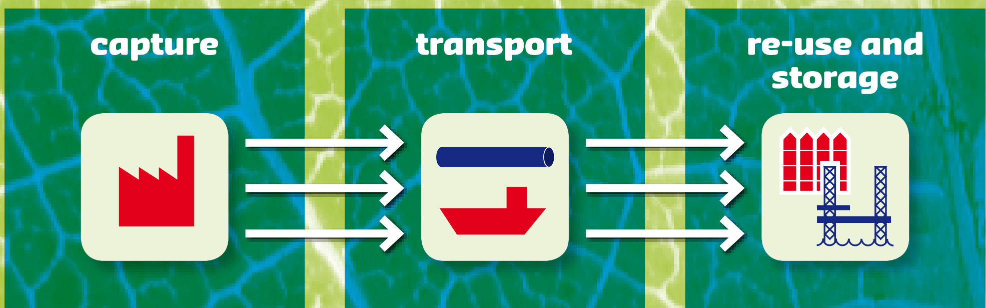
ROTTERDAM.**CLIMATE**.INITIATIVE

# $CO_2$ capture and storage in Rotterdam

## A Network Approach




May 2011 • 2nd, updated, edition

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# Introduction

'Rotterdam World Port World City' is the slogan of Rotterdam. As one of the largest seaports in the world, we are aware of our responsibility to reduce Rotterdam's impact on climate change. Our climate approach is more than a sustainability strategy: it is also an economic strategy. We are convinced that continuing development of the port and the city of Rotterdam can only be realized in a sustainable manner. In the Rotterdam Climate Initiative, municipal and regional authorities work side by side with the corporate sector, to reduce our $CO_2$ emissions by half by the year 2025, while at the same time adapting to the effects of climate change and promoting the economy in the Rotterdam region.

CCS, the capture, re-use and underground storage of $CO_2$, especially under the North Sea bed, is an important part of our strategy to reduce $CO_2$ emissions, along with energy conservation and renewable energy. With its concentration of industry and energy, the Rotterdam region offers excellent conditions for the large-scale application of this technology.

Rotterdam's achievements as a world port and major industrial centre is based on collaboration of stakeholders. We deal with environmental challenges by sharing our viewpoints and solutions. Collaboration on a voluntary basis is also characteristic for our CCS approach. All parties concerned have joined together to pursue the common goal: a comprehensive, efficient and economically feasible network for CCS. The CCS Business Platform hosted by Deltalinqs Energy Forum, provides a platform for information exchange and learning in a public-private setting.

As the vice-mayor for Sustainability I am proud of what we have achieved in recent years. Rotterdam is considered internationally as an important location for large-scale $CO_2$ capture, transport and storage or re-use. The first projects within the network have already started. All our efforts will lead to an annual avoidance of at least 2.5 megaton by 2015, and up to 17.5 megaton in 2025!

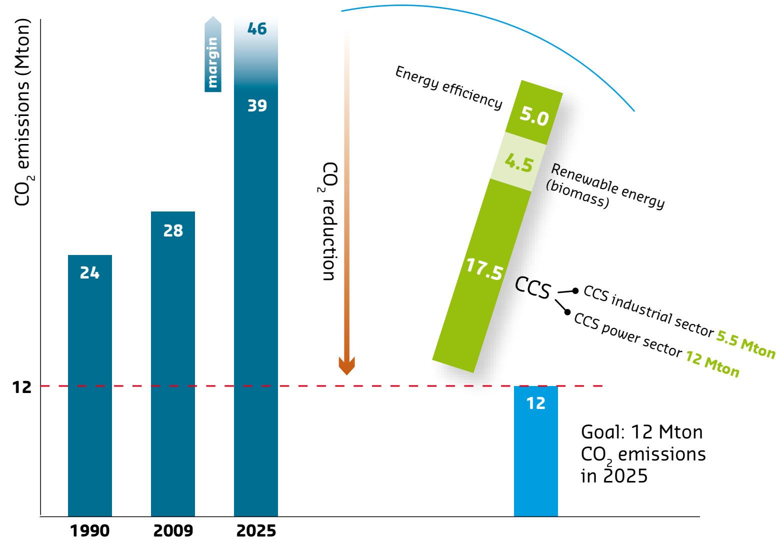
The CCS approach is part of Rotterdam's sustainability policy. Our ambitions and accomplishments in the field of the environment, climate, energy and water management all contribute to a clean, green, healthy and economically strong city – Rotterdam will be the world's most sustainable port city of it's kind.

Alexandra van Huffelen
Vice-mayor for Sustainability, the City Center and Public Spaces

# The Rotterdam climate approach

Rotterdam is responsible for sixteen percent of carbon dioxide ($CO_2$) emissions in the Netherlands. As an international port with a large $CO_2$ intensive industrial sector, which is set to grow over the coming years, Rotterdam is acutely aware of its responsibility to act on the climate change issues it is facing. This resulted in the ambitious Rotterdam Climate Initiative (RCI) programme, designed to:

- achieve a fifty percent reduction of $CO_2$ emissions in the Rotterdam region by 2025, as compared to 1990.
- climate-proof and adapt the city to the consequences of climate change.
- strengthen the Rotterdam economy.




**CCS will contribute to more than half of Rotterdam's emission reduction target**

RCI is a collaboration of the Port of Rotterdam, the City of Rotterdam, port and industries' association Deltalings, and the DCMR Environmental Protection Agency.

The greatest share of RCI's ambition to reduce $CO_2$ emissions will be realized through energy efficiency measures in industry (two percent annually), buildings and transportation, sustainable energy – predominantly biomass, use of residual heat and wind energy – and through carbon capture and storage (CCS). Given the large presence of the industry and power sector in the port, CCS is a logical and crucial means by which to achieve $CO_2$ emission reduction. Over half of the projected reduction, 17.5 Mton, must be achieved through CCS. Approximately thirty percent of the CCS objective comes from industrial installations. The aim is to realize full-scale CCS application by 2025.

This publication presents the current situation and explains how we intend to achieve full-scale application of CCS. The maps in the centre serve to illustrate the network development as it will progress from the present situation to the demonstration phase and eventually to full-scale deployment. The factsheets further down in this publication show eleven concrete initiatives taken by companies to realize CCS.

## $CO_2$ emission growth

As an international seaport city, Rotterdam's economy depends on an energy and emission intensive industry and power sector. With economic expansion underway in the port, these emissions are set to grow in a business as usual scenario. By 2025 the $CO_2$ emitting installations in the Rotterdam area will include:

- five refineries
- at least two coal-fired power plants
- two gas-fired power plants
- dozens of chemical plants
- numerous CHP installations.

## The role of CCS

Despite maximum efforts on energy efficiency and renewable energy, over half of Rotterdam's $CO_2$ reduction goal can only be achieved through the capture of $CO_2$ emissions for re-use or permanent underground storage: $CO_2$ Capture and Storage. Moreover, CCS is considered to be the only technology capable of directly abating $CO_2$ emissions from both industrial facilities, such as refineries or steel plants, and fossil fuel power plants. With several pilot projects, a leading R&D-programme and a huge potential of storage sites, the Netherlands has outstanding opportunities to implement CCS. Recently, the Dutch government decided to support only offshore CCS.

## The opportunities Rotterdam offers

Rotterdam offers excellent opportunities for the development of a shared CCS network. Large $CO_2$ emitters are clustered in the area, and large offshore storage sites are accessible nearby in depleted oil and gas fields and other suitable geological formations. The closest suitable fields are the P18/P15 gas fields only 20 kilometres from the port, operated by TAQA.
This network will connect multiple emitters to multiple storage sites. RCI expects this network to benefit both climate change policies and the investment climate in the port.
The conditions described above create economies of scale and help to lower the overall cost of implementing CCS. Perhaps the most attractive benefit of a Rotterdam-based CCS network is that it would accelerate CCS deployment by providing a $CO_2$ transport and storage infrastructure with associated facilities such as transhipment and processing. The Port of Rotterdam,in cooperation with OCAP, Gasunie and Stedin is developing the Rotterdam $CO_2$ Common Carrier Pipeline (R3CP), a collection network for $CO_2$ in the port. This carrier will yield the lowest costs for $CO_2$ transportation to the Maasvlakte for market parties. This will facilitate emitters, who are currently considering implementing $CO_2$ capture, and offshore storage and/or enhanced oil recovery (EOR).

## CCS technology

CCS technology involves separation of $CO_2$ from other gases emitted by power plants and industrial facilities. After transportation of the captured $CO_2$, by pipeline or ship, to an appropriate facility, the $CO_2$ can either be re-used or stored underground.
Captured $CO_2$ is used in greenhouses and in the food industry. RCI supports initiatives such as the OCAP project to increase the use of captured $CO_2$ in greenhouses. Furthermore, $CO_2$ is used for enhanced oil and gas recovery (EOR and EGR). RCI is cooperating with Maersk, who is developing opportunities for EOR. These methods help to reduce $CO_2$ emissions.
The $CO_2$ that cannot be used, is stored permanently in deep underground reservoirs such as depleted gas and oil fields and saline aquifers. For the near future, RCI focuses on storage in depleted offshore oil and gas fields. Under the authority of RCI, TNO has performed an independent storage assessment of several storage fields in the North Sea (see the box on page 6).

### Safety first

Safety, the protection of human health, animals and the environment, comes first. For this reason, DNV, on behalf of the Port of Rotterdam, has conducted a study on the safety of transport and transhipment of $CO_2$ in the port. The study shows that the handling and transporting of $CO_2$ is as safe as other current operations in the port of Rotterdam.

***Rotterdam-based CCS network will benefit the investment climate in the port***

## The Independent Storage Assessment

RCI launched an Independent Storage Assessment (ISA) to better define available offshore $CO_2$ storage options, for both depleted hydrocarbon fields and aquifers. The Global Carbon Capture Storage Institute (GCCSI) and five major Rotterdam emitters, (E.ON, Electrabel GDF Suez, Shell, Air Liquide and Air Products) financed this study, which was carried out by TNO. The Dutch CCS R&D Programme CATO-2 contributed in kind.

The ISA consisted of two phases:
In phase 1 data was collected and reviewed, to identify the most attractive $CO_2$ storage options on a 2015 time horizon and to ensure that no good short-term prospects were overlooked.
Phase 2 consisted of a detailed assessment of the four most attractive $CO_2$ storage options, including feasibility level analysis of the technical viability, availability and cost of using each site for $CO_2$ injection from 2015. This included a site development plan for each site, outlining the timeline for actions to bring each site into operation as well as the cost of those actions and key risks.
This, one of the most in-depth studies of its kind in the world, identified the fields P18, Q1, P6 and K12-B as the most attractive $CO_2$ storage options on a 2015 time horizon and identified P15 and Q1B as attractive $CO_2$ storage options on slightly longer time horizons.
RCI is planning a follow up study to the ISA, focussing on the identification of potentially major storage sites for $CO_2$ on the entire Dutch part of the continental shelf. This study will include hydrocarbon fields, aquifers and EOR opportunities.

# Rotterdam-based companies join forces

RCI and its partners are at the forefront of global CCS development, both in the power sector and the heavy industry.
In the power sector E.ON and Electrabel are jointly developing ROAD, a post-combustion capture project at the E.ON coal/biomass power plant. This project has already secured substantial funds from the EU and the Dutch government. An industrial project is being developed by Air Liquide, intending to capture and store $CO_2$ arising from the production of hydrogen. These initiatives are supported by the CINTRA-consortium an alliance between Gasunie, Vopak, Anthony Veder and Air Liquide, for the exploitation of a $CO_2$ terminal and $CO_2$ transport by ship and the development of the Common Carrier Pipeline (R3CP).
A third project that has been initiated is the Pegasus project, intending to build a 340 MWe oxyfuel power plant with full scale $CO_2$ capture and storage.

RCI has a long established cooperation with private initiatives. This collaboration has culminated in a substantial number of Letters of Cooperation (LoCs) with projects, including: CINTRA, Maersk, E.ON, Electrabel, Air Liquide, Air Products and Shell. As a follow-up on these bi-lateral agreements, RCI is seeking ways to strengthen the cooperation between the front runner companies, to continue working towards the development of a Rotterdam CCS Network. Other stakeholders, including local communities, the Dutch and EU governments and other companies in the port of Rotterdam who are interested in implementing CCS at a later stage, support the efforts of these companies. The CCS Business Platform, hosted by Deltalinqs, provides a mutual basis for information exchange and learning in a public-private setting, in a transparant manner.

Some results over the past years of RCI and its partners are:

- 18 major companies cooperated to provide feasibility-level engineering studies for $CO_2$ capture projects and a CCS infrastructure network in the Rotterdam area. RCI facilitated validation and analysis by expert engineering (Foster Wheeler) and financial (Climate Change Capital) consultants. The results have culminated in the RCI report $CO_2$ Capture, Transport and Storage in Rotterdam (2009).
- An independent storage assessment by TNO (see the box on this page).
- Stakeholders analysis by Twynstra Gudde.
- A study on safety of transport and handling of $CO_2$ in the port by DNV (see the box on page 5).

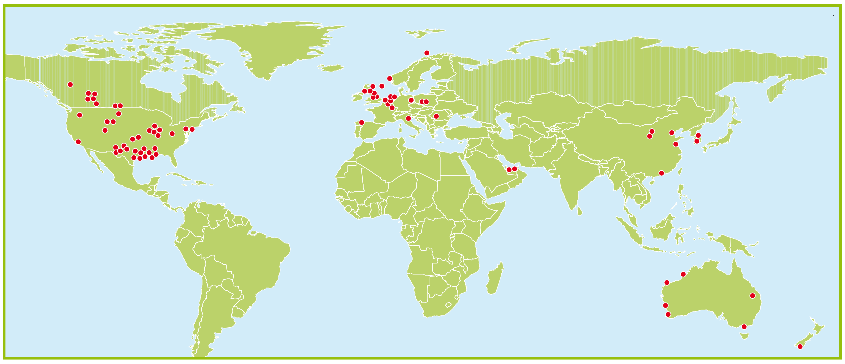
## (Inter)national network

Throughout the world, many initiatives are taken to establish CCS projects. RCI collaborates closely with other CCS initiatives around the world. It is a partner in the Clinton Climate Initiative and has, in cooperation with and financed by the Global Carbon Capture Storage Institute (GCCSI), initiated a study on the liquid logistics concept (which resulted in the CINTRA-consortium), the independent storage assessment and a study on lessons learnt. The activities of RCI are also supported by the European Climate Foundation.
Furthermore, RCI is involved in European initiatives on CCS, such as the Berlin Forum on (sustainable) fossil fuels, the European Technology Platform for Zero Emission Fossil Fuel Power Plants and the North Sea Basin Task Force.
Regions play a vital role in establishing CCS. They are key in facilitating implementation of projects and are in many cases also the drivers for CCS and CCS networks. This is why RCI is one of the initiators of closer cooperation between the CCS regions in Europe. The regions include Scotland, Yorkshire and Humber, Le Havre, North Rhine Westphalia, Brandenburg and Eemshaven. This cooperation allows the regions to share knowledge and experiences, raise key issues at the appropriate levels of government and be a sparring partner for institutions such as the European Commission.

In the Netherlands, RCI participates in the Dutch CCS R&D programme CATO-2 and collaborates closely with Eemshaven - Energy Valley, another Dutch region that offers good long-term CCS development prospects.

## Economic impact

RCI has assessed the economic impact of the development of the CCS network in Rotterdam, based on studies by Ecorys and CE. For the studies three scenarios were used, varying in the total amount of $CO_2$ captured and stored. Assumed was an ETS price of 35-40 Euros in 2030. These studies show that the development of full scale CCS in the port of Rotterdam should result in the creation of up to 1,900 jobs. These figures are inter alia the result of direct investments in CCS and cluster effects.
The lower marginal CCS costs, the re-use of $CO_2$ and positive externalities associated with clusters within the CCS-network could become an important determining factor with regard to location selection. Knowledge spill-over in the CCS-network clusters is also expected to have positive economic effects.



**(Proposed) CCS projects in Europe and globally (source: GCCSI).**

# Key requirements for CCS

- Building public confidence is a prerequisite for further development of CCS. As long as the public is not convinced of the necessity and the safety of any new technology, it remains reluctant to accept such developments. RCI favours therefore a national dialogue on energy and climate policies and the inevitable role CCS plays in those policies. Furthermore, complete and balanced information on CCS should be made easily accessible to the public, for instance through the national website www.co2afvangenopslag.nl.
- CCS is a bridging technology towards a full sustainable energy supply. Implementing CCS is above all depending on a firm climate change policy. RCI highly endorses tightening of the ETS-cap, which will lower the amount of $CO_2$ emitted in Europe. At the same time, enabling CCS also makes a tighter ETS-cap more feasible, since it gives emitters an extra option by which to reduce their $CO_2$ emissions.
- It is uncertain if the ETS alone is an adequate incentive to achieve commercial deployment of CCS by 2025. Currently ETS-prices are considered too low and too volatile to trigger full-scale deployment. We believe therefore that additional incentives, such as an emission performance standard (a $CO_2$ norm per produced kWh), are needed to ensure the successful implementation of CCS. At the same time a (international) level playing field will have to be maintained. RCI is actively involved in talks with national emitters and in round-table discussions with the major players on the Northwest European electricity market to look into possible ways of accelerating the implementation of CCS.
- To reach full-scale deployment of CCS, large-scale demonstrations are needed. RCI applauds the funding through the European Energy Programme for Recovery (EEPR) of the ROAD-project and supports the NER300 funding applications from the Air Liquide and Pegasus projects. Such demonstrations are an essential step towards full-scale deployment of the technology. Moreover, these projects are the nodes from which the Rotterdam $CO_2$ collection network will develop. RCI advocates financial support from the Dutch Government for the establishment of this network, the Common Carrier.
- To develop cost-efficient and accessible storage facilities (connected to regional and national transport networks) and to fully develop the storage potential of the North Sea, cooperation and coordination by the national governments is needed. RCI believes that its independent storage assessment could be a valuable contribution.
- Although the implementation of the CCS directive into Dutch legislation is on track, there are many legal issues that still have to be resolved:
  - The requirements regarding proper operation and decommissioning of storage sites have yet to be defined. To be able to develop their business cases, operators need a clear view of what is expected from them with regard to issues such as long-term liabilities, financial security for liabilities and transfer of responsibilities of closed storage sites to the state.
  - One distinctive issue is the cross-seaborder transport and storage of $CO_2$ under the seabed. Both the London Protocol and OSPAR convention have been amended to allow cross-seaborder storage, but both amendments are still not in force.

## Opportunities for expansion

While the network starts in Rotterdam, it is not limited to the Rotterdam area. There are many possibilities to expand the network to other areas, either in the Netherlands or in Northwest Europe:

- Firstly, a $CO_2$ trunk line, operated by OCAP, runs in the direction of Amsterdam/IJmond. Many potential storage sites are located off the IJmond shore. RCI explores the possibilities for establishing a connection with industries located in this area, and continuation of the connection to storage locations off the shore of IJmond.
- Secondly, RCI foresees that in the long run, many of the large-scale storage sites in the North Sea will be interlinked. Two of the demonstration projects in Rotterdam intend to store their $CO_2$ in storage sites some distance from Rotterdam. Pegasus is planning to lay a cross-border $CO_2$ pipeline for storage in the British part of the North Sea. Air Liquide intends to transport its $CO_2$ to the Danish part of the North Sea for storage and enhanced oil recovery in a field exploited by Maersk.
- Thirdly, Rotterdam is within 500 km of nearly one third of continental Europe's industrial emissions and is a strong player in the European transport market. The Rotterdam CCS network could, in future, also provide solutions to other industrial regions. The port could act as a commercial hub, connecting regions that either seek storage for their $CO_2$ or have offshore locations available for $CO_2$ storage.
- Fourthly, the development of shipping options, such as the CINTRA concept, will substantially increase the possibilities for flexible connections. Small emitters and small storage locations throughout Northwest Europe can become part of the network at lower costs. Supply and demand can be matched more easily.

## RCI's role, now and in future

RCI will continue to build on what it has achieved, in addressing key challenges in developing the Rotterdam CCS network. Our current agenda includes the following goals and activities:

- Contributing to the dialogue with the public and with non-governmental organizations to increase mutual understanding of each others viewpoints on the utilisation of CCS.
- Providing support for the CCS projects under development. In particular the concrete large-scale demonstration projects ROAD, Air Liquide and Pegasus.
- Further development of, and involvement with, the establishment of the Common Carrier and ultimately the development of a CCS cluster.
- Ensure, together with NGO's and industry, conditions that provide support and incentive, in addition to the EU-ETS system, to the development of CCS in Northwest Europe.
- Continuation of the $CO_2$ Business Platform as a means of exchanging information between (local) industries, Rotterdam Climate Initiative and national and regional government.
- Providing support and expertise on CCS in the legislative process, environmental impact assessments and permit procedure for the regional and local permitting authorities.
- Drawing up a long-term strategy on offshore carbon storage as a follow up on the independent storage assessment.
- Cooperation and knowledge sharing with other CCS regions throughout Europe. Mirror and interact with the European Commission's CCS Project Network.
- Involvement with the North Sea Basin Taskforce. Providing input from a regional development perspective. Stressing the need of an overall view and action plan aimed at developing the storage potential on the continental shelf.
- Evaluating RCI's experiences with the aim of sharing our 'lessons learnt' to other CCS projects around the world. This study is financed by the GCCSI.

# Getting there

In RCI's view, the Rotterdam CCS network should scale up rapidly from a demonstration phase around 2015 to a commercial phase handling as much as 17.5 Mton of $CO_2$ annually from the Rotterdam industry and power plants by 2025, providing the backbone for low-carbon industrial and economic growth in Rotterdam. This development is illustrated in the transparent maps of Rotterdam-Rijnmond on the next pages.

The first map shows the **present situation**: several companies, active in RCI, already operate CCS projects. OCAP delivers $CO_2$ from the Shell refinery and the Abengoa bio-ethanol plant to greenhouses. E.ON's CHP plant, RoCa, also delivers $CO_2$ to greenhouses. Other examples include GDF Suez, which is operating a small scale $CO_2$ injection project in an offshore gas field (K12B) since 2004, and the '$CO_2$ catcher' at the E.ON Maasvlakte coal-fired power plant. This pilot capture plant is part of the CATO-2 R&D programme.

The second map shows the projected developments for the period 2015-2020, when the CCS network will evolve into its **demonstration phase**. Large-scale demonstrations will serve as stepping stones towards full-scale implementation:

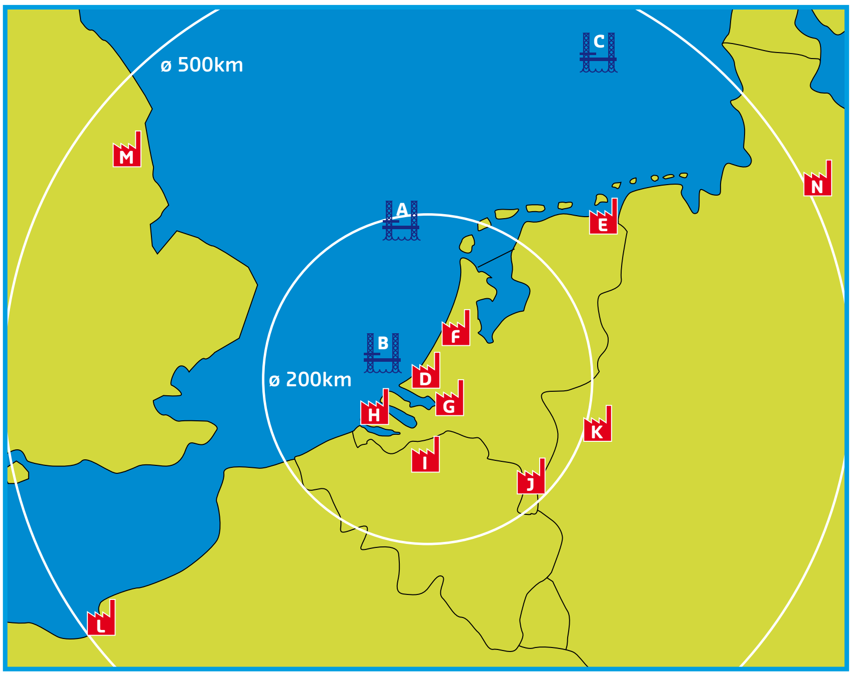
- These projects will lead to the development and improvement of capture technologies.
- These will enable cost reduction for CCS.
- These are the start of the CCS network.

The most prominent demonstration is the ROAD project, which has been granted funding. Both the Air Liquide and the Pegasus projects have applied for a NER300 grant. RCI's partner the Port of Rotterdam is developing a Common Carrier, enabling other emitters to connect to this $CO_2$ collection network.

As shown on the third map, the demonstration projects form the stepping stones towards **full-scale deployment** of CCS by 2025 in the Rotterdam area, enabled by the establishment of the Rotterdam CCS network. RCI anticipates that the demonstrations will capture and store $CO_2$ on a full-scale and that an increasing part of the Rotterdam industry will apply CCS by 2025.

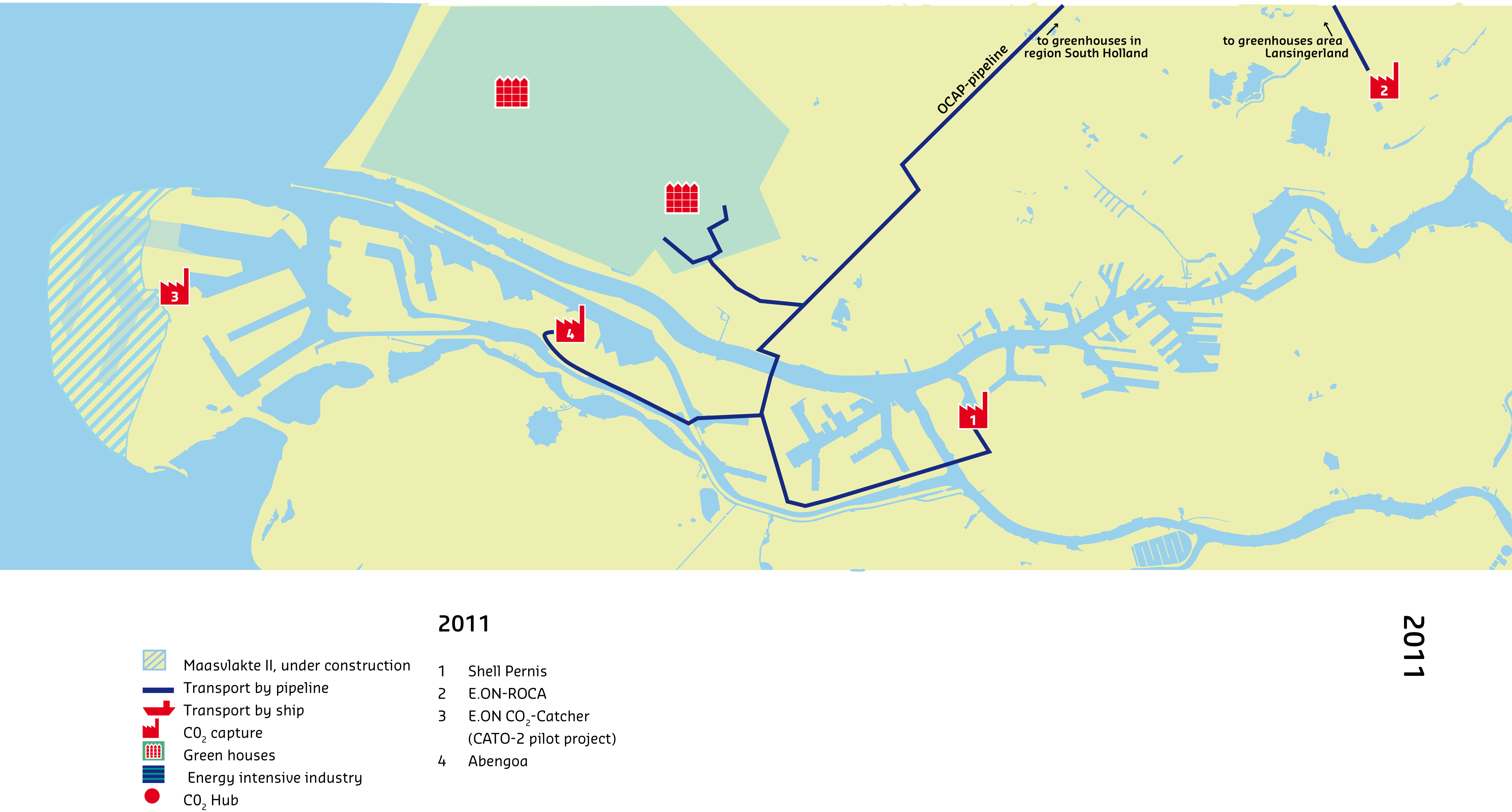
## Future connections beyond Rotterdam

The three transparent maps also indicate the connections RCI expects the $CO_2$ network to make outside the Rotterdam-Rijnmond region. Below is a map of Northwest Europe, showing the locations of those connections, including offshore storage sites the RCI partners intend to use.

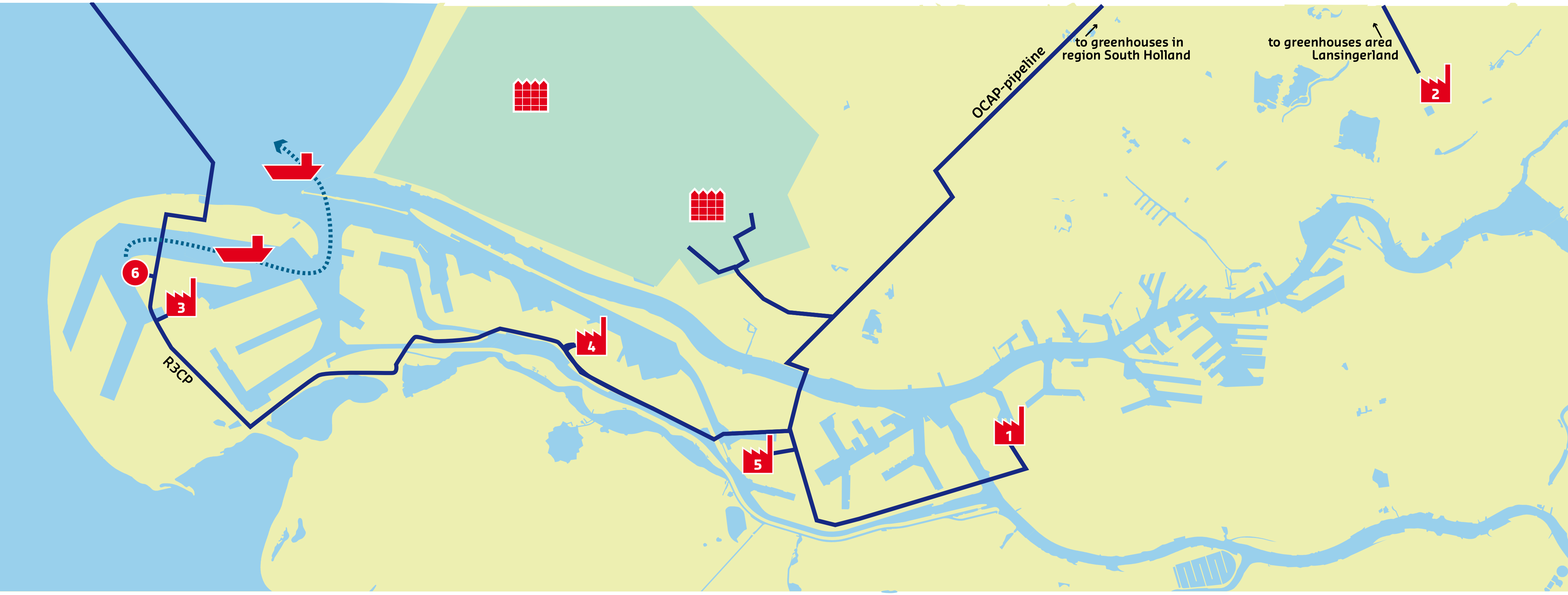



A K12-B (GDF Suez Fields)
B P18/P15 (TAQA fields)
C Danfield (Maersk field)
D Rotterdam industrial complex
E Eemshaven industrial complex
F Amsterdam-IJmond industrial complex
G Moerdijk industrial complex
H Zeeland industrial complex
I Antwerp industrial complex
J Limburg industrial complex
K Ruhr Area industrial complex
L Le Havre industrial complex
M Yorkshire & Humber industrial complex
N Hamburg industrial complex

$CO_2$ capture
$CO_2$ storage


to greenhouses in
region South Holland
to greenhouses area
Lansingerland
OCAP-pipeline
1
2
3
4
2011
Maasvlakte II, under construction
Transport by pipeline
Transport by ship
$CO_2$ capture
Green houses
Energy intensive industry
$CO_2$ Hub
1 Shell Pernis
2 E.ON-ROCA
3 E.ON $CO_2$-Catcher
(CATO-2 pilot project)
4 Abengoa

2011



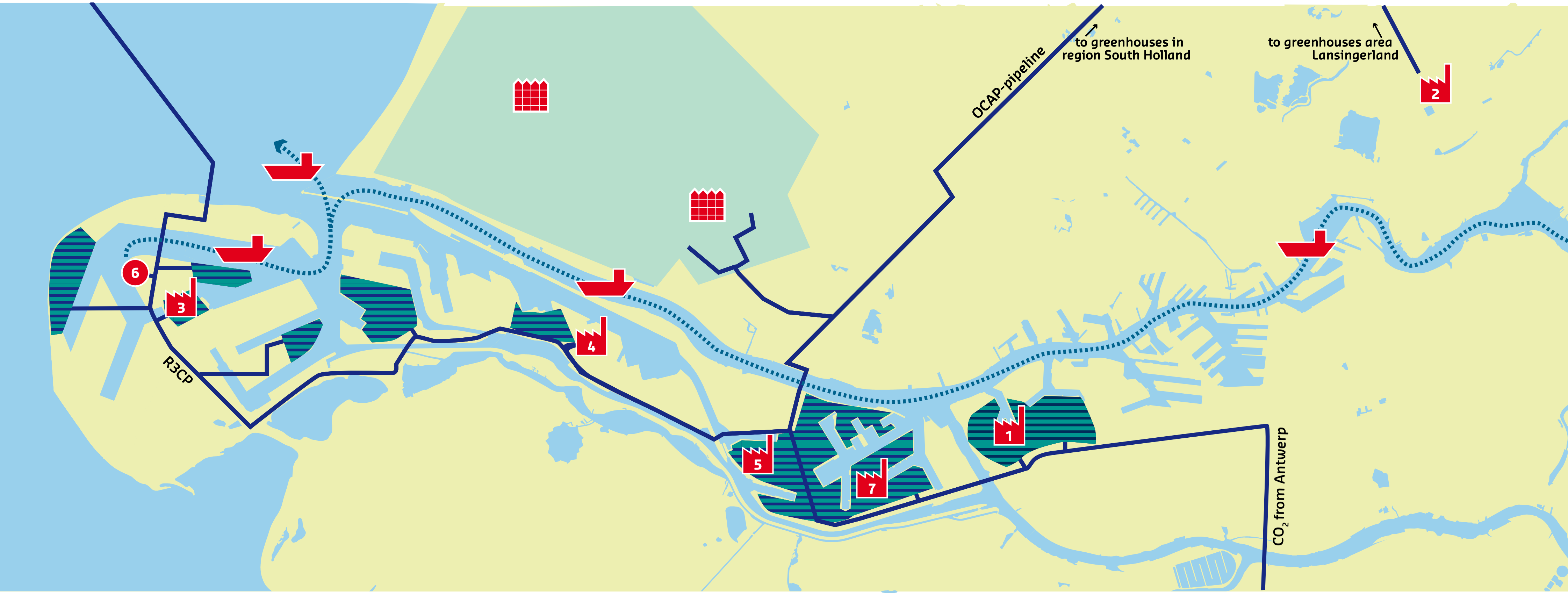

Transport by pipeline
Transport by ship
$CO_2$ capture
Green houses
Energy intensive industry
$CO_2$ Hub

## 2015

1 Shell Pernis
2 E.ON-ROCA
3 ROAD
4 Abengoa
5 Air Liquide
6 $CO_2$ Hub CINTRA

Pegasus: location not yet determined

2015



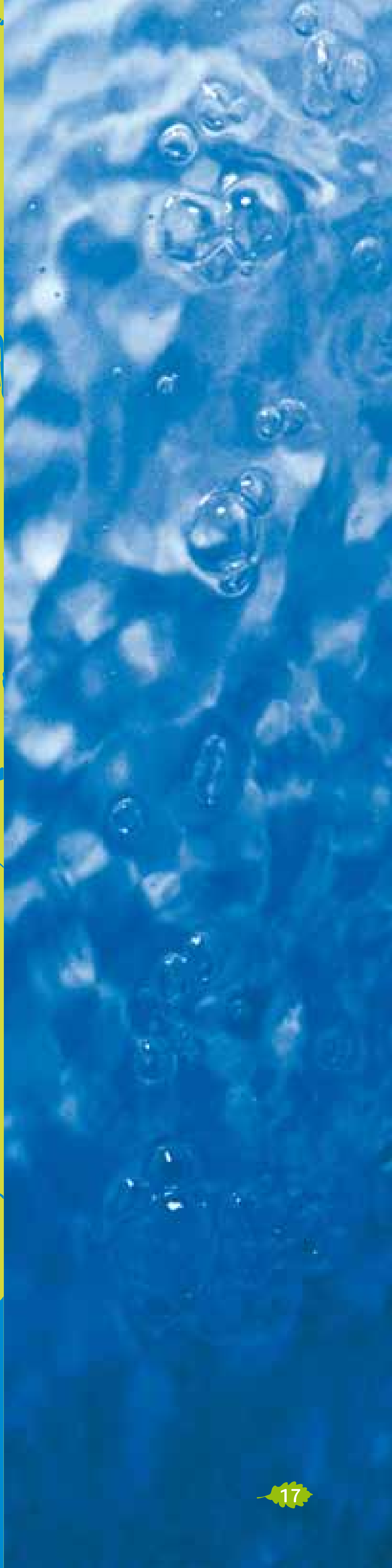

- Transport by pipeline
- Transport by ship
- $CO_2$ capture
- Green houses
- Energy intensive industry
- $CO_2$ Hub

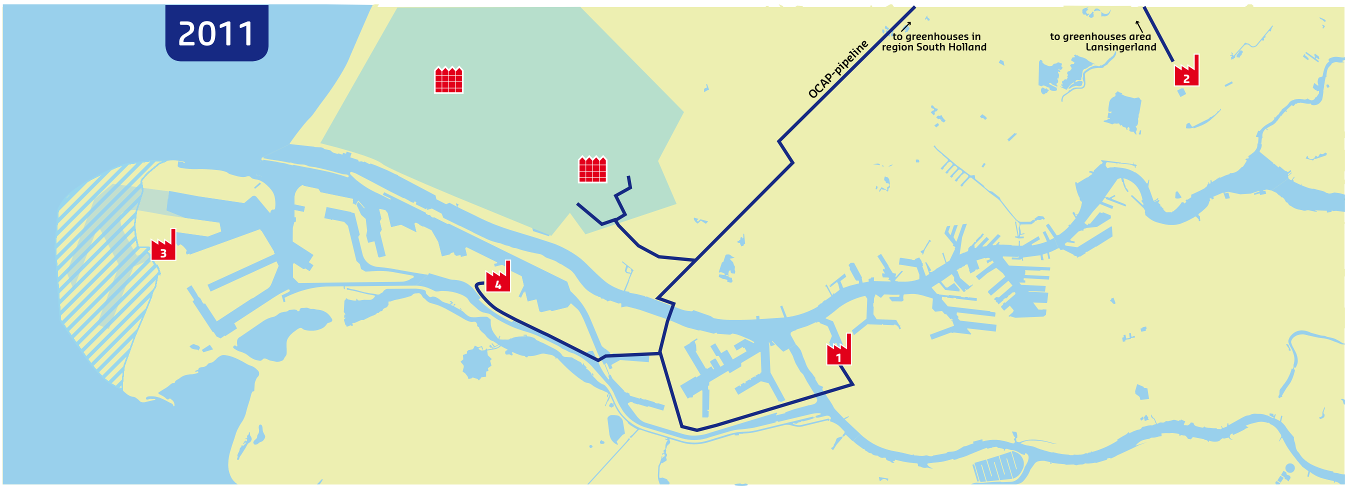
## 2025

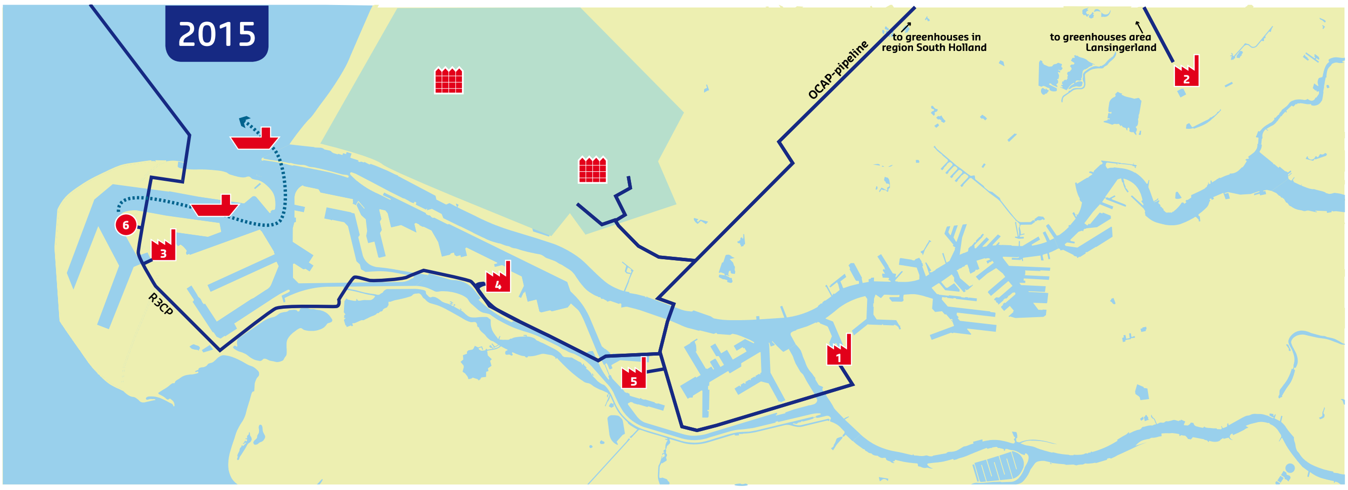
1 Shell Pernis
2 E.ON-ROCA
3 ROAD
4 Abengoa
5 Air Liquide
6 $CO_2$ Hub CINTRA
7 Air Products

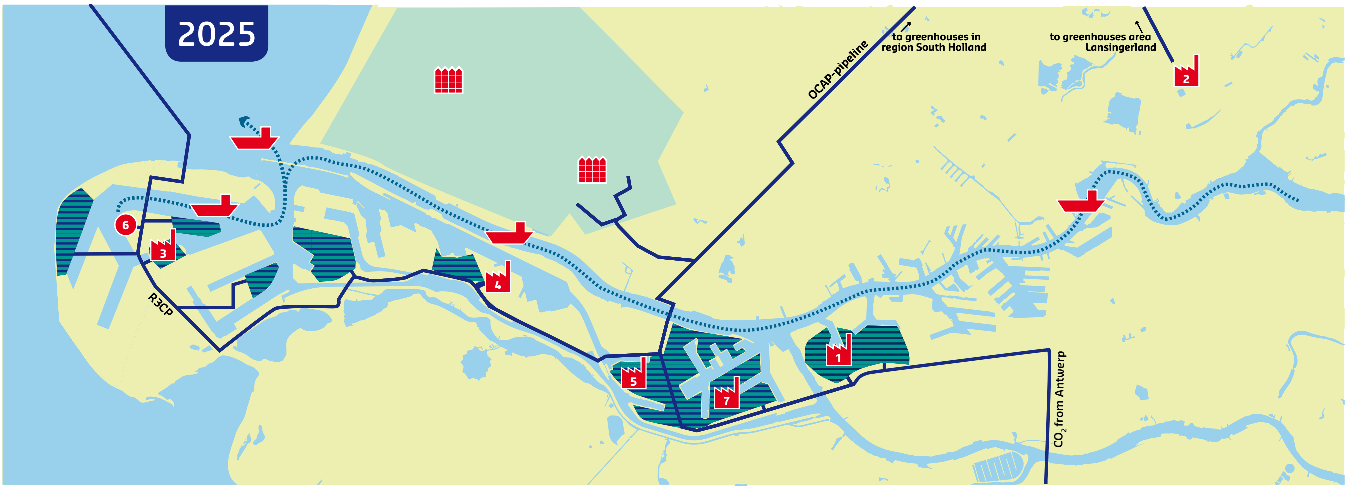
Connecting industry to CCS network (not just large scale demo's)

Pegasus: location not yet determined




1 Shell Pernis
2 E.ON-ROCA
3 E.ON $CO_2$-Catcher (CATO-2 pilot project)
3 ROAD
4 Abengoa
5 Air Liquide

6 $CO_2$ Hub CINTRA
7 Air Products
Connecting industry to CCS network (not just large scale demo's)

Pegasus: location not yet determined

Maasvlakte II, under construction
Transport by pipeline
Transport by ship
$CO_2$ capture
Green houses
Energy intensive industry
$CO_2$ Hub

# Factsheets



**capture**

Air Liquide
Air Products
Pegasus
ROAD
Shell

**transport**

CINTRA
GdFSuez
OCAP
Pegasus
R3CP

**re-use and storage**

GdFSuez
Maersk
OCAP
Pegasus
Taqa

# ROAD

| ROAD *facts and figures* | |
|---|---|
| **Capture technology** | Post-combus-tion capture (pulverized coal) power plant |
| **Storage technology** | Depleted gas fields |
| **Start operation** | 2015 |
| **Capacity (MWe)** | >250 MWe |
| **Amount of $CO_2$ captured** | 1.1 Mton/y |
| **% biomass** | 20% |
| **Public financing** | 330 M€ (max.) |

www.road2020.nl

## The project as part of the network

The ROAD project is one of the first industrial, integrated CCS demonstration projects in the world. E.ON Benelux and Electrabel Nederland/GDF-SUEZ Group have formed a joint venture to build a carbon capture unit with a capture capacity equivalent to 250 MW generation at the new coal-fired power plant E.ON is building at the Maasvlakte.

ROAD (Rotterdam Opslag en Afvang Demonstratieproject) is developed in close co-operation with:

- TAQA, which is envisaged to become responsible for storage, in the offshore P18 fields. The storage capacity of these gas fields is estimated at 35 Mton, which will gradually become available for storage over the years 2015-2017. TAQA will develop and operate the facilities which inject the $CO_2$ and monitor the stored $CO_2$;
- GDF Suez, which will develop and operate a new pipeline, with a capacity of approximately 5 Mton annually, to the TAQA fields.

The complete ROAD project is designed to capture, transport and permanently store 1.1 Mton of $CO_2$ annually. Both the pipeline and storage location have the capacity to serve other $CO_2$ emitters in the Rotterdam area.

Both partners in the joint venture are building a power plant in the Rotterdam port:

- The coal-fired/biomass power plant E.ON is building, the Maasvlakte Power Plant 3 (MPP3), has a capacity of 1,070 MW. The commercial start of this power plant is projected for 2013. The capture installa-tion will be built at this plant.
- The coal-fired/biomass power plant Electrabel is building, also at the Maasvlakte, has a capacity of 800 MW. Operation should start in 2013.

Operation of the industrial, integrated CCS chain should start in 2015. Full-scale deployment of CCS for both the E.ON and the Electrabel power plants will be considered after the successful finalization of the demonstration project in 2020.

## Status

The project has been awarded a grant to a maximum of 180 M€ by the European Union under the European Energy Programme for Recovery. In addition, the Dutch Government has awarded a subsidy to a maximum of 150 M€. This subsidy requires the construc-tion of the entire chain and a minimum of 4 Mton of $CO_2$ to be stored. Based on this external funding, the joint venture will finance the remaining investments required and the costs for operations. Both E.ON and Electrabel plan to their final investment decision the third quarter of 2011.
The selection process for the capture equipment facility is being completed. The storage location is being explored further and the environmental impact assessment for the permit procedure has been carried out.
Both joint venture partners have signed a letter of co-operation with RCI in 2009. RCI gives policy support to this project and contributes to the development of the project through the independent storage assessment it has commissioned.

# Air Liquide

## The project as part of the network

Air Liquide is building a new hydrogen plant at its site in the Botlek area in Rotterdam. This 160 M€ project will come on line in 2011 and will supply up to 130,000 $Nm^3/h$ of hydrogen to Air Liquide's Northwest European hydrogen network.
The plant will be capture-ready, meaning that it could easily be equipped with an installation to capture up to 500kt/y of $CO_2$. The costs of capture on a hydrogen plant are relatively low. This capture capacity will be on top of the 50kt/y, which Air Liquide already captures from its existing units in the Botlek area. This $CO_2$ is delivered in particular to the greenhouse market in the Netherlands.

To recover the $CO_2$, Air Liquide uses in-house cryogenic technology, which is integrated into steam reforming units. Such a carbon capture unit, called cryogenic purification unit (CPU), can either be installed on new hydrogen units or be retrofitted to Air Liquide's existing units. Air Liquide has finalised the CPU design and is currently evaluating projects where such a unit could be installed. Air Liquide expects that the unit could be installed within 24 -30 months from the date of investment decision.

Air Liquide is also a partner in the CINTRA consortium,that aims to create a $CO_2$ hub in Rotterdam (see page 27). The objective of the hub is to collect $CO_2$ from various emitters in Rotterdam and transport it to depleted offshore oil and gas fields by pipeline or in liquid form by ship.

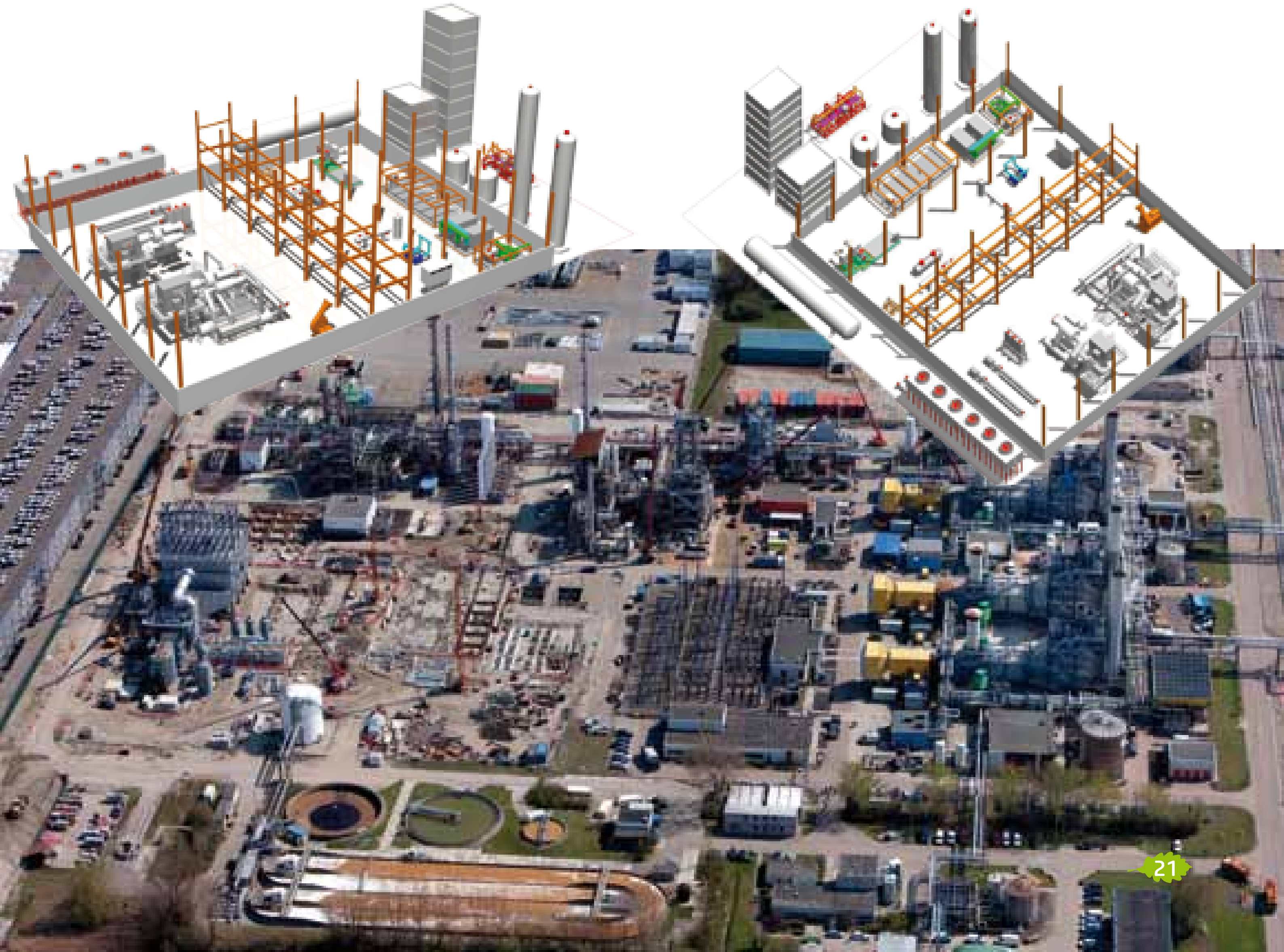
## Status

Air Liquide has applied for NER300 subsidy for its CCS-project. Intention is to start operation of the capture unit by the end of 2015. Transport will be handled by the CINTRA consortium. Air Liquide is considering the possibility of storing the $CO_2$ at the Maersk EOR-project. Air Liquide and RCI have signed a letter of co-operation.

**Air Liquide**
***facts and figures***

| | |
|---|---|
| **Capture technology** | Hydrogen plant |
| **Start operation** | 2011 (H2 plant)<br>2015 ($CO_2$ capture) |
| **Capacity** | 130,000 $Nm^3/h$ |
| **Amount $CO_2$ captured** | 0.5 Mt/y |
| **Investments costs** | 160 M€ (plant)<br>~ 50 M€ (capture) |
| **costs / kt $CO_2$** | ~ 40 €/t |

www.airliquide.nl



# The Pegasus Project: a Zero Emission Power Plant (ZEPP)

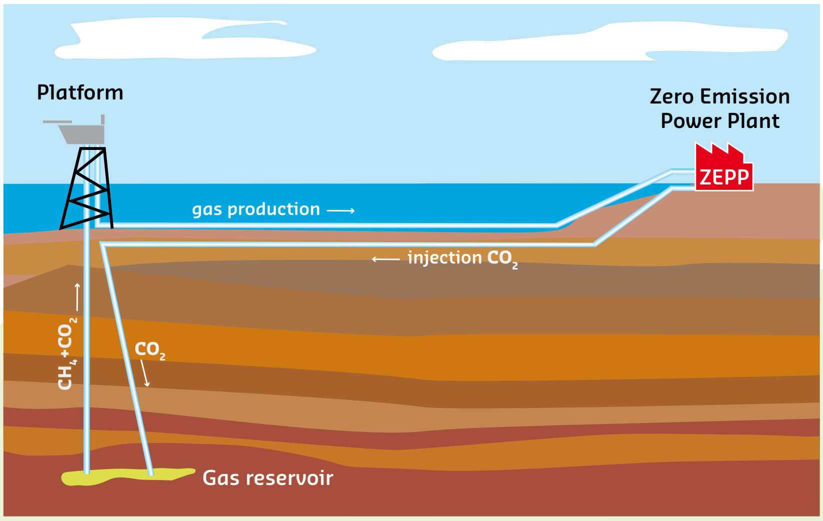
| **Pegasus** *facts and figures* | |
|---|---|
| **Capture technology** | Oxyfuel power plant |
| **Storage technology** | Depleted gas field |
| **Capacity (MWe)** | 340 MWe |
| **Amount of $CO_2$ captureds** | 2.5 Mton/y |

## The project as part of the network

The Pegasus Project will construct a commercial scale oxy-fuel natural gas-fired combustor, Zero-Emission Power Plant ('ZEPP') of about 340 MWe nett capacity. Part of the plant will be the capture and storage of all $CO_2$ produced. The advantage of this technique is the efficient power generation with low calorific natural gas.

The fuel used will be natural gas, containing a high percentage of $CO_2$, supplied from a field in the North Sea. This gas will be transported to Rotterdam by pipeline, where it will be fed into a highly innovative 'oxy-fuel' combustor combined within a Combined Cycle Gas Turbine ('CCGT') Power Plant.

The flue gas contains a high concentration of $CO_2$ of about 2.5 Mton/year. A second pipeline will be constructed to the offshore field where the natural gas for the plant originated. The $CO_2$ will be stored in this field, which is situated in the British part of the North Sea.




The Pegasus project contributes in several ways to the economic and sustainable development of the port of Rotterdam:

- The Pegasus-ZEPP Project enables the future application of CCS on all kind of gaseous-fuel. Opening the door to an affordable future for more CCS on gas. Gas being an important bridging fuel towards a sustainable energy supply.
- A mature 'oxy-fuel' technology will create opportunities for many other green development applications, for instance, power production with biogas, syngas (coal gasification) or different industrial gases. The 'oxy-fuel' technology could be a key element to advance the development of all these clean power production projects.
- The large volume of $CO_2$ and the infrastructure required for this project will strengthen the $CO_2$ infrastructure from Rotterdam and in the North Sea, facilitating participation for other industries. The large volumes also makes a CCS infrastructure viable for further commercial use.

Pegasus has been initiated by SEQ International, with participation of AES Transpower as potential lead investor. The oxy-fuel combustor will be provided by CES (U.S. based). Linde Gas is responsible for the oxygen supply, Siemens will develop and build the adapted CCGT.

## Status

Pegasus is currently developing a pilot for this combustor at the Tata steel plant in IJmuiden, for which it was granted a subsidy from the Dutch Government in 2007. Pegasus intends to build the full-scale plant with a grant from the NER300. It is currently developing its business case and engaged in dialogue with the Port Authority on the location for its plant in the port of Rotterdam.

# Shell

## The project as part of the network

Shell has a presence in the greater Rotterdam area with the refinery and petro-chemical plants of Pernis and Moerdijk. Shell has several projects running with regard to the capture of $CO_2$.

1. Since 2005, pure $CO_2$ has been captured from a hydrogen plant at the Pernis refinery, compressed by Linde Gas Benelux, and transported to the beverage industry to carbonate soft drinks.
2. Another part of the Pernis $CO_2$ goes through the OCAP network to greenhouse farmers, where the $CO_2$ is used as a nutrient for vegetables and flowers.
3. A small volume of pure $CO_2$ from Shell's Moerdijk petro-chemical plant is sold to industrial customers.
4. Shell will continue to consider and review opportunities to capture further volumes of $CO_2$ from its facilities as legislation and the European Emissions Trading System develop.

## Status

- Since 2005, Shell has delivered well over one million tons of $CO_2$ to the OCAP network.
- Most of the $CO_2$ for greenhouses is used in the spring and summer, as a result the $CO_2$ off-take at Pernis is not constant year round. Shell has sought to direct the surplus $CO_2$ to the Barendrecht $CO_2$ storage project. The Dutch government cancelled the Barendrecht project at the end of 2010. Shell is considering alternative options for the surplus $CO_2$.
- Shell has signed a letter of cooperation with RCI in 2009 in support of the development of CCS opportunities in the Rotterdam area.

**Shell**
***facts and figures***

| | |
|---|---|
| **Capture technology** | Capture at an oil refinery |
| **Storage technology:** | Reuse and storage in depleted gas field |
| **Start operation** | Reuse: 2005 |
| **Capacity OCAP** | 0.3 Mt/y |
| **Beverage industry** | 0.15 Mt/y |

www.shell.nl

# Air Products

www.airproducts.nl

## The project as part of the network

At the site of the Exxon Mobil refinery in Rotterdam-Botlek, industrial gas producer Air Products is building the advanced hydrogen plant HYCO-4. From this plant substantial quantities of hydrogen will be delivered to other refineries and chemical plants in the Rotterdam industrial complex.

The Air Products plant will be fully integrated into the refinery:

- Where the refinery now uses its refinery flue gases for the production of steam in boilers, the new hydrogen plant will use these flue gases for the production of hydrogen and steam. A significant part of the hydrogen produced and all the steam is delivered back to the refinery, allowing the refinery to shut down some of its boilers.The hydrogen is used in the refinery for the production of low-sulphur fuels and the steam for heating and driving pumps.
- The shift from separately produced hydrogen and steam to the combined production thereof and the use of off-gases as feedstock to the hydrogen plant lead to higher efficiency and more effective use of the flue gas. This results in significantly lower emissions of $CO_2$ and $NO_x$. Further integration with the refinery is found in connecting waste-water and fire-fighting water systems.

Hydrogen plants such as these, using the steam reforming process are very well suited for $CO_2$ capture. By adding a capture installation, 70% of the total $CO_2$ produced can be captured, i.e. 500.000 tonnes of $CO_2$ annually. The costs of capture on a hydrogen plant are relatively low, with little technology risk.

## Status

Air Products signed a letter of cooperation with RCI in 2009 to investigate the possibility of setting up a large demonstration project for the capture of $CO_2$. Air Products also collaborates closely with RCI and other participating parties to investigate the possibilities of applying for a NER300 subsidy. This investigation includes generating better estimates of the cost of capture and compression, and engaging with several parties to obtain proposals for transport and storage of $CO_2$. Based on the data collected, Air Products has concluded that the first round of NER300, for which the submission closed early February 2011, came too soon, given a number of uncertainties around available subsidies, liabilities for $CO_2$ stored and higher than expected capital cost. Building on its experience with similar projects in the US, Air Products will continue to monitor the CCS developments in Europe and Rotterdam in particular, expecting that the given uncertainties will in due course be addressed. Air Products believes Rotterdam is well placed to serve as a hub for $CO_2$.

**Air Products** ***facts and figures***

| Capture technology | Start of operation of the plant | Amount of $CO_2$ captured | Investment costs | costs/kt of $CO_2$ |
|---|---|---|---|---|
| Hydrogen plant | 2011 | | 200 M€ (plant) | |
| $CO_2$ capture, drier and compression plant | > 2015 | 0.5 Mton/y | 100 M€ (capture & compression) | 35 ~ 40 €/t |

Note: The investment numbers presented in this table are rounded off numbers and the cost per kT of $CO_2$ assumes significant subsidies.

# R3CP

## The project as part of the network

The Port Authority is developing with OCAP, Gasunie and Stedin a $CO_2$ common carrier pipeline system in the port of Rotterdam. This infrastucture, intended to facilitate the developing CCS market, is called 'Rotterdam $CO_2$ Common Carrier Pipeline' (R3CP).

A Common Carrier in the Rotterdam port has several advantages:

- Transportation of $CO_2$ will be done at the lowest possible costs for market parties.
- Providing access for all interested parties at public tariff and transport conditions.
- Efficient use of pipeline corridors, and thus of the scarce space in the port.

This infrastructure will therefore play a key role in the development of a CCS-network in the Port of Rotterdam and will thus contribute to the investment climate and sustainable growth in the port of Rotterdam area.

The first customer of the Common Carrier will be the Air Liquide project, connecting the Air Liquide Hydrogen plant in the Botlek with the CINTRA $CO_2$ shipping terminal at Maasvlakte 2.

## Status

Two options on how to develop the Common Carrier are under study. One of the options is extending the existing OCAP pipeline system towards Maasvlakte 2. OCAP delivers $CO_2$ from port industries to greenhouses (see page 26).
Another possibility is a new pipeline, running from Air Liquide (see page 21) towards Maasvlakte 2. This new pipeline could be connected to OCAP, to create synergy with the existing $CO_2$ pipeline system. On Maasvlakte 2 the $CO_2$ will be collected and transported offshore to storage locations, either by offshore pipeline, ship or both.
By 2025, the R3CP is expected to be extended outside the port area to the industrial locations Moerdijk and Antwerp.

# OCAP

**OCAP**
***facts and figures***

| | |
|---|---|
| **Type of project** | Transport, reuse and storage |
| **Start operation** | 2005 |
| **Amount of $CO_2$ re-used** | 0.3 Mton/y |
| **Investment costs** | >100 million |

www.ocap.nl

## The project as part of the network

The core business of OCAP is the delivery of $CO_2$ from industrial sources to greenhouses. By using this $CO_2$, instead of producing their own by burning natural gas, the greenhouses save energy. It also provides the grower with an alternative to fossil fuel (which is used for both heating during the cold season and for producing $CO_2$), using instead a combination of $CO_2$ delivery and renewable energy sources, such as geothermal energy, (industrial) waste heat, etc. This project thus realizes an important environmental benefit. OCAP delivers over 300 kiloton of $CO_2$ from the Shell refinery Pernis to some 500 greenhouses. From mid 2011, OCAP will take $CO_2$ from bio-ethanol producer Abengoa. OCAP has a $CO_2$ pipeline running through the port of Rotterdam.

The experience of OCAP, a joint venture of Linde Gas Benelux and Volker Wessels, in compressing, transporting and using $CO_2$ makes the company a useful partner in other projects. OCAP is participating in the R3CP project to extend this pipeline and to develop a $CO_2$ Common Carrier transport network in the port. The current pipeline connects to a large $CO_2$ transport pipeline from Rotterdam to Amsterdam. From this main pipeline, an extensive network delivers $CO_2$ to the individual greenhouses. Currently, 1,700 hectares of greenhouses are supplied. Since the main pipeline runs along a total of 5,000 hectares of greenhouses, OCAP is preparing to extend its delivery network.
In addition to the supply to greenhouses, the OCAP network can be used for the transport of $CO_2$ for permanent storage. It is possible to extend the main transport pipeline from Amsterdam to the North Sea, thus enabling the use of the pipeline for offshore CCS. This creates the unique opportunity to reuse a maximum of industrial $CO_2$ in greenhouses, while the remainder is being stored in depleted oil and gas fields offshore.

## Status

OCAP is looking for additional $CO_2$ suppliers in order to reuse $CO_2$ in greenhouses. This would increase security of $CO_2$ supply and would create an opportunity to expand the $CO_2$ supply to other greenhouse areas. It is the ambition of OCAP to expand its annual delivery volume to greenhouses to approximately one megaton of $CO_2$.

# CINTRA

## The project as part of the network

Vopak, Anthony Veder, Air Liquide and Gasunie are pooling their resources and expertise in the CINTRA-consortium (formerly the Liquid Logistics Shipping Concept) with the aim of creating a turnkey solution to the logistical CCS challenge both emitters and $CO_2$ storage providers have to face. Captured $CO_2$ is to be gathered at a $CO_2$ hub either through (inland) barges or through pipelines (see also R3CP at page 25). At the hub, the $CO_2$ can be intermediately stored and treated (i.e., vaporized and/or liquefied) and subsequently transported, again by ship or pipeline, to offshore storage facilities on the Dutch, UK, Danish and Norwegian continental shelves. The envisaged seagoing vessels will be able to offload the $CO_2$ through an offshore infrastructure (e.g. submerged flexible hoses, fixed loading towers or other Single Point Mooring) on a stand-alone basis.

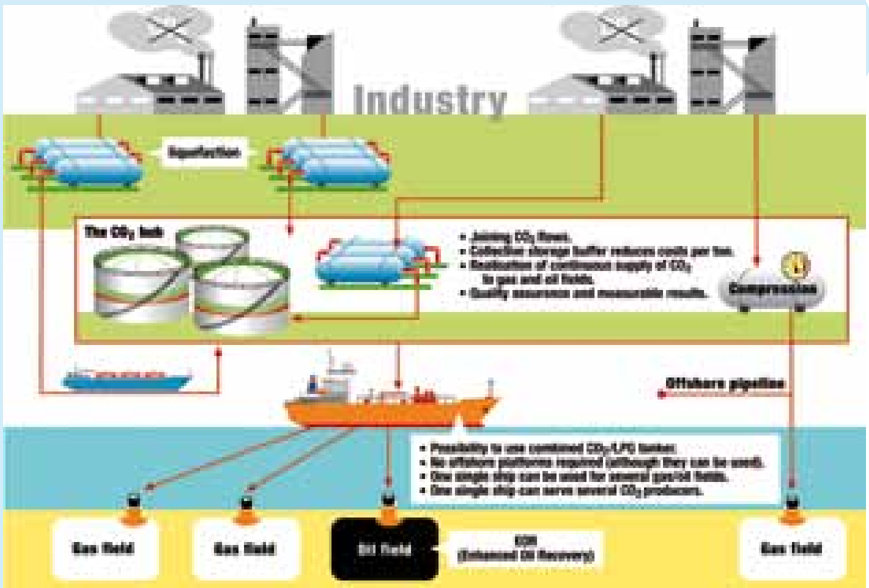
As such, the CINTRA-Concept offers maximum flexibility to multiple emitters as it gives them cost-effective solutions for $CO_2$ transport to multiple storage locations. Subsequently, higher reliability levels can be achieved than with single point-to-point transport solutions between emitter and storage location and the costs for common facilities can be shared rather than carried by a single emitter project. Furthermore, given the flexibility being offered, this concept also allows for small emitters and small storage locations to be connected to the network and enjoy the eventual cost synergies. In addition to various power plants in the port area, other potential industrial sources could be connected to the hub:

- CINTRA is a partner in the Air Liquide project (see page 21), and will be responsible for the transport of the $CO_2$ from the $CO_2$ hub to offshore operations of Maersk Oil at the Danish Continental Shelf, where the $CO_2$ will be used for Enhanced Oil Recovery and eventually stored.
- In turn, this hub could also be connected to the pipeline planned to connect the ROAD project to the TAQA P18 field or the OCAP pipeline to greenhouses.

## Status

The four companies jointly signed a letter of cooperation in 2010 with RCI expressing their clear intention to cooperate with RCI and the Rotterdam-based emitters to offer a 'one-stop shop' for all $CO_2$ logistical issues, taking $CO_2$ and transporting it via the $CO_2$ hub to offshore storage locations. A formal Dutch legal entity called Rotterdam CINTRA B.V.,established in November 2010 is ready to engage in full transport agreements. By the end of 2010 this joint venture had made a range of non-binding commercial offers to the main Rotterdam emitters, to transport their $CO_2$ to various offshore locations.

The partners in CINTRA have performed a range of detailed design studies including a technical optimization covering the entire CCS logistics chain, some with both emitters and storage operators, to align the needs and tackle the challenges that CCS presents.




**CINTRA**
***facts and figures***

| | |
|---|---|
| **Type of project** | Ship transport and $CO_2$ hub facilities |
| **Start operation** | 2015 – with first NER300 and EEPR projects |
| **Capacity** | Initial throughput flows are expected to be around 1.5 Mton/y, growing to a potential of 10 Mton/y or more in 2025 |

www.cintra.nl *

* under construction

# TAQA

www.taqa.ae/nl

## The project as part of the network

TAQA is evaluating the potential for the first industrial-scale offshore $CO_2$ storage facility in the Netherlands. TAQA operates the P18-A gas platform and P18 reservoirs only 20km offshore Port of Rotterdam as well as the P15 fields. The scale, location and maturity of these reservoirs make them ideal for an early commercial-scale demonstration of the potential of Carbon Capture and Storage (CCS). The P18 gas reservoirs are 3,500 metres deep under the seabed with capacity to store up to 35 million tonnes of $CO_2$.

P18-A satellite platform:

- 35 million tonnes of $CO_2$ storage capacity
- 3,500 metres deep under the seabed
- 5 wells can be converted for injection
- 0.5 to 1.5 million tonnes per year of injectivity per well
- 2015: first injection
- Up to 15 years of continuous injection

TAQA is the preferred storage provider for ROAD (see page 20). According to the project planning, the capture, transport and storage of $CO_2$ should be operational in 2015.


## Status

Currently, concept engineering is being performed on the P18 fields. Design options for the transport and storage facilities are being evaluated. Under the CATO-2 programme, P18 is used as a field case for storage assessment: reservoir modelling, seal and fault integrity, well integrity and monitoring techniques are studied and applied to P18 as part of CATO-2. A detailed storage plan to support a licence application is underway, as is the development of an environmental impact assessment. The permit procedure has started.
TAQA supports the independent storage assessment initiated by RCI.

After the final investment decision for ROAD, a front-end engineering design (FEED) study for the storage facilities will be executed. Construction of the pipeline should commence in 2013 and the platform will be modified in 2014. First injection will be in 2015.

**TAQA** ***facts and figures***

| Type of project | Start operation | Platform | Theoretical storage capacity | Reservoirs | Injection capacity 2015 | Maximum injection capacity 2020 |
|---|---|---|---|---|---|---|
| P18 Storage | 2015 | P18-A | 35 Mton | P18-6, P18-4, P18-2 | 1.5 Mton/y | 4 Mton/y |
| P15 Storage | After 2019 | P15-ACD | 44 Mton | Potentially all 8 P15 gas reservoirs | 5 Mton/y | 5 Mton/y |

# Maersk

www.maerskoil.com

## The project as part of the network

Maersk Oil is working to develop an opportunity for Enhanced Oil Recovery (EOR) in the Danish part of the North Sea in combination with $CO_2$ storage. Such projects may use and store significant volumes of $CO_2$ captured in the Rotterdam port area. Maersk Oil is actively participating in several CCS projects under development in Rotterdam and supports the idea of establishing a shipping terminal in Maasvlakte II for the potential export of millions of tonnes of liquefied $CO_2$ to its mature Danish oil fields from 2015.

The injection of $CO_2$ into mature oil fields could allow Maersk Oil to produce significant volumes of what would otherwise be non-extractable oil, whilst simultaneously storing $CO_2$. As a consequence, the revenues from EOR may potentially reduce the net cost of CCS, making CCS more economically feasible than would otherwise be the case.

Shipping $CO_2$ in tanker vessels in many cases requires less capital expenditure than using pipelines and may provide flexibility in terms of access to multiple storage sites. $CO_2$ tanker vessels can also be used to transport other gaseous products such as LPG, providing additional flexibility.

## Status

Maersk Oil is currently identifying suitable offshore $CO_2$ storage sites in the North Sea in close cooperation with a number of $CO_2$ emitters in Rotterdam. Air Liquide (see page 21) has identified storage in a Maersk Oil oilfield as one of the possible solutions for its NER300 project.

Maersk Oil, together with Maersk Tankers, signed a letter of cooperation with RCI in 2010 to participate in activities in the Rotterdam port area related to the transport, utilisation and storage of $CO_2$.

# GDF Suez, K12-B $CO_2$ Injection Project

www.k12-b.nl

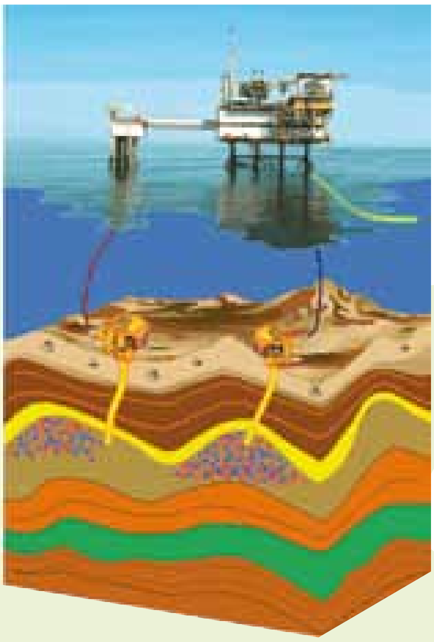
## The project as part of the network

GDF Suez is actively involved in both the transport and storage parts of the CCS chain. K12-B is the first site in the world where $CO_2$ is being injected into the same reservoir from which it was produced. GDF Suez has been injecting $CO_2$ in the K12-B gas field since 2004. The project has successfully demonstrated the offshore injection, storage and monitoring & verification of $CO_2$.

The K12-B gas field is located in the Dutch sector of the North Sea, approximately 170 km northwest of Rotterdam. Since 1987, it has produced natural gas with a relatively high $CO_2$ content. GDF Suez initially received a subsidy from the Dutch government for the storage of $CO_2$. Prior to transporting the gas to shore, GDF Suez separates out the $CO_2$ and partly re-injects the separated $CO_2$ back into the gas field, at a depth of approximately 4000m, rather than releasing it back into the atmosphere. $CO_2$ injection continues at K12-B and so far a total of 80,000 tonnes of $CO_2$ have been successfully stored, monitored and verified.

## Status

GDF Suez is investigating together with RCI the economic and technological preconditions for storing larger amounts of $CO_2$, from $CO_2$ capture projects, in K12-B. $CO_2$ storage operations could give new life to the platform. Furthermore, GDF Suez will develop and operate a pipeline connecting the ROAD-project with the TAQA fields.



## Abbreviations

| | |
|---|---|
| **CATO-2** | $CO_2$ Afvang, Transport en Opslag 2, the (second) Dutch R&D Programme |
| **CCS** | Carbon Capture and Storage |
| **CHP** | Combined Heat and Power |
| **CINTRA** | $CO_2$ In Transport |
| **$CO_2$** | Carbon Dioxide |
| **CPU** | Cryogenic Purification Unit |
| **EEPR** | European Energy Programme for Recovery |
| **EGR** | Enhanced Gas Recovery |
| **EIA** | Economic Impact Assessment |
| **EOR** | Enhanced Oil Recovery |
| **ETS** | Emission Trading Scheme |
| **EU** | European Union |
| **FEED study** | Front End Engineering Design study |
| **FID** | Final Investment Decision |
| **IGCC** | Integrated Gasification Combined Cycle technology |
| **ISA** | Independent Storage Assessment |
| **LPG** | Liquefied Petroleum Gas |
| **LoC** | Letter of Cooperation |
| **NER300** | New Entrants Reserve 300 Package |
| **$Nm^3$** | Normal cubic meters |
| **OSPAR** | Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic |
| **R3CP** | Rotterdam $CO_2$ Common Carrier Pipeline |
| **RCI** | Rotterdam Climate Initiative |
| **ROAD** | Rotterdam Opslag en Afvang Demonstratieproject (Rotterdam storage and capture demonstration project) |

## Colophon

**Rotterdam Climate Initiaitve**
Improving the climate for the benefit of people, the environment and the economy; that is the challenge confronted by the collective initiators: Port of Rotterdam, the City of Rotterdam, port and industries' association Deltalinqs and DCMR Environmental Protection Agency Rijnmond. The Rotterdam Climate Initiative creates a movement in which government, organizations, companies, knowledge institutions and citizens collaborate to achieve a fifty per cent reduction of $CO_2$ emissions, adapt to climate change, and promote the economy in the Rotterdam region.

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Deltalinqs

Port of Rotterdam

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**$CO_2$ capture and storage in Rotterdam • *A Network Approach***

May 2011