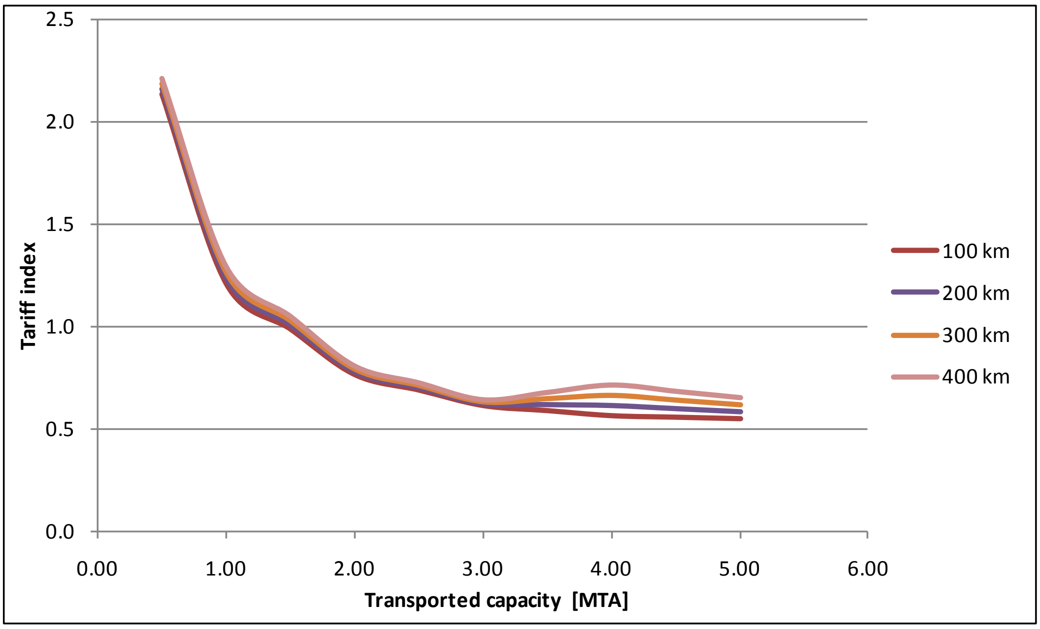

Fig. 15 : Offshore liquid CO_2 transportation costs for various transportation distances

The sailing time of the liquid CO_2 carriers is relatively short compared to the other operational activities, like loading and unloading, required for liquid CO_2 transport. This makes liquid CO_2 shipping almost independent of distance, for the distances reviewed in this study. The results also show that low transportation capacities have a negative impact on the costs per tonne of CO_2. The slight increase at higher capacities is a result of the limited number of ship sizes used in the analysis. Ship size is a more important variable in offshore transport as compared to onshore transport where barge sizes are limited by the sluice sizes along the rivers Rhine and Maas.

Terminal costs

The terminal costs are depending on the required chain components based on capacities and transportation types from the emitters and to the sinks. The three chain component costs at the terminal are vaporization of liquid CO_2 for offshore pipeline transport, liquefaction of CO_2 for liquid shipping and terminal costs including storage tanks and all other requirements for the terminal. The cost per ton of CO_2 is presented as tariff index for the different components as a function of capacity in Figure 16. The results show that economy of scale mainly applies to the terminal costs itself, where liquefaction and vaporization capacity have little influence on the cost per tonne CO_2.

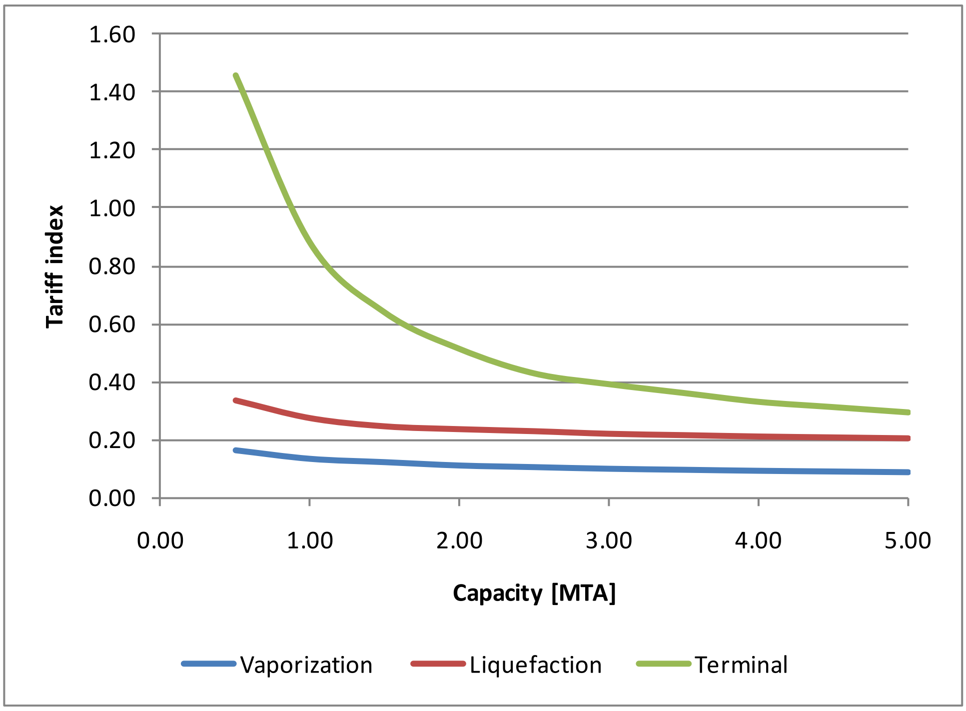

Fig. 16 Terminal component costs

The high sensitivity of the terminal tariff is caused by the requirement to have a minimum storage capacity available regardless of throughput in order to guarantee a certain chain reliability. This demonstrates that the emitters' required flow flexibility in relation to the chain reliability they require has a significant impact on terminal tariffs: a high design vs normal operating flow requirement in combination with a high chain reliability calls for large terminal tanks and thus tariffs.

Direct connection scenarios

Initial development projects will most likely be developed for single source connection to a single sink. First these direct connection development are reviewed to identify the variables that influence the transportation costs of a certain concept. This review will provide an indication of the best option for transport based on variation of distance and capacity. In the direct connection scenarios four different options can be identified in the presented system, which are discussed in the next paragraphs.

Pipe → pipe

The first scenarios are referred to as "pipe → pipe". In these scenarios CO_2 is transported from an emitter to a sink only by pipeline, for both onshore and offshore. This scenario is schematically presented in Figure 17. This shows that for a direct connection by pipeline between emitter and sink no terminal is required.

Fig. 17 Schematic representation of "pipe → pipe"-scenario

The three main components included in this scenario are the compression/treatment plant at the emitter, an onshore pipeline and an offshore pipeline. The cost figures were estimated based on a constant compressor discharge pressure and arrival pressure for pipelines operating in the supercritical regime. In other words, a constant pressure drop was assumed over the pipelines. The pipeline size and associated costs are a result of the pipeline length.

To illustrate the impact of the distance between source and sink on the transport costs, four different cases are presented, each for different distance at 2 MTA transport capacity. The onshore and offshore pipeline section lengths are equally distributed for these cases over onshore and offshore. The second figure presents the impact of capacity for a fixed transport distance of 200 km (100 km onshore and 100 km offshore).

The cost per tonne CO_2 transported increases with distance, but decreases with capacity. In Figure 18 the distribution of the costs show that both the onshore as well as the offshore section cost increases with distance as both pipeline costs are distance dependent.

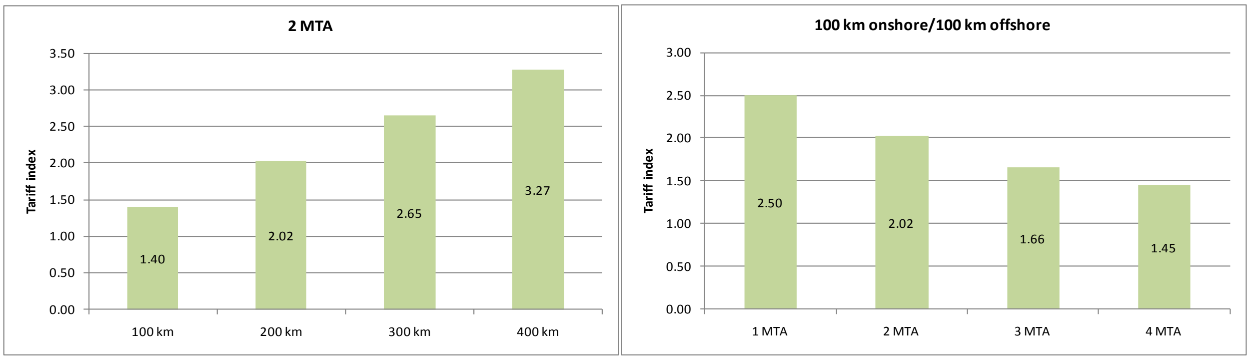

Fig. 18 "pipe → pipe"-scenario distance and capacity impact

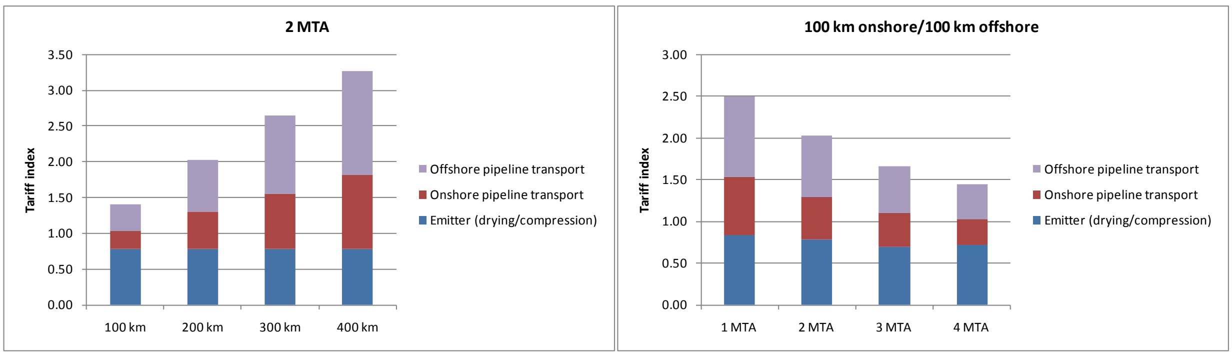

Fig. 19 "pipe → pipe"-scenario cost distribution

Pipe → ship

The second scenario is referred to as the "pipe → ship"-scenario. This means that the CO_2 is transported from the emitter to a terminal by pipeline, where it is liquefied for ship transport to the offshore sink. This scenario is schematically represented in Figure 20.

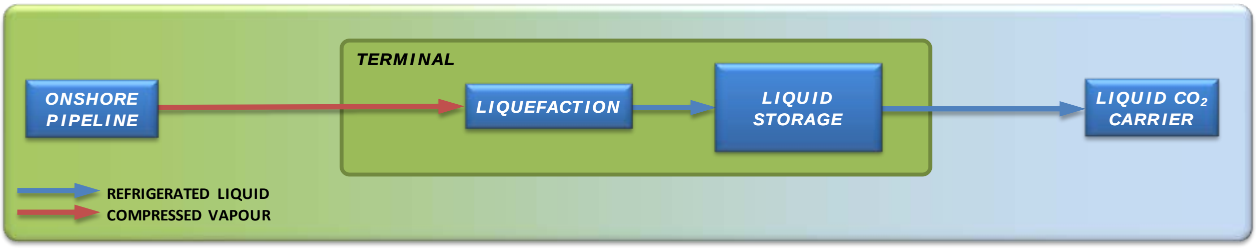

Fig. 20 Schematic representation of “pipe → ship”-scenario

The main components in this scenario are a compression/dehydration plant at the emitter, onshore pipeline, liquefaction unit and liquid storage at the terminal, a liquid CO_2 carrier and offloading facilities at the sink location.

The results in Figure 21 first show the impact of distance on the cost. The results show that cost per tonne CO_2 transported increases with distance. The main cost increase is located in the onshore section involving pipeline transport, while cost implication of transportation distances on the terminal and offshore sections is much smaller as shown in Figure 22. Increasing capacity will reduce the cost per tonne CO_2 transported. Figure 22 also shows that terminal and shipping costs are relatively high at low transportation capacities.

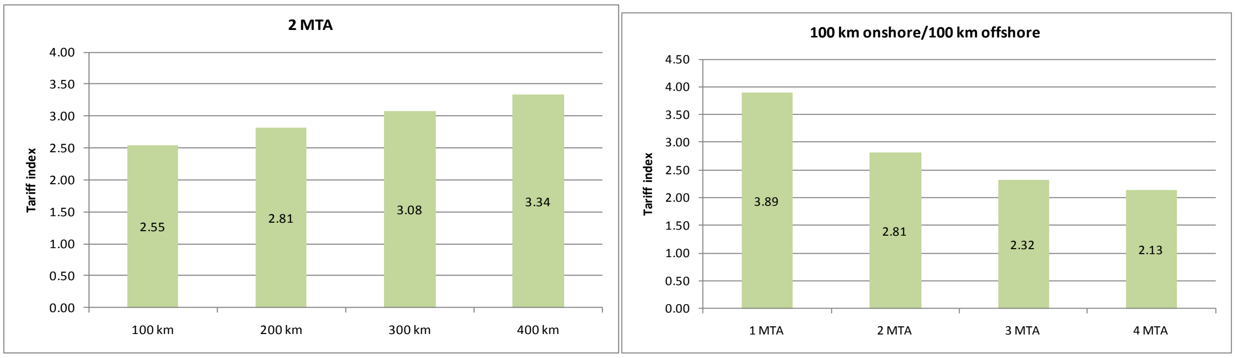

Fig. 21 “pipe → ship”-scenario distance and capacity impact

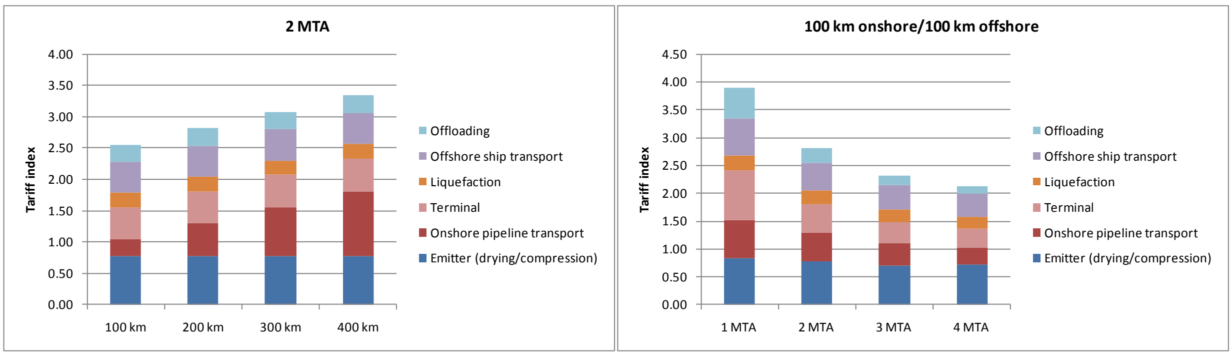

Fig. 22 “pipe → ship”-scenario cost distribution

Barge → ship

The third scenario is a fully liquid transportation chain involving transportation of liquefied CO_2 by barge to a terminal for transfer to a liquid CO_2 carrier for offshore injection at a sink. The scenario is schematically represented in Figure 23.

Fig. 23 : Schematic representation of "barge → ship"-scenario

The main components in this scenario are a compression/dehydration/liquefaction plant and barge terminal with intermediate storage at the emitter location, liquid CO_2 barge(s), intermediate storage terminal, liquid CO_2 carrier and offloading facilities at the sink.

For this scenario Figure 22 shows the impact of distance and capacity variations. The impact of distance is very small. In the cost distribution in Figure 23 it can be seen that the onshore transport by barge is more affected by distance variations than offshore transport by carrier. The reason is that due to the smaller ship sizes actual sailing times are a larger part of the operation compared to the larger carriers, for which the sailing time is only a fraction of the total operating time. In this scenario transportation cost per tonne CO_2 are almost independent of transport distance. A variation in capacity shows that this scenario is more suited for larger transportation capacities. Cost distribution for these cases remains similar for different capacities as each chain component cost per tonne CO_2 is reduced at higher transport capacities.

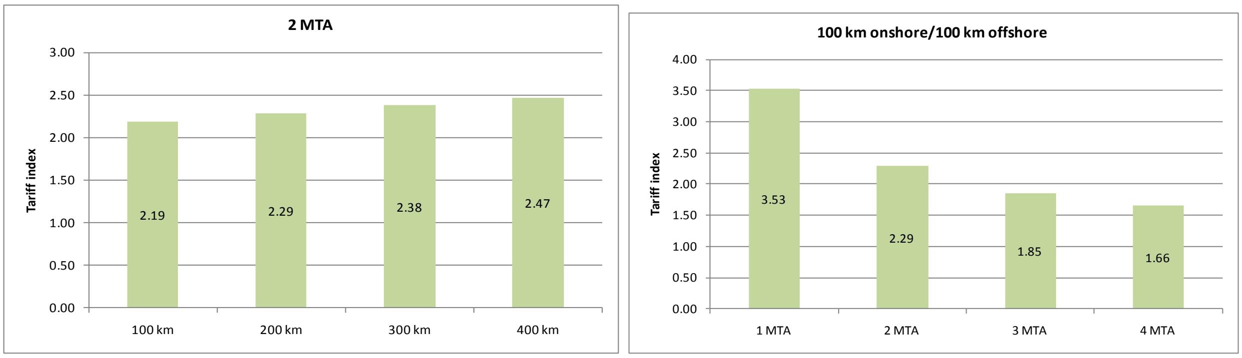

Fig. 24 "barge → ship"-scenario distance and capacity impact

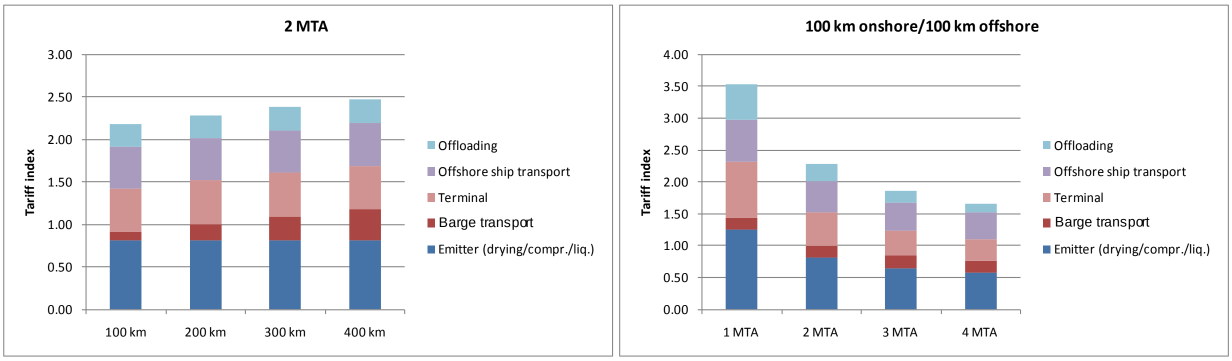

Fig. 25 "barge → ship"-scenario cost distribution

Barge → pipe

The last scenario is based on inland transport by barge and offshore transport by pipeline. Again a schematic representation of this scenario is provided.

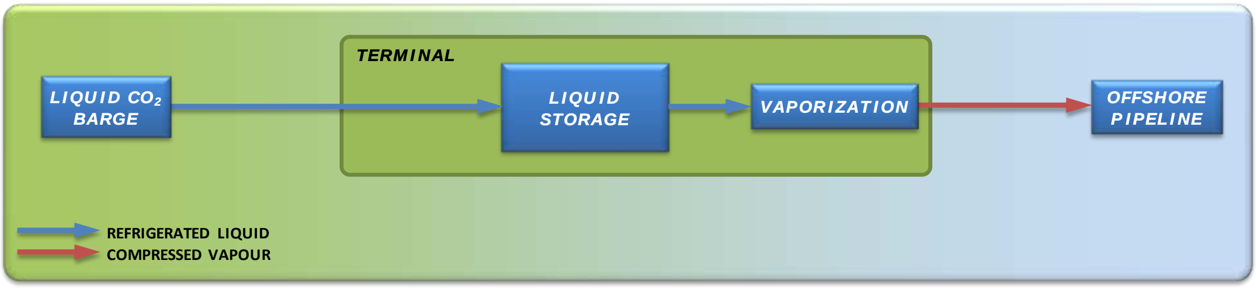

Fig. 26 Schematic representation of "barge → pipe"-scenario

The main component in this scenarios are a compression/dehydration/liquefaction plant and barge terminal at the emitter site, liquid CO_2 barge(s), a terminal with intermediate storage and vaporization or regasification for transport by an offshore pipeline to the sink.

The cost of transportation increases with increased distance between emitter and sink as presented in Figure 27. The cost increase is mainly due to cost increase of the offshore pipeline section as presented in Figure 28. Again this scenario is very sensitive to capacity variations resulting in lower transportation costs at higher capacities.

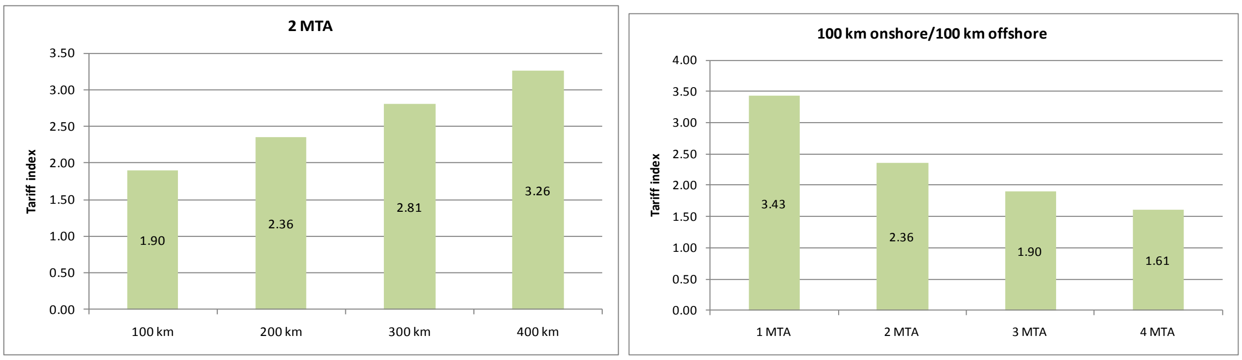

Fig. 27 "barge → pipe"-scenario distance and capacity impact

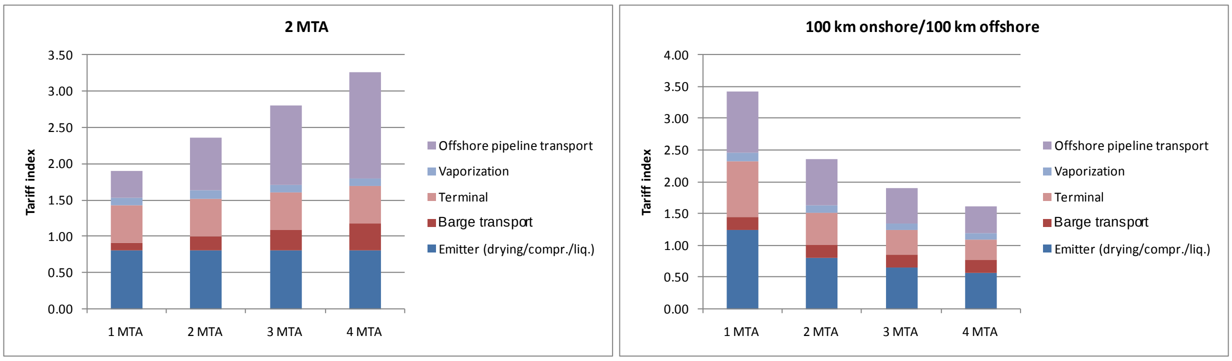

Fig. 28 “barge → pipe”-scenario cost distribution

Direct connection optimization

The different scenarios for development of a direct connection between an emitter and sink were presented, but not yet compared to each other. To illustrate the impact of the discussed variables, distance and capacity, the scenario with the lowest cost is presented in Table 2 for different combinations of onshore transport distance, offshore transport distance and capacity.

Capacity	Onshore distance	Offshore distance 50	100	150	200	250	300	350	400
1 MTA	50	pipe → pipe	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	100	pipe → pipe	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	150	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	200	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	250	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	300	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	350	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	400	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
Capacity	Onshore distance	Offshore distance 50	100	150	200	250	300	350	400
2 MTA	50	pipe → pipe	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	100	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	150	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	200	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	250	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	300	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	350	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	400	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
Capacity	Onshore distance	Offshore distance 50	100	150	200	250	300	350	400
4 MTA	50	pipe → pipe	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	100	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	150	pipe → pipe	pipe → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	200	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	250	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	300	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	350	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship
	400	barge → pipe	barge → pipe	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship	barge → ship

Table 2 Configuration comparison for different capacities

The influence of capacity on the selection of the preferred configuration is limited and the impact on the actual cost per tonne CO_2 transported decreases with increased capacity. The main conclusion is that for longer distances ship transport is preferred, both onshore as well as offshore. The application of barge or ship transport of liquefied CO_2 is competitive to pipeline transport, not only from a flexibility perspective, but also from a cost perspective for transportation distances exceeding approximately 150 – 200 kilometers (see Figure 30 and 31).

Checks have been performed with pipeline systems with only a 10 bar instead of a 100 bar pressure drop: the outcome was identical meaning that apparently the lower compressor costs compensated the higher pipeline costs.

For the specific case of injection of CO_2 in depleted reservoirs in the Dutch waters of the North Sea, Figure 29 shows that the majority of these fields are located between 150 to 250 kilometers from the port of Rotterdam. Ship transport for these fields would be competitive to pipeline transport with regard to costs. This also shows that the location of the terminal is an important factor in the configuration of a CO_2 network.

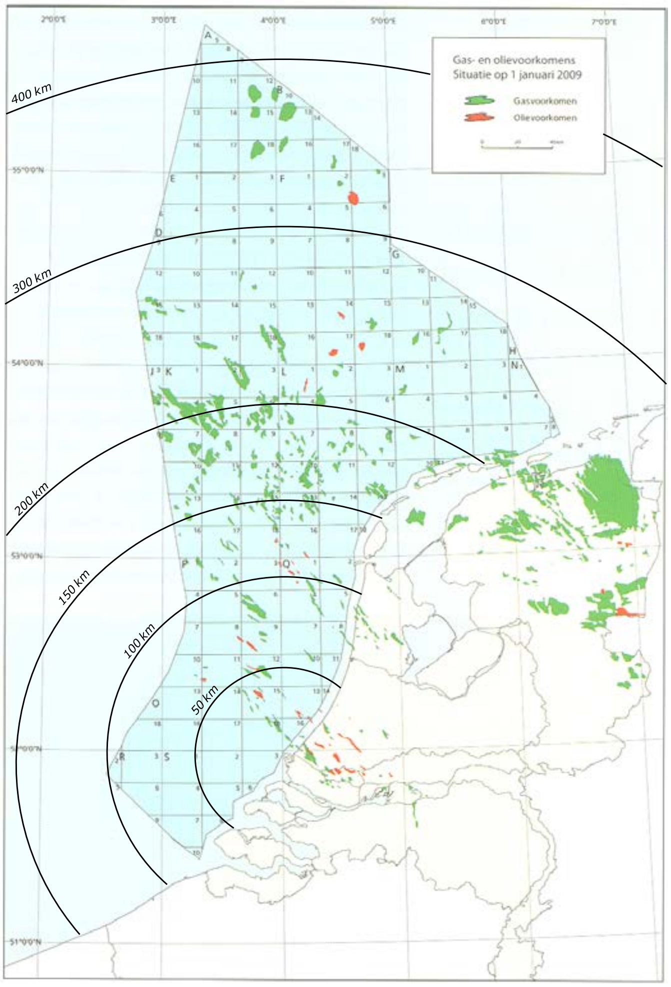

Fig. 29 Oil and gas fields in the Dutch area of the North Sea and their distance to the Rotterdam harbor

Distance intervals of 50 kilometers are used in this study. For industrial areas like the Rotterdam area, distances from the emitters to the terminal can be much shorter than the 50 kilometers taken here as the minimum. This is the reason that the "pipe → ship"-scenario is not in the results presented in Table 2. This configuration will be a competitive configuration for the Rotterdam area for cases where onshore transport distances are small.

Reviewing the cost for onshore and offshore transport by pipeline or by barge/ship is complicated, since it is very depending on the assumptions. In Figure 30 the transport costs for barge and pipeline serviced emitters is presented. The costs include all assets and operational costs required to transport the CO_2 from the emitter to a terminal either by pipeline or barge. For pipeline transport the compression costs, drying and pipeline cost are included. For barge transport the liquefaction, barge, barge terminal and hub terminal costs are included. The results show that the preferred option is depending on capacity and distance, but breakeven distances for barge versus pipeline transport are around 200 km.

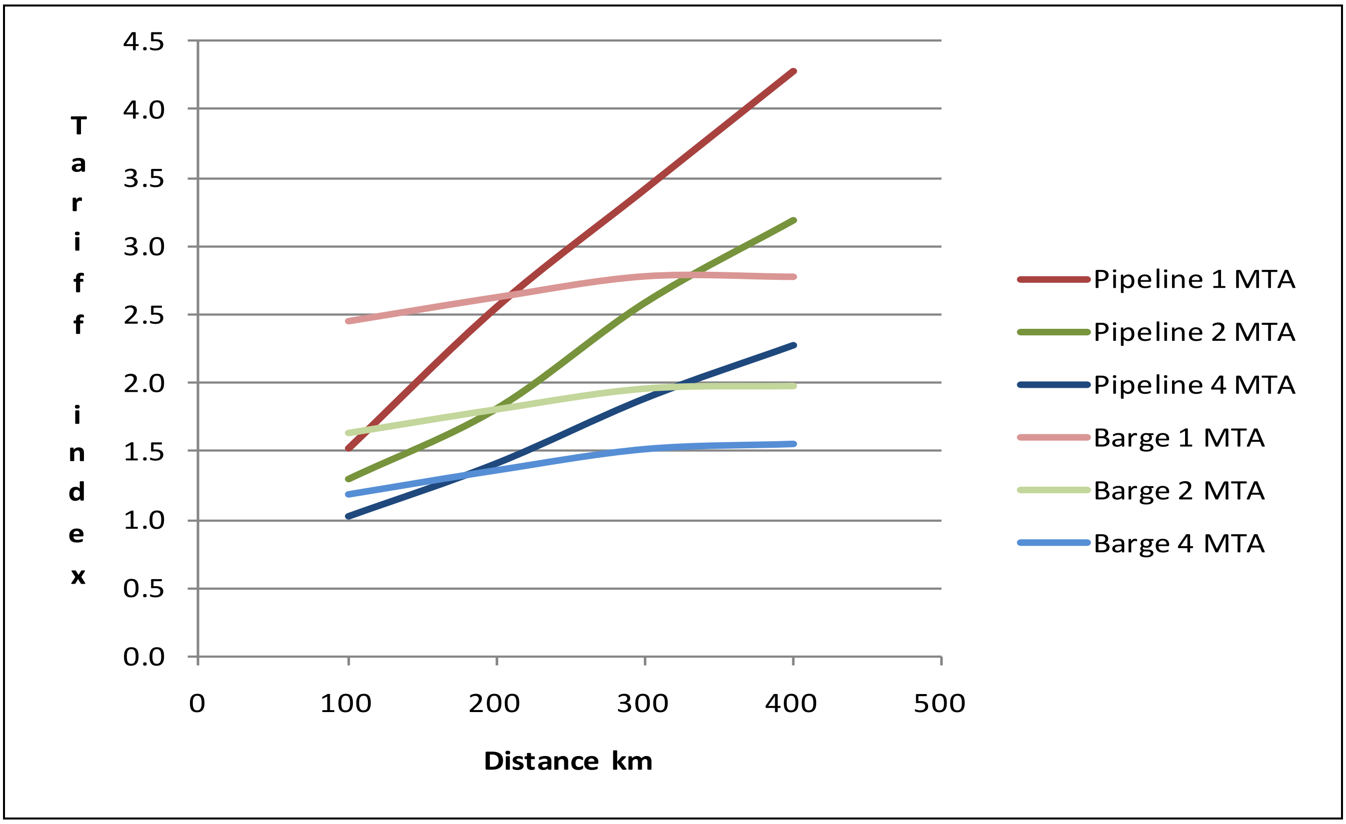

Fig. 30 Barge versus onshore pipeline cost comparison

For offshore a similar comparison is done. The transport tariff for pipeline transport is very sensitive to transport distance and breakeven distances with ship transport are increasing with capacity. Included costs for shipping are the liquefier, hub, ship and offloading system. For the offshore pipeline costs the compression plant and pipeline have been taken into account. The results show that the preferred option is depending on capacity and distance, but breakeven distances for ship versus pipeline transport are around 150 km.

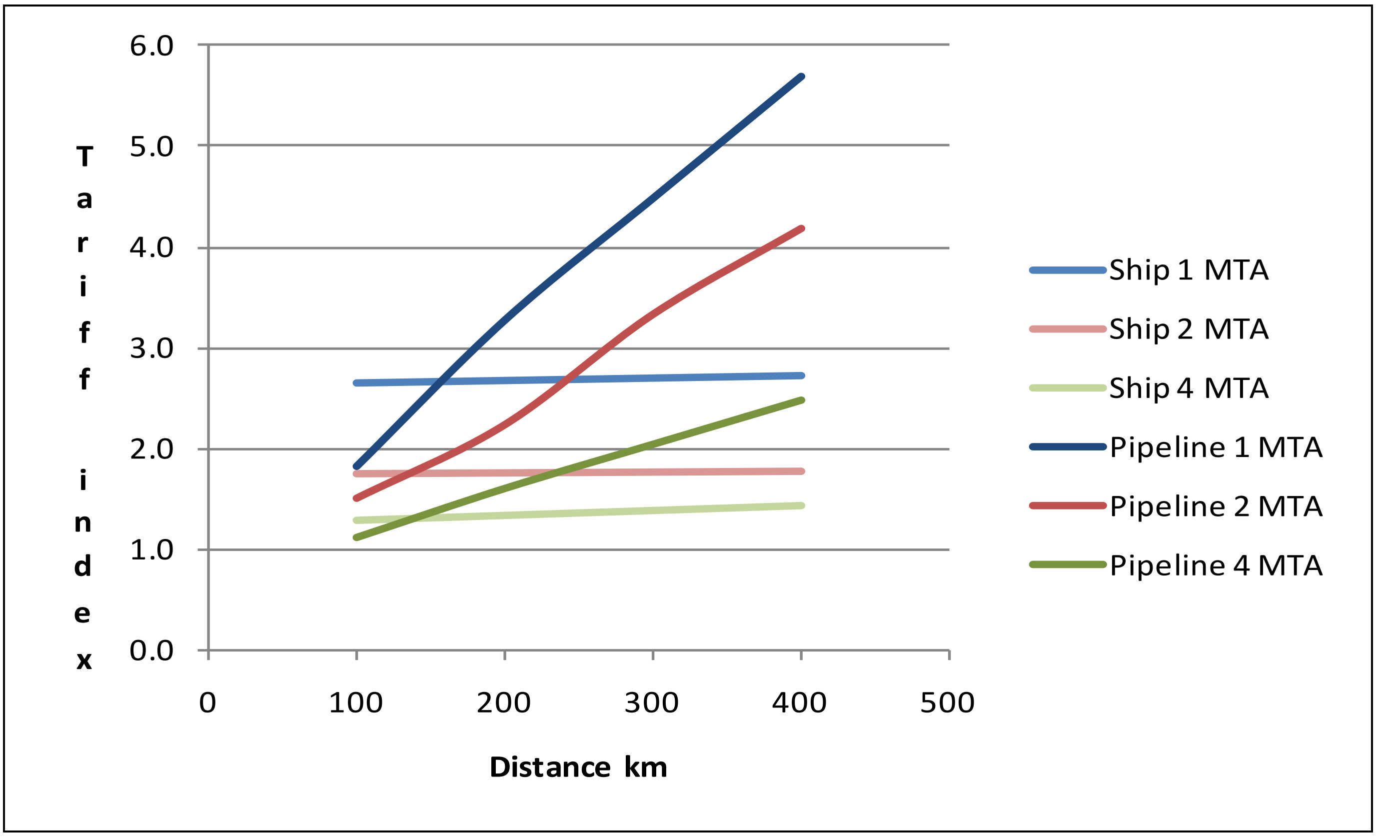

Fig. 31 Ship versus offshore pipeline cost comparison

3.2 Rotterdam volume growth scenarios

The following emitters in the Rotterdam area are envisaged to hook on to the CINTRA CO_2 hub until 2020:

Launching Rotterdam emitters:

- A coal fired power plant
  - **Average Capacity:** min. 4 million tons in the first 5 years, 1.1 MTA on average
  - **Design capacity:** 1.5 MTA
  - **Envisaged contract duration:** 11 years
  - **Location:** Situated 2 km east of the planned CO_2 hub
  - **CINTRA scope:** liquefaction, on shore storage, ship transportation and off shore conditioning
  - **Status:** main commercial principles being discussed

- Air Liquide Green Hydrogen Project:
  - **Subsidies:** Euros EU and Dutch funding under the NER300 scheme.
  - **Average Capacity:** 0.4 million tons annually obliged.
  - **Design capacity:** 0.5 MTA
  - **Envisaged contract duration:** 10 years
  - **Location:** Situated 25 km east of the planned CO_2 hub
  - **CINTRA scope:** liquefaction, on shore storage, ship transportation and off shore conditioning
  - **Status:** main commercial principles agreed

Subsequent Rotterdam emitters pre 2020:

- Refineries
- Bio-ethanol plant
- Hydrogen plant

Rotterdam emitters post 2020:

- Existing EON Coal fired power plant: 4-5 MTA
- Existing Electrabel coal fired power plant: 4-5 MTA

Non-Rotterdam emitters post 2018:

- Netherlands: power plants along the Rhine such as the Buggenum IGCC
- Belgium: Antwerp Region
- Germany: Power plants and steel mills in the Ruhr area and along the Rhine

CO_2 from Belgium and upstream the Rhine river into Germany is all envisaged to be barged to the hub. For the German emitters this implies that the CO_2 will be disposed of in the same way as their fuel and/or feed stock has been brought in. A significant portion of the hub's volume growth on the mid term is envisaged to come over the river Rhine. Therefore a mature scheme will also comprise of a logistic network on the river including transshipment terminals etc.

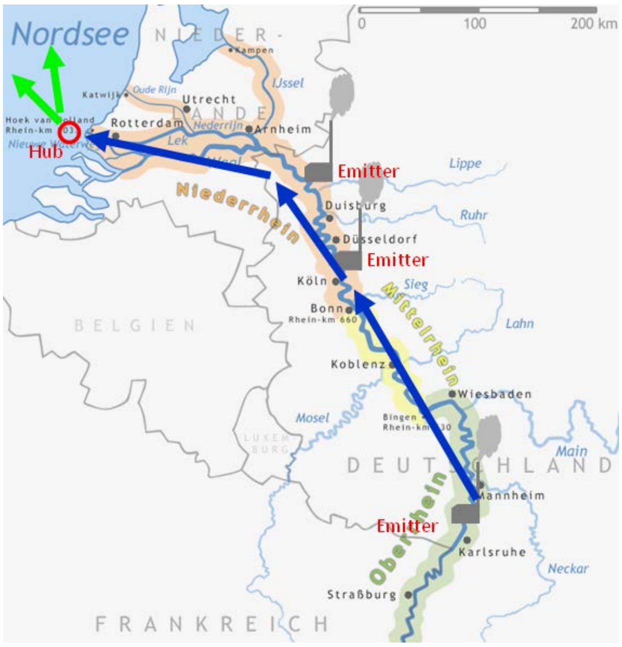

Fig. 32 CINTRA's hub connected to the hinterland via barges

Also on the down stream side of the Rotterdam CO_2 terminal the chain is envisaged to grow into a network. Customers from the Le Havre region may be bringing in their CO_2 via ship for bulk making in Rotterdam prior to shipment to an off shore sink. In addition several CCS projects in the UK are targeted to create a link with in order to enhance the economy of scale. The fact that ships and barges may be deployed on other routes as the chain grows greatly increases the feasibility of this strategy.

For the mid term the most likely growth scenario anticipates on an ETS price of +/- 50 Euro/ton in 2025 which leads to the following scenario:

TERMINAL IMPORT	**Year**	**2016**	**2017**	**2020**	**2025**
Import by onshore pipeline	MTA	1.5	1.7	1.7	3
Import by barge	MTA	0	1	6	15
TOTAL	**MTA**	**1.5**	**2.7**	**7.7**	**18**
TERMINAL EXPORT	Year	**2016**	**2017**	**2020**	**2025**
Export via offshore pipeline	MTA	0	0	3	12
Export via ship	MTA	1.5	2.7	4.7	6
TOTAL	**MTA**	**1.5**	**2.7**	**7.7**	**18**
# combi berths	#	1	1	1	1
# barge berths	#	0	0	1	3
Required storage volume	[m^3]	27,000	45,000	78,000	100,000

Table 3 Growth scenario for the terminal in the Rotterdam area

4 Stakeholder and communication management

CCS holds an uneasy position in the public debate. On the one hand it is recognized that CCS will decrease the emission of green house gases (GHG) but on the other hand CCS is also considered to be an inferior solution since it doesn't tackle the root cause by reducing GHG production but merely "hides" the problem underground. In addition the general public appears to perceive CO_2 as a dangerous gas which gives rise to objections against pipeline transportation and underground storage since people fear these will start leaking over time.

Thus the public posture with respect to CCS is such that public communication for any CCS project requires special attention. In addition CCS pilot projects often concern the involvement of multiple parties in order to set up a complete logistic chain that is currently unavailable. This is especially true for the CINTRA project since it links two emitters (a coal fired power plant and a hydrogen plant) with one sink via 2 joint venture projects (on shore pipeline and CINTRA hub). Therefore CINTRA plans to contract a communication agency that will take care of its stakeholder management. A communication advisor is to be part of the team in order to properly translate technical information into a form that is not only understood by the general public but is also presented in a realistic and understandable perspective.

In order to get a project accepted by society it is essential to involve stakeholders at an early stage and to address their wishes and concerns and to be open towards the project's surrounding community. One should be aware of any negative public perceptions, which social issues these relate to etc. Based on this information a clear strategy can be defined on how to communicate towards the stakeholders regarding the project and which activities can increase the public support for it. This process is called environment or stakeholder management. A stakeholder management strategy will allow the project to interact with the environment in a proactive rather than a reactive manner as has mostly been the strategy for industrial projects in the past.

Another contribution of the stakeholder management process is that CINTRA plans on optimizing its permit application processes based on its findings and activities. As a result the stakeholder management activities should be synchronized with the permitting activities.

Stakeholder and communication management are considered to be separate but synchronized trajectories. There interaction is depicted below:

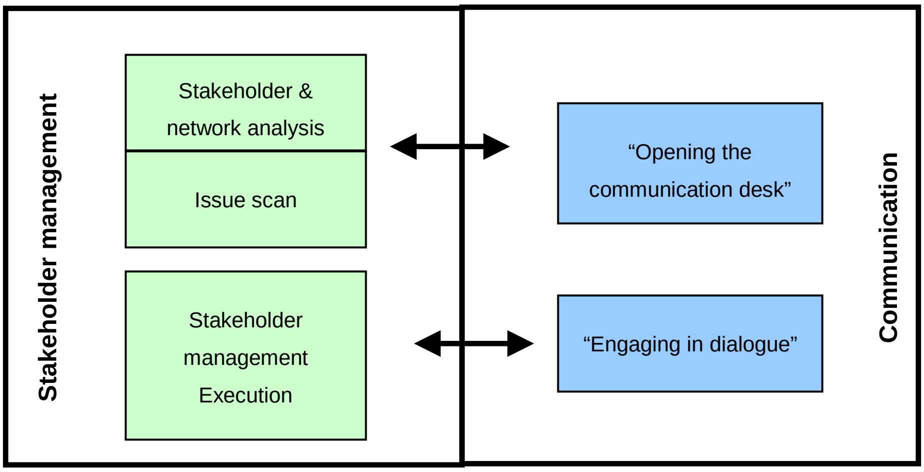

Fig. 33 Relationship between stakeholder management and the communication processes

In order to come to a proper and adequate stakeholder and communication management strategy, first the stakeholders and their relationships are mapped including the various issues they perceive with respect to the project. Based on this information the stakeholder and subsequent management strategy is set up. Only after completion of both, these two strategies are executed.

Definition of stakeholder management strategy

First of all an issue and stakeholder scan will be executed. The issue scan is performed in order to come to a first group of potential stakeholders. Then the links between these stakeholders will be mapped and parties will be interviewed if in doubt. At the end of this process the interests of each stakeholder shall be clear. Other points of interest in this respect are the stakeholders' basic posture, their level and type of influence on other stakeholders and at which point in the process their involvement becomes relevant. Finally the identified stakeholders are mapped in a chart of issue defined as per the example given below.

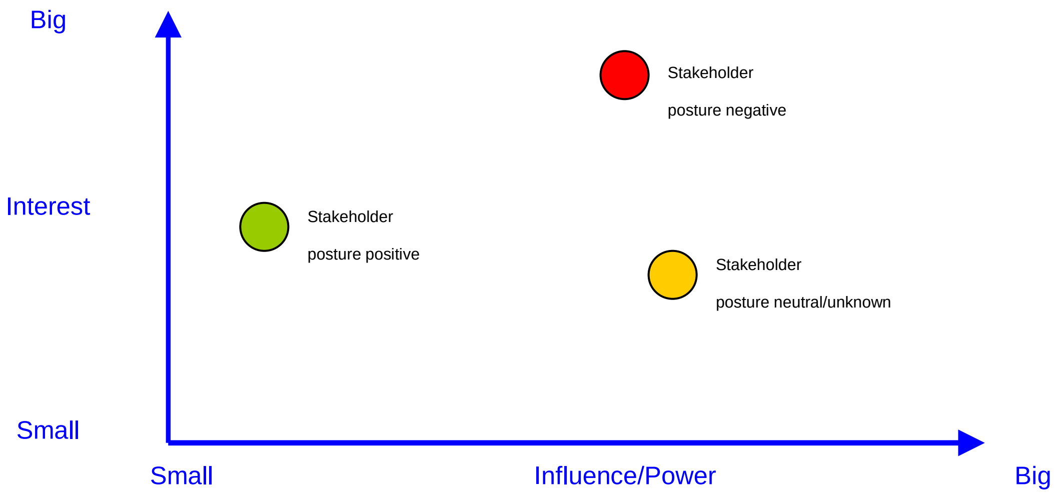

Fig. 34 Stakeholder chart

The following subjects shall be addressed in the stakeholder management strategy:

- Which stakeholders need to be involved more strongly
- Which parties need to be invited for talks
- Organization and responsible persons/parties towards the project's surroundings
- Execution plan and schedule
- Which means of communication shall be utilized and which means of communication shall be used for which stakeholder.

In the strategy the means of communication and information sharing are linked to the various stakeholders, based on where a stakeholder is situated in the network. To this end the stakeholder are ranked based on position in the project and how they can be approached.

The levels of stakeholder involvement in the project are (in increasing order):

1. Inform: keep update on plans, ideas, status etc
2. Counsel: get knowledge or opinions from experts or stakeholders
3. Advise: ask advise regarding project plans (involve actively)
4. Coproduce: jointly set up plans or solutions as peers (limited dialogue)
5. Participate: grant a vote in the project's decision making process

Researching one's image and reputation is part of the stakeholder and communication management process. This research is to point out discrepancies between the perception of your organization or project and its surroundings.

Execution of stakeholder management strategy

It is critical to communicate in an open and transparent manner towards the project's surroundings and the tone of voice matches that of its receptor. Fronting is an important factor in this respect therefore it is wise to choose a spokesperson with local credibility.

Although communication is viewed as a separate activity, its interaction with the overall strategic stakeholder management process is important. Therefore it is advised to make a communications experts part of the stakeholder management team.

Good communication starts with setting up an easy accessible communication desk to engage in a dialogue with the project's surroundings from the very start. A communication strategy links the stakeholder (issues) analyses with the communication means to be engaged and the goals to be achieved. Part of this exercise is the set-up of a communication strategy describing the extent and format of this desk: a web site, social media (Facebook, Twitter or Linked-in accounts) setting up standard project communiqués etc.

The issue scans and stakeholder analyses will create insight in the kind of information desired by the project's stakeholders. In the communication strategy it will be addressed how to tackle this and may result in the set-up of risk analysis, SHE plan or a voluntary environmental impact assessment etc.

5 Global rollout

5.1 Repeatable Formula

If the CCS industry is to grow as envisaged by the WEO's blue map scenario, it implies that CCS is to take care of 15-20 % of the total GHG reduction by 2050. This means that its scale is not only planned to be enormous but in addition it will also need to grow at an unprecedented speed.

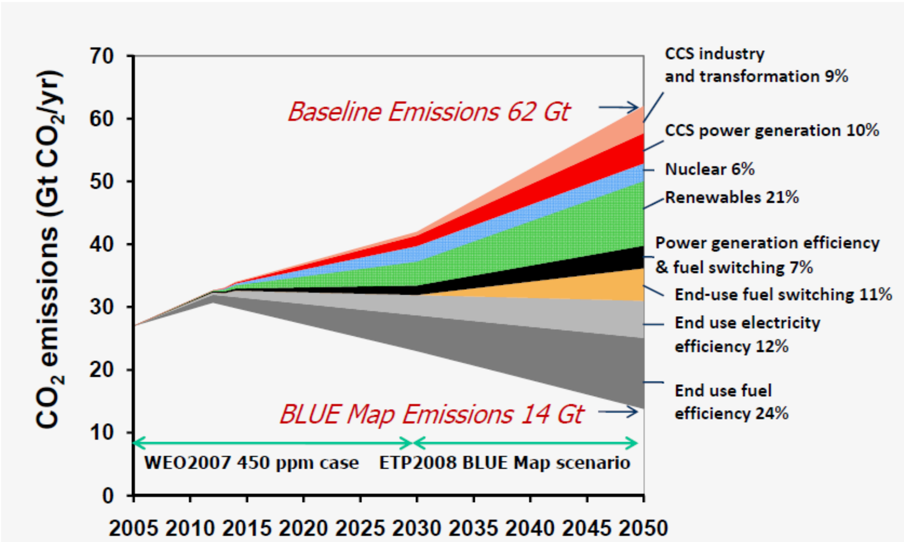

Fig. 35 Comparison of the World Energy Outlook 2007 450 ppm case and the BLUE Map scenario, 2005-2050

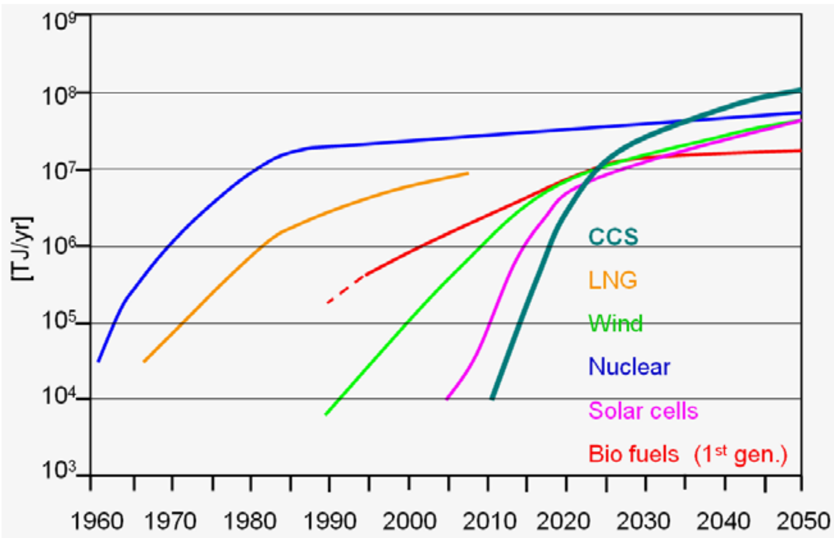

Fig. 36 CCS industry planned growth rate versus other new energy industries

In order to meet these two requirements CINTRA's logistic chain components' design is fully based on repeatable formulas since this allows for:

1. Minimal engineering per scheme: fast fabrication and deployment of assets
2. Scaling up on the fly by simply adding identical modules
3. Procurement risk mitigation: parallel ordering of multiple pieces of identical equipment at different shops
4. Procurement leverage: equipment is ordered in larger volumes on multiple occasions over a longer period of time allowing for the set-up of partnership contracts for materials and services with the same parties
5. Redeployment of assets in other situations based on same formula and thus based on same modules and equipment
6. Maximum economy of scale: as the chain grows, even at different locations, operational and maintenance activities are merged more easily
7. Less childhood illnesses: once experience has been gained with the first schemes, any startup problems in the chain component's design will be eliminated.

Risks associated with this approach are:

1. As technology evolves superior technologies may arise over time
2. Some strategic partners selected may not be accepted by CINTRA's customers all over the globe
3. Local parties may be able to offer materials and services more cost effectively than a strategic partner selected earlier
4. A repeatable formula also implies that the size and capacity variations of the chain's building blocks is limited meaning that in certain cases this may lead to a sub optimal proposal to CINTRA's customers.

If the risks above are closely monitored on a continuous basis, the repeatable formula is believed to be the best approach for the deployment of the CINTRA concept.

5.2 Organic Growth

The CO2 logistic chain is expected to evolve in a similar fashion as other logistic systems of similar size. Ultimately the global CO2 logistic infrastructure is to show a size comparable to that of the coal, crude oil and natural gas sector for the simple reason that CO2 is mainly created by burning these fuels, i.e. combing these with oxygen from the atmosphere and thereby almost quadrupling these fuels' mass. Thus the CO2 infrastructure will be of a vast size, providing that international legislation will create the incentive, largely by means of setting the right ETS price. As a result this chain will be of a similar nature as the fuel chains mentioned above: a mix of both pipeline and shipping operations spanning the globe. The choice between these two types of transport modalities is done on a case by case basis, driven mainly by costs minimization/optimization. The five main parameters to be taken into account here are: emitter type and size, sink type, distance between them and the type of transport route.

In addition the CO2 infrastructure's vast scale and associated massive upfront investments are expected to lead to an organic growth pattern in spite of the fact that the speed of growth may call for a more structured approach. More intense international governmental involvement may cause a slight shift towards the latter but is not expected to be likely. However, this infrastructure is currently almost non-existent which makes that wherever this organic growth will start, its launching scheme will be on a scale that is typically an order of magnitude lower than eventually needed. This requirement was also take into account when setting up the technologies regarding CINTRA's repeatable formula discussed in par. 5.1.

Summarizing: the asset building is to follow the volume build-up. The above leads to the following key requirements for the CINTRA concept:

- Cost effective scalability of same concept allowing for the use of the same chain components
- Allowing for chain expansion while in operation by adding and relocating assets when a shift from a pipe to barge or ship solution becomes more opportune as the volumes grow

To illustrate the above a scheme's lifespan is divided in three categories: an early, intermediate and a mature phase.

- Early scheme: initial set-up of the chain based on a minimum start volume. Normally a ship is involved since transporting up to at least 5 MTA to a sink more than 150 km off shore is done via ship in lieu of a pipeline.
- Intermediate scheme: emitters and possible extra sinks are added to the scheme. Ships may be relocated to other routes as certain sinks may now best be served by a pipeline instead of a ship. One important aspect regarding the ships in this respect is the fact that they may be redeployed in LPG service in case they become (temporarily) redundant. Another scenario could however involve an increased flow to a certain sink serviced by one ship thus located far away that may now have two ships sailing to it in parallel.
- Mature scheme: the chain now actually has turned into a network involving multiple emitters and sinks. Any on shore pipeline system running through an industrial area now has likely grown into a true "third party access" pipeline network transporting the CO_2 for the complete industrial community towards the coastal hub. As certain sinks get filled up, new ones may be hooked on to which the ships get re-routed. Multiple hub terminals may get involved now for bulk making along the river routes and at the coastal hub closest to the off shore fields.

Appendix A-1: CO_2 thermodynamics

Carbon dioxide in the presented LLSC occurs in several different phases. For transport purposes it is better to transport CO_2 in a more dense phase, the occupied volume is less compared to vapor transport due to the increased density. The properties of CO_2 allow for transport in either liquid phase or supercritical phase. The transitions are not very clear, therefore liquid and supercritical phase are generally referred to as dense phase, based on the increased density of both phases. The temperatures and pressures associated with phase transitions can be derived from the phase diagram as on the next page. The properties of carbon dioxide differ with the state it's in and the main properties are presented in the next paragraphs.

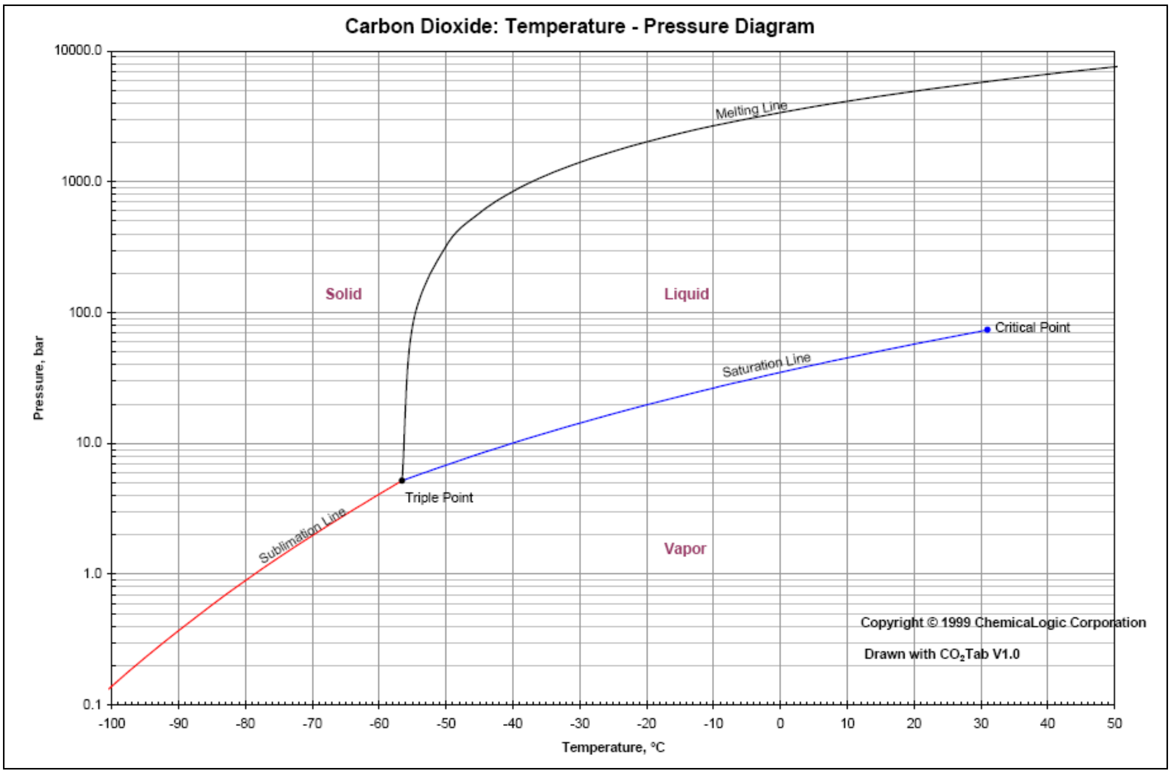

Figure A-1: Phase diagram – Carbon dioxide

The main general properties of pure carbon dioxide are presented in the following table.

Chemical formula	CO_2
Molecular structure	O=C=O
Molecular weight	44.011 kg/kmol
Molecular volume (normal conditions)	22.263 m^3/kmol
Critical temperature	31 °C
Critical pressure	73.83 bara
Critical density	466 kg/m^3
Sublimation point	-78.9 °C @ 0.981 bara
Triple point	-56.6 °C @ 5.18 bara

Table A-1: General properties – carbon dioxide

A more extended presentation of phase transitions of pure CO_2 is provided by a "log P-H"-diagram. The diagram provides information on density, enthalpy, entropy in addition to pressure and temperature. The "log P-H"-diagram of pure CO_2 is presented below, with an overlay of the different phases. The distinction between liquid, supercritical and vapor phase is set by the critical pressure and temperature of CO_2. This is not a strict distinction, but a matter of definition.

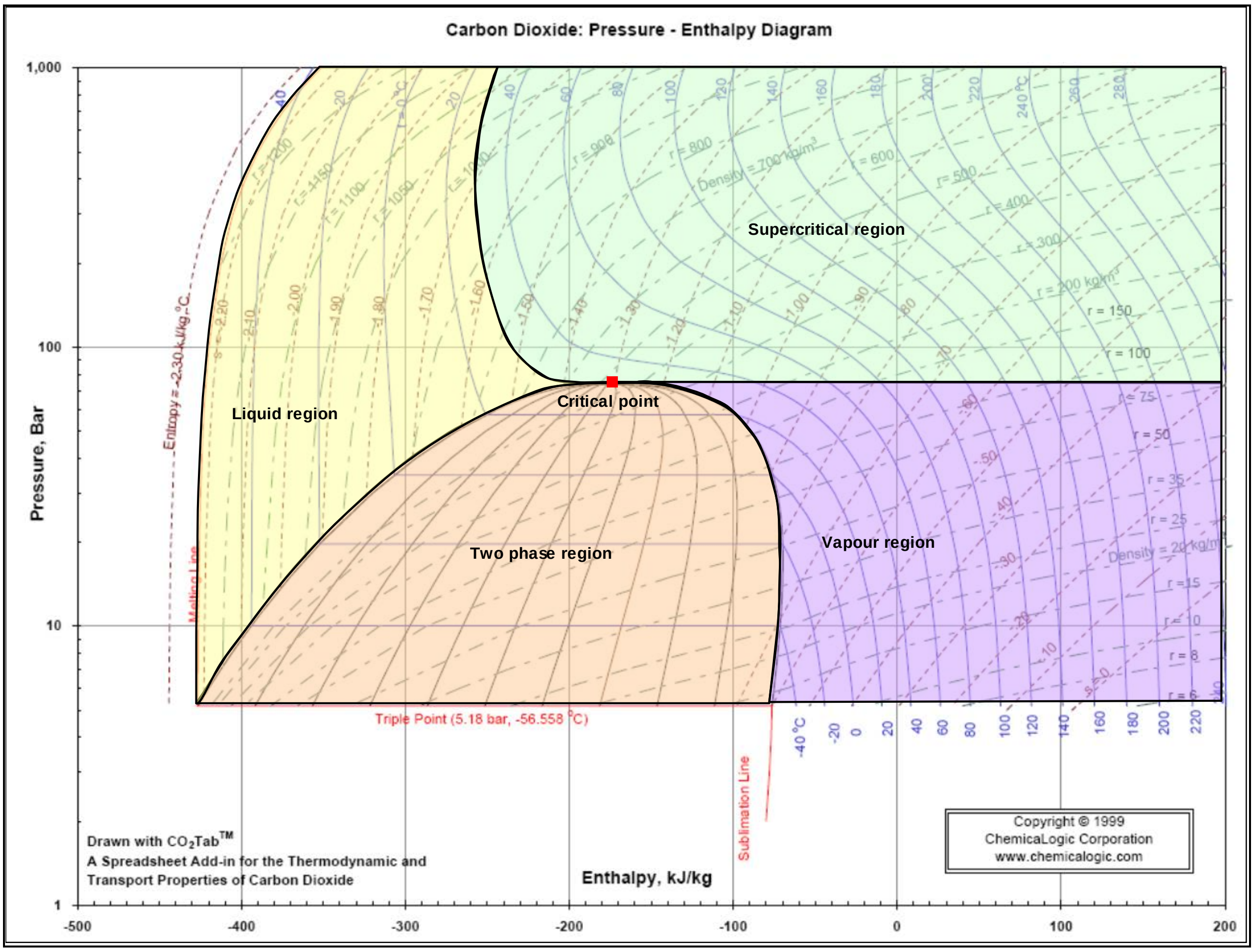

Figure A-2: "log P-H"- diagram – Carbon dioxide

Process names

The liquefaction process is referring to the phase transition from the vapour to the liquid phase. The vaporization (or regasification) process is referring to the phase transition from the liquid to the vapour or supercritical phase, although the latter is strictly incorrect because there is no real phase transition to be observed. The compression process is referring to a pressure increase in the vapor phase while the pumping process is referring to a pressure increase in the liquid or supercritical phase.