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D1.5 Aligning NSE 3 with the CCUS roadmap

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Key Messages

- CCS provides a cost-effective means of reducing CO_2 emissions from sources in the industrial and power sectors; for several sectors, CCS is the only technology that allows significant reduction on a short timescale, notably process-related emissions.
- Ongoing CCS initiatives in NL target injection rates that sum up to 19Mt/yr (+2/-5) in 2030, and increasing to 27Mt/yr (+6/-6) in 2050, of which 5-8Mt/yr for the production of up to 100PJ of blue H_2 in (mainly) the Rotterdam, Amsterdam and Eemshaven industrial clusters.
- Although there is enough CO_2 storage capacity in fields offshore, the projected max. injection rates per year of fields that are included in published feasibility studies (in P, Q, K, L blocks) cannot sustain the above-mentioned 27Mt/yr scenario beyond 2045. Other candidate fields (in E, G, J, K, L blocks) should also be studied.
- Synergy can be achieved by electrifying oil & gas platforms and re-using them for CCS. A cabled connection to an offshore windfarm provides a reliable, stable power supply, and greatly reduces the risk of power interruptions, something that is not easily achieved with autonomous solutions.
- A longer-term vision on the development of transport and storage infrastructure should be developed that aligns and integrates ongoing commercial CCS initiatives in NL and the wider the North Sea region. Such an "international CCS infrastructure outlook" should explore (and exploit) synergies to reduce total system cost.

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Introduction

Introduction

- CCS can play an important role in reaching the 2030 and 2050 emission reduction target of resp. 49% and 95% less CO_2 emissions compared to 1990. In the Dutch Climate Accord (2019), it is stated that the implementation of CCS is seen by government and industry as an important and imperative measure to achieve the climate target cost-effectively.
- CCS requires a transport and storage infrastructure to be developed in the North Sea, and therefore lays a spatial claim on parts of it. CO_2 will be captured from sources onshore, and stored in depleted gas fields in the North Sea. Transport of the CO_2 between sources and storage sites will occur by pipeline or by ship. An important aspect is the re-use of parts of the existing oil- and gas infrastructure (wells, platforms, pipelines) for CCS, which becomes redundant once hydrocarbon production ceases.
- CCS is an activity that may interfere with or complement other important existing and future North Sea-based activities (offshore wind, production of hydrogen, electrification, fishery, shipping, nature reserves, recreational uses). Hence, alignment is needed.
- In this workpackage, alignment was sought by presenting the state of play of CCS in NL and the wider North Sea region, organizing meetings and workshops with internal and external stakeholders of CCS and other activities, and exploring the potential for synergies between CCS and other activities, in particular the production of blue hydrogen, and platform electrification.

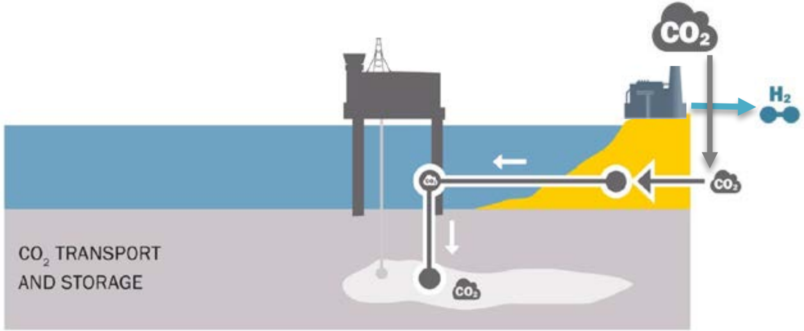
Goals and Approach

- Align NSE3 with the CCUS roadmap
  - Early on it became clear that there is no orchestrated CCUS roadmap, but rather that there are commercial development projects (called “Porthos”, “Athos” and “Aramis”) ongoing in NL that aim to put in place transport and storage infrastructure for customers that plan to decarbonize their production activities by capturing CO_2 and storing it permanently in the subsurface. In countries around us, notably in the UK (Acorn), Norway (Northern Lights) and Ireland (ERVIA), similar development projects are underway. Furthermore, multi-partner public-private research projects such as ALIGN-CCS and ELEGANCY unite science and industry to advance CCS towards commercialization and transform EU industrial regions into economically robust, low-carbon centres. To provide a view on the state-of-play of CCS in NL and countries around us, information on these initiatives is included in this deliverable.
  - This information was used to obtain an up-to-date projection of the bandwidth of possible yearly rates of CO_2 injection in NL between 2020 and 2050. A minimum and maximum CCS scenario (Mt/yr) was then defined and shared with WP1.2 of this NSE3 project to constrain the application of CCS in the energy system model.
  - A “likely” CCS injection scenario was then defined, for which a CCS transport and storage infrastructure roll-out scenario was developed using publicly available data on storage capacities and injection rates of fields. It shows which fields in the Dutch part of the North Sea could be used, when they would have to be available for CCS, and for how many years, and how the connecting transport infrastructure between source areas and storage sites could be developed.
- Explore synergies between CCS, hydrogen production, and electrification
  - Synergy with H_2 production was explored by aligning blue H_2 demand with WP1.5 of NSE3, and then integrating the additional amount of CCS in the roll-out scenario to assess whether there would be sufficient storage capacity.
  - Synergy with electrification was explored by comparing power requirements for CCS with that of gas production, and by looking into alternatives for power supply to a platform after gas production. The results were shared with WP3.5 on Future Power Grid.

Exploring Synergies

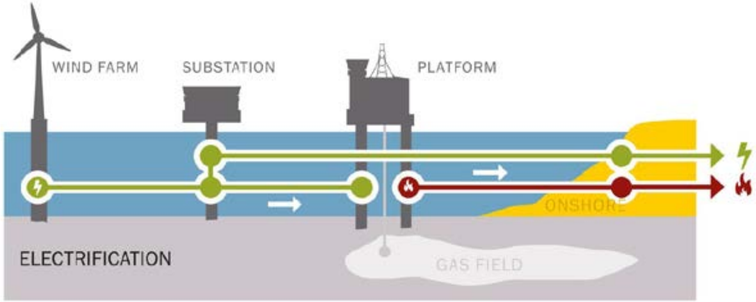
Blue H_2 production and CCS

- 7.5Mt CO_2 is produced for every 100PJ of H_2 (9kg CO_2/1kg H_2) hence blue H_2 production can only take place if the captured CO_2 can be stored.
- Here, we assess if there is enough storage capacity (on top of the storage capacity required for non-H_2 CCS plans) to fulfill two possible H_2 demand scenarios.
- Furthermore, we explore how this required capacity could be accommodated in a field-level CO_2 storage infrastructure roll-out plan based on publicly available data on storage capacities and injection rates of fields.



Electrification and CCS

- Gas production and CCS both need power for their operations. Offshore wind can provide clean power for both.
- Synergy could be achieved by electrifying a platform for gas production, and then re-using the cabled platform for CCS.
- It would decarbonize the production and storage operations, and solve the power challenge for CCS, i.e., once gas production ceases there is no gas available to produce electricity by CCGT.
- Here, we assess how power needs for CCS compare to those of gas production, and what alternatives exist to supply this power for CCS.



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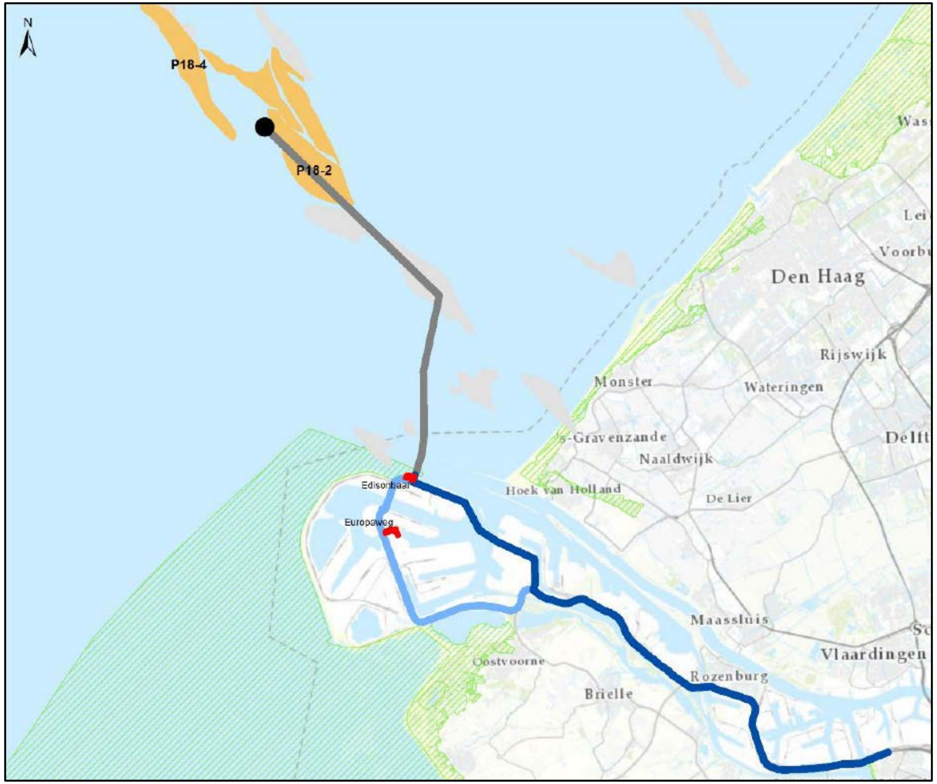
CCS activities in The Netherlands

Porthos

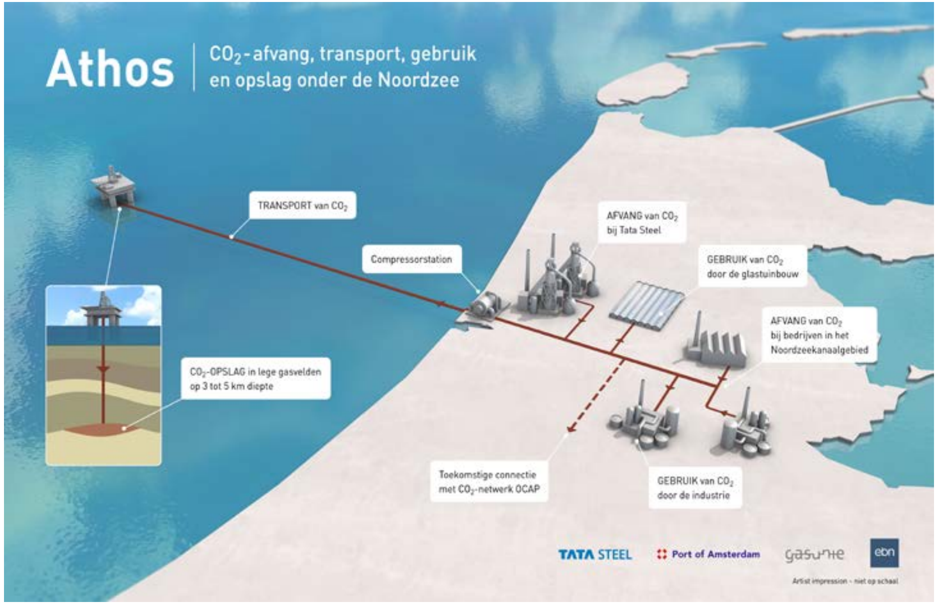
- **Porthos** aims to develop an open-access CCS transport and storage infrastructure for CO_2 sources in the Port of Rotterdam (PoR) and potentially Antwerp and Terneuzen industrial clusters (through PCI CO2TransPorts, see slide 14).
- Partners are EBN, Gasunie and PoR.
- Amounts: 4-5Mt/yr in 2030, and 8Mt/yr by 2040.
- Transport by dedicated CO_2 pipeline to offshore fields in the P-18 block (initially).
- 1st injection in 2024 (FID end 2021).



Ref: Notitie Reikwijdte en Detailniveau - Rotterdam CCUS Project (Porthos)

Athos

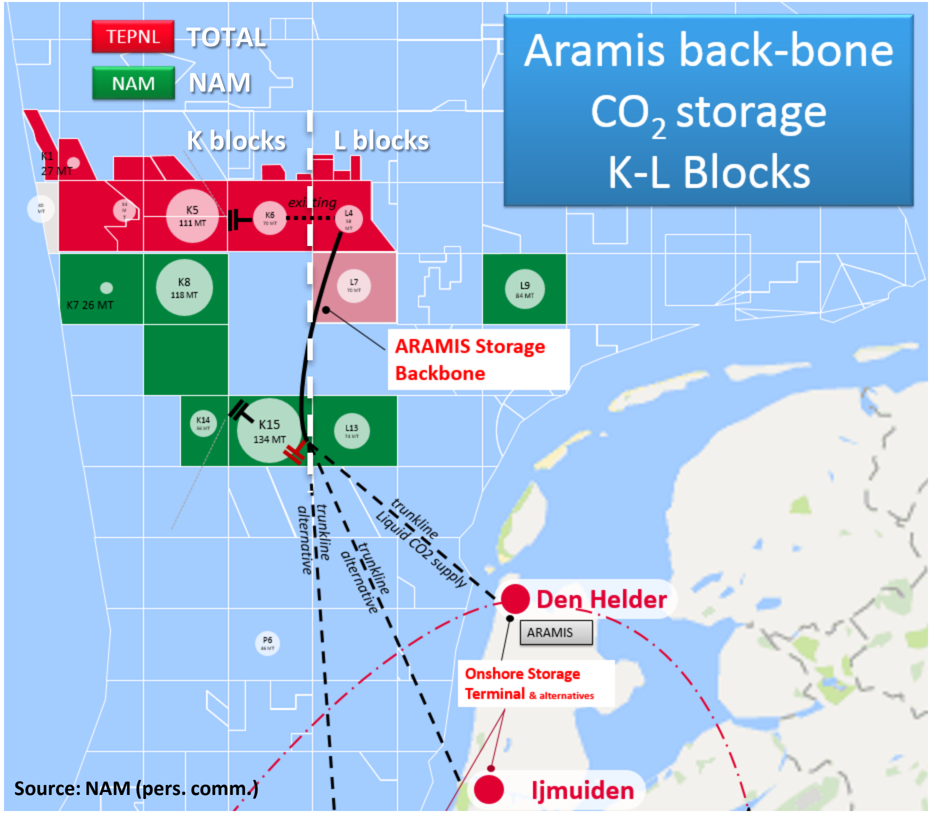
- **Athos** aims to develop a CCS transport and storage infrastructure for CO_2 sources (Tata Steel, municipal waste incinerators) in the IJmuiden and Port of Amsterdam (PoA) region.
- Partners are Tata Steel, PoA, EBN, and Gasunie.
- Amounts: 4-5Mt/yr in 2030.
- Transport either directly by dedicated CO_2 pipeline to offshore fields in the K, L blocks, or by ship to Den Helder (connecting to Aramis, next slide), and from there by pipeline to those fields.
- Also partly CCU via OCAP pipeline to consumers in SW Netherlands region (e.g. greenhouses)
- 1st injection in 2027.



https://www.ebn.nl/studie-athos-toont-haalbaarheid-aan-noordzeekanaalgebied-biedt-potentieel-voor-co2-infrastructuur/

Aramis

- **Aramis** aims to develop a CCS transport and storage infrastructure for yet undisclosed CO_2 sources.
- Sources could be industrial clusters such as NZKG (Noordzeekanaalgebied), Zeeland, and international (NW Europe)
- Partners are NAM, Total and EBN
- Amounts: 4-8Mt/yr in 2030
- Transport by ship to Den Helder or alternative Dutch seaport, and from there by dedicated CO_2 pipeline to offshore fields in the K, L blocks.
- Timing of 1st injection unknown



Source: NAM (pers. comm.)

Other CCS activities in NL

- **BioCCS Eemshaven:** aims to developed a 250MW bioCCS demo plant, commissioning year 2030, but possibly earlier with CCU.

- **Chemelot, Geleen:** targets to capture 0.5-0.8Mt/yr by 2025, most of which is pure CO_2 from OCI. CO_2 is to be transported by barge to Rotterdam to be fed into the Porthos CCS infrastructure. Timing is uncertain, also because the barges will first have to be developed and regulated.

- **Zeeland, North Sea Port:** aims to implement CCS by 2030 at a rate of 1.7Mt/yr, and increasing to 3.1Mt/yr by 2040, and decrease afterwards due to use of H_2. For CCS there is a linked to Porthos foreseen, i.e., a pipeline from the Zeeland area to Rotterdam.

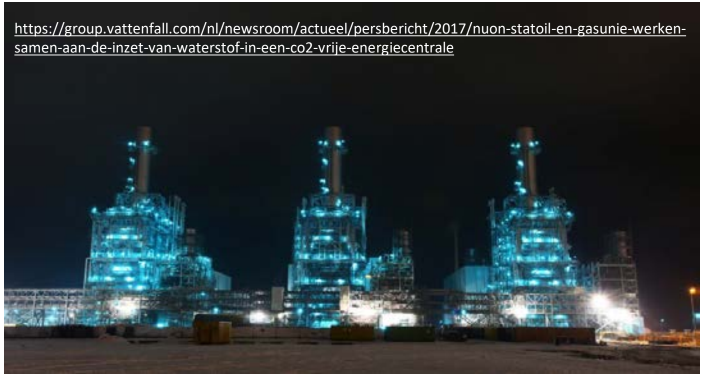
https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/01/08/achtergrondnotitie-industrie-jff-css/Industrie+-+JFF+CSS+Eindrapportage.pdf

CCS activities in NL linked to Hydrogen

- **H-Vision** aims for large-scale blue H_2 production through ATR (Auto Thermal Reforming) in the PoR region, which is estimated to require 2Mt/yr CCS in 2025, and up to 6Mt/yr in 2030. H-Vision ([link]() to final report of feasibility study) is linked to Porthos for CCS.

https://www.portofrotterdam.com/nl/nieuws-en-persberichten/h-vision-blauwe-waterstof-voor-een-groene-toekomst

- **H2M** (Gasunie, Equinor, Vattenfall) aims to produce blue H_2 through ATR in the Eemshaven region to be used as fuel for the Magnum power plant, which is estimated to require 2Mt/yr CCS from 2024 onwards. H2M is linked to the Northern Lights PCI project (see slide 15) for CCS, i.e., the CO_2 would be shipped to Norway.



https://group.vattenfall.com/nl/newsroom/actueel/persbericht/2017/nuon-statoil-en-gasunie-werken-samen-aan-de-inzet-van-waterstof-in-een-co2-vrije-energiecentrale

https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/01/25/achtergrondnotitie-elektriciteit-en-industrie-waterstof/Waterstof+binnen+het+klimaatakkoord_eindrapport.pdf

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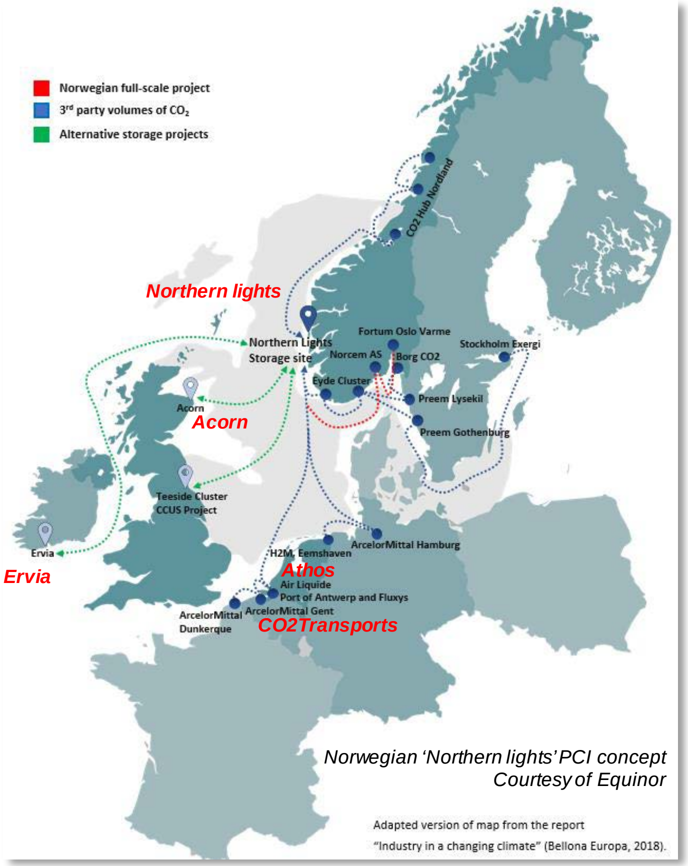
European CCS activities

CO_2 Projects of Common Interest (PCI)



Norwegian 'Northern lights' PCI concept
Courtesy of Equinor

Adapted version of map from the report "Industry in a changing climate" (Bellona Europa, 2018).

- Key cross-border infrastructure projects linking energy systems of EU countries
- PCIs have right to apply for funding from the Connecting Europe Facility (CEF).
- CO_2 transport projects can apply for PCI status since 2017

- 1st round of CO_2 PCI's – 4 projects
  - Northern Lights (Norway + UK)
  - Rotterdam Nucleus (Netherlands + UK)
  - CO_2 SAPLING (transport element of ACORN project, UK + NO)
  - Teesside (UK + NO)

- 2nd round of CO_2 projects – 5 projects
  - Northern Lights (Norway + UK + NL + EI)
  - CO_2TransPorts (Netherlands + Belgium)
  - CO_2 SAPLING (transport element of ACORN project, UK)
  - ERVIA (Ireland + NL + UK + NO)
  - Athos (Netherlands + Ireland) – see slide 8

(https://ec.europa.eu/info/sites/info/files/detailed_information_regarding_the_candidate_projects_in_co2_network_0.pdf)

Northern Lights & CO_2 TransPorts

- **Northern Lights** (Equinor, Shell, Total) aims to develop a CO_2 transport and storage infrastructure for sources in the Oslo region. Transport from Oslo to west coast of Norway by ship, and from there via dedicated CO_2 pipeline to the Sleipner platform. Initially rates of 1-2 Mt/yr are expected (starting in 2023), but there is growth potential through import from other EU countries (https://northernlightsccs.com/en/about).

- **CO2TransPorts** aims to develop Rotterdam, Antwerpen and Terneuzen ports into green ports. Porthos is an integral part of this PCI (ref: NieuwsbladTransport).

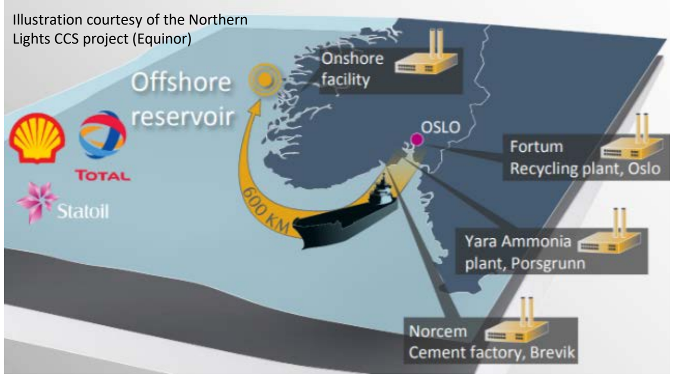
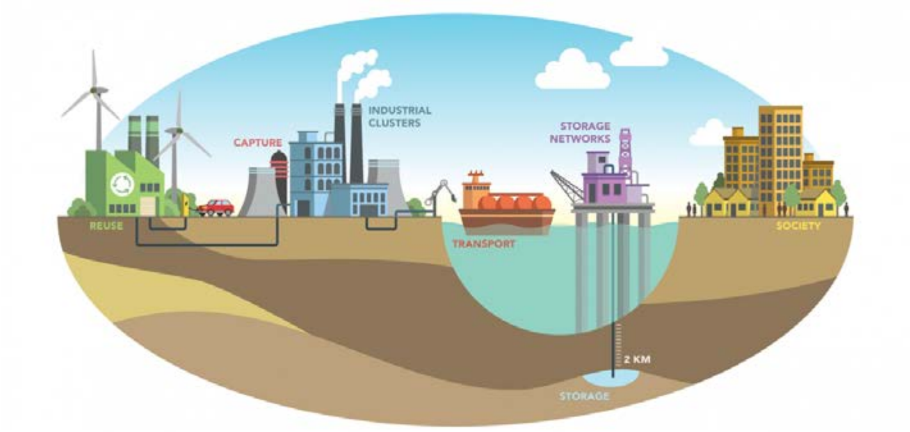


Illustration courtesy of the Northern Lights CCS project (Equinor)

https://www.globalccsinstitute.com/news-media/insights/ccs-features-at-european-sustainable-energy-week/

Other EU activities > ALIGN-CCUS

- The **ALIGN-CCUS research project** unites science and industry in a shared goal of transforming six European industrial regions into economically robust, low-carbon centers by 2025.
- An international partnership of 34 research institutes and industrial companies has secured European and national funding for six specific but interlinking areas of research into carbon capture, utilization and storage (CCUS).
- Research results will be used to draw up blueprints to deliver CCUS in the industrial regions of Teesside and Grangemouth in the UK; Rotterdam in the Netherlands; North Rhine-Westphalia in Germany; Grenland in Norway; and Oltenia in Romania.



https://www.alignccus.eu/about-project

Other EU activities > ELEGANCY

- ELEGANCY - Enabling a Low-Carbon Economy via Hydrogen and CCS
- Decisions on full-scale CCS deployment need to be made as a matter of urgency in order for Europe to achieve the steep build-out required to deliver on the Paris Agreement – and avoid irreversible climate change. ELEGANCY is designed specifically to provide the knowledge needed to make such decisions on an informed basis.
- The primary objective of ELEGANCY is to fast-track the decarbonization of Europe's energy system by exploiting the synergies between two key low-carbon technologies: CCS and H_2.
- To this end, ELEGANCY aims to:
  - Develop and demonstrate effective CCS technologies with high industrial relevance.
  - Identify and promote business opportunities for industrial CCS enabled by H_2 by performing five national case studies.
  - Validate key elements of the CCS chain by frontier pilot- and laboratory-scale experiments.
  - Optimize combined systems for H_2 production and H_2-CO_2 separation.
  - De-risk storage of CO_2 produced from NG reforming for H2 production by providing experimental data and validated models.
  - Enable safe, cost-efficient design & operation of key elements of the CCS chain by developing innovative design and simulation tools.
  - Provide an open source techno-economic design and operation simulation tool for the full CCS chain, including H_2 as energy carrier.
  - Assess societal support of key elements of CCS, enabling early identification and mitigation of risks.
- In Elegancy, which runs in period August 2017 – August 2020, 10 research partners and 12 industry partners participate.

https://www.sintef.no/projectweb/elegancy/

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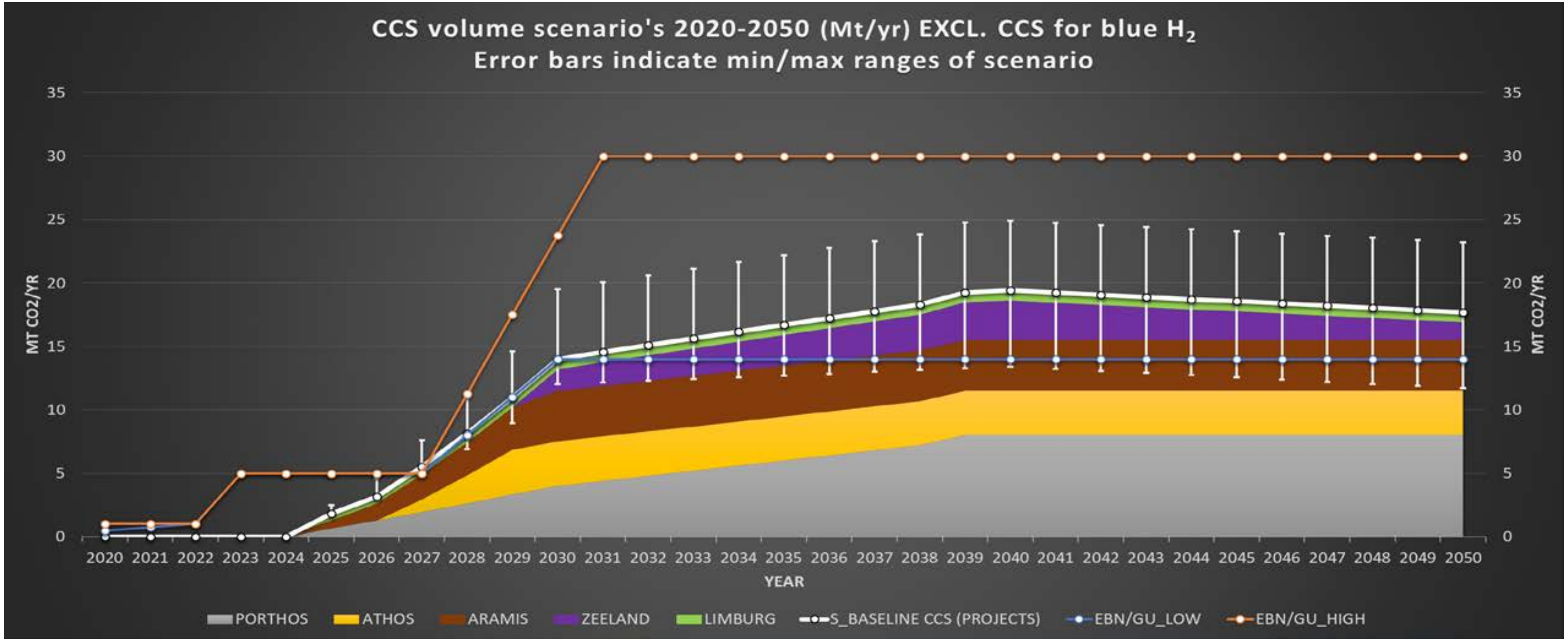
CCS Injection and Roll-Out Scenario’s

Data Sources, Scenarios and Assumptions

- **Sources of data**
  - Gasunie/EBN reports – “Transport en opslag van CO_2 in Nederland” (2018) and “CO_2 transport en opslagstrategie”(2010)
  - Joint Fact Finding CCS – Report of the “Industrie tafel”, written in the context of the Climate Accord (2018)
  - Report of the “Werkgroep H_2”, written in the context of the Climate Accord (2018)
  - Porthos – “Notitie reikwijdte en Detailniveau”
  - Athos – Press release (September 2018)
  - H-VISION project – Final results report (July 2019)
  - ALIGN project – Intermediate results
  - Report “Potential for CO_2 storage in depleted gas fields at the Dutch Continental Shelf” by DHV and TNO (2008)
  - CATO-2 deliverable D08 of WP2.4 on transport and storage economics of CCS, and final report of WP9 on shipping
  - Neele et al., “Initiating large-scale storage in the Netherlands offshore”, GHGT-14 (October 2018)
  - NSE - earlier work in context of NSE 1 and NSE 2, and WP leads of other workpackages in NSE 3 (WP 1.2, WP 1.5, and WP 3.5)

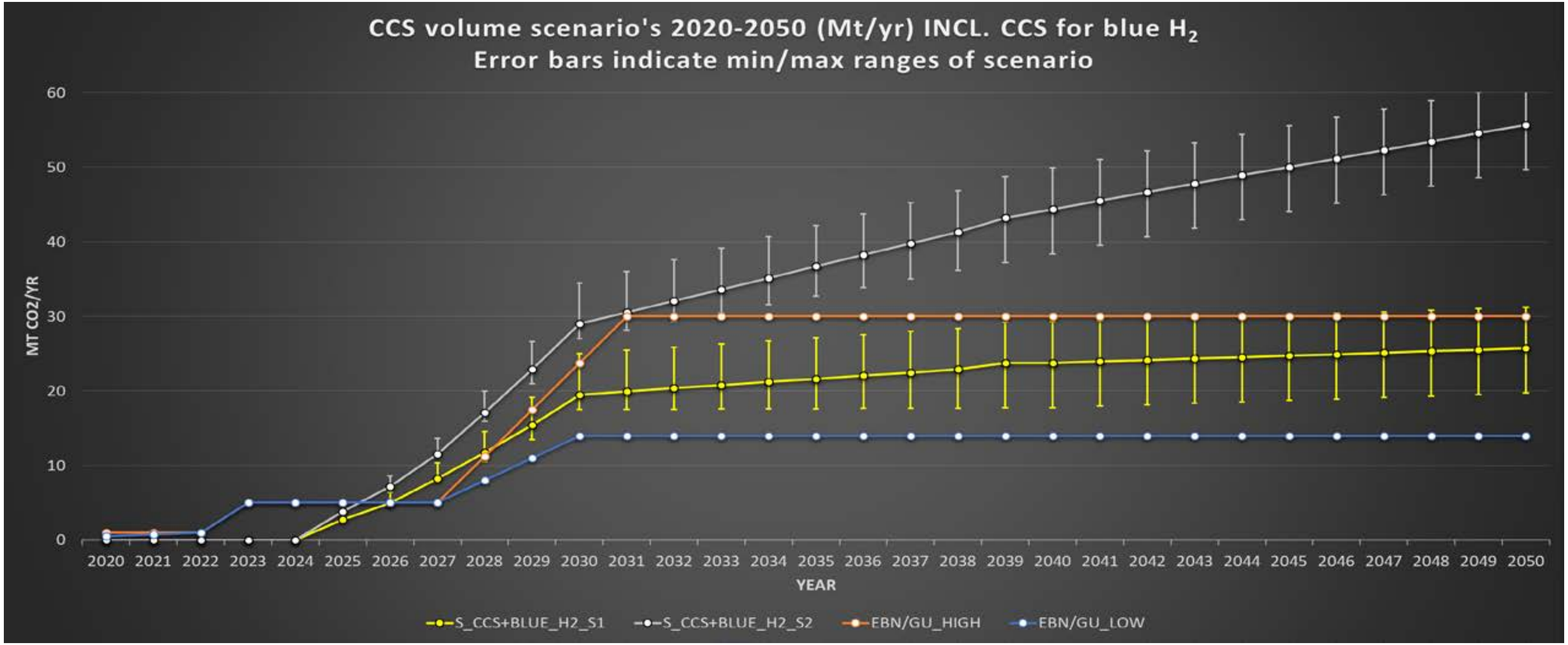
- **Scenarios without and with storage of additional CO_2 for blue H_2 and assumptions**
  - CCS rates not restricted by Climate Accord targets (14.3Mt/yr in 2030, of which 7.2Mt/yr subsidized)
  - Fields that are included in the roll-out plan (see slides 21-23) are available in time for CCS (1st injection in 2025 for all projects)
  - Underlying assumptions regarding storage capacities and injection rates per field taken from various sources (see above) are valid
  - A baseline CCS scenario (S_BASELINE_CCS) was defined as the sum of volumes of the 3 projects (Porthos, Athos, Aramis) plus expected volumes from Zeeland and Limburg clusters (which are not explicitly included in the projects).
  - Storage of additional CO_2 required for blue H_2 production is calculated based on two H_2 demand scenario’s in Climate Accord:
    1. S_CCS+BLUE_H2_S1 (hereafter also referred to as “S1”) : Mid-level scenario, requiring up to 100PJ blue H_2 (or import)
    2. S_CCS+BLUE_H2_S2 (hereafter also referred to as “S2”) : High-level scenario, requiring up to 500PJ blue H_2 (or import)
  - S1, S2 assume 130-380PJ green H_2 can be produced (ref: Climate Accord), this as been subtracted from demand to obtain PJ blue H_2

Baseline CCS Scenario [Mt/yr] – Sum of Projects



Graphs shows the baseline CCS scenario (“S_BASELINE_CCS”, white) obtained by summing volumes of the 3 projects (grey, yellow and red areas) and expected volumes from Zeeland (purple area) and Limburg (green area) clusters. Error bars visualize the min/max bandwidth of CCS scenario’s of the Porthos, Athos and Aramis projects. Also displayed are the two scenario’s from the Gasunie/EBN benchmark report of 2018 (blue line, orange line).

CCS Scenario’s incl. CCS for Blue H_2 [Mt/yr]



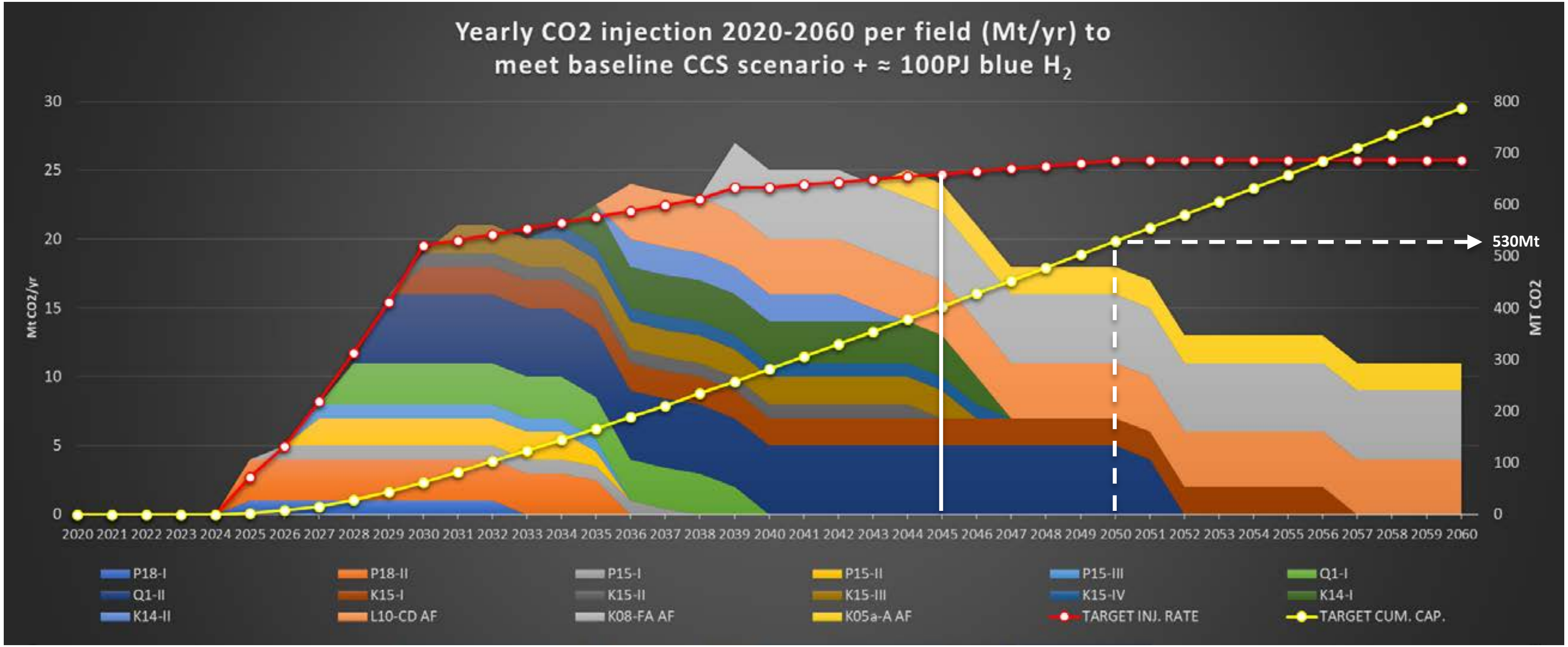
Graphs shows the 2 CCS scenario’s that include the additional CO_2 to be stored to meet the mid-level (“S_CCS+BLUE_H2_S1”, yellow line) and high-level (“S_CCS+BLUE_H2_S2”, grey) demand from Climate Accord. Also displayed are the 2 scenario’s from the Gasunie/EBN benchmark report of 2018 (blue, orange). Error bars on the yellow and grey lines visualize the min/max bandwidth of CCS scenario’s of the Porthos, Athos and Aramis projects. Please note that there may be some double-counting of CCS amounts in particular in the “S_CCS+BLUE_H2_S2” because the use of the blue hydrogen to decarbonize emitters (thus reducing required CCS amounts) is not analyzed at emitter level in detail.

A roll-out scenario for scen. “S_CCS+blue_H2_S1”

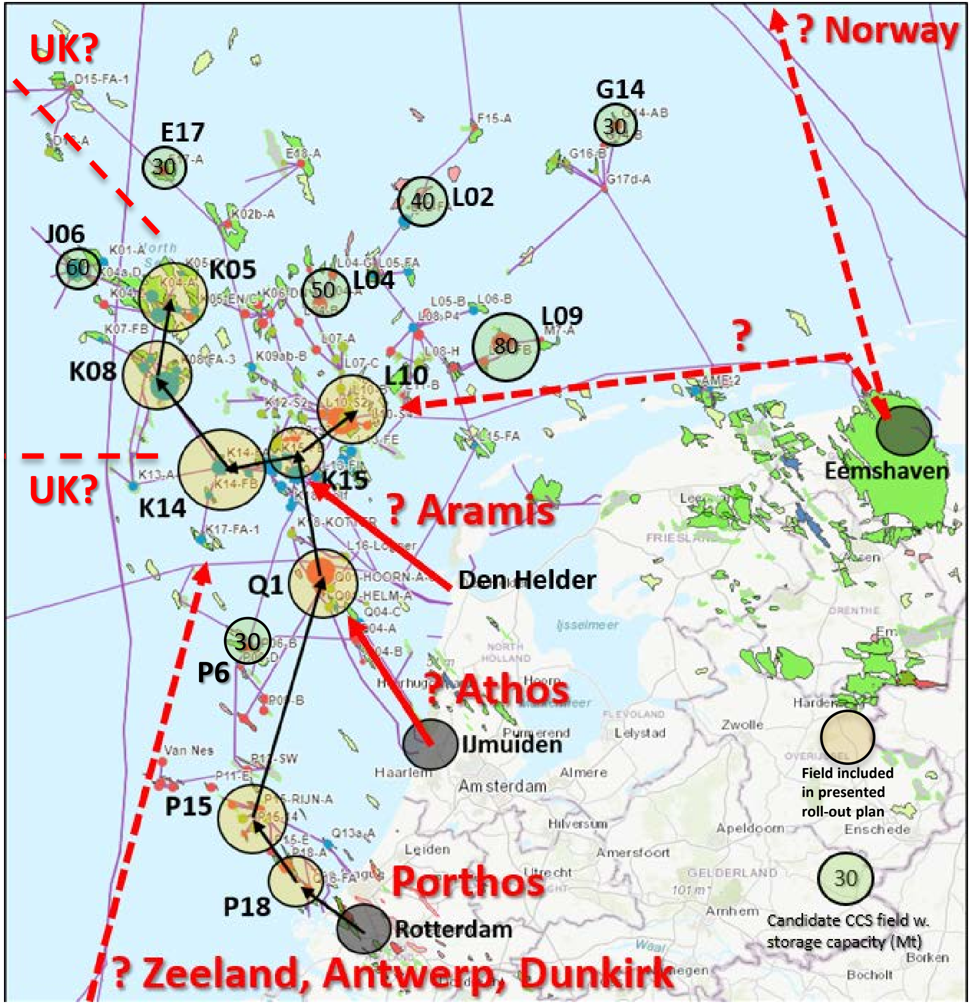
- A CCS transport and storage infrastructure roll-out scenario was developed that meets the injection rates of the baseline CCS scenario plus the additional CCS for 100PJ of blue H_2 production (scenario S_CCS+BLUE_H2_S1).
- In the table on the right, the 16 fields / clusters for which sufficient information is available in the public domain are listed, along with their estimated storage capacity. Total storage capacity of these fields / clusters is 685Mt ,which is sufficient to meet the capacity need of the scenario (530Mt) until 2050.
- Start year, end year and injection rate are variables of the scenario. Injection rate per field is allowed to vary between 0.5-5Mt/yr. Start year will be constrained by the year of cessation of production (COP) of natural gas, which is uncertain for many fields because they are still producing. The COP will probably also be influenced to some extent by the prospect of re-use for CCS.
- Although the capacity need can be met until 2050, the graph on slide 23 shows that this roll-out scenario can only meet the required rate of injection until 2045, after which new fields must come online to sustain injection at the required rate.
- On slide 24 the spatial component of this roll-out scenario is shown on a map.

Cluster	Mt CO2	Start yr	Mt/yr	End yr
P18-I	8	2025	1	2032
P18-II	32.5	2025	3	2035
P15-I	11.4	2026	1	2037
P15-II	17.1	2027	2	2035
P15-III	8.9	2027	1	2035
Q1-I	35	2028	3	2039
Q1-II	114	2029	5	2051
K15-I	54	2030	2	2056
K15-II	15	2030	1	2044
K15-III	30	2031	2	2045
K15-IV	15	2034	1	2048
K14-I	35	2035	3	2046
K14-II	15	2036	2	2043
L10-CD	125	2036	4	> 2060
K08-FA	130	2039	5	> 2060
K05a-A	40	2044	2	> 2060

Filling sequence of fields to meet target inj. rate



Graphs displays the sequence of filling of the fields in the roll-out scenario to meet the yearly injection rate of scenario "S_CCS+BLUE_H2_S1" ("target inj. rate", red line, amounts on left axis). Colored areas indicate for every field when injection occurs. After 2045 (white vertical line), this roll-out scenario cannot sustain the target of 25Mt/yr. Yellow line (amounts on the right axis) displays the cumulative amount of CO2 storage capacity required for the S1 scenario, which is 530Mt in 2050.



Spatial view on roll-out

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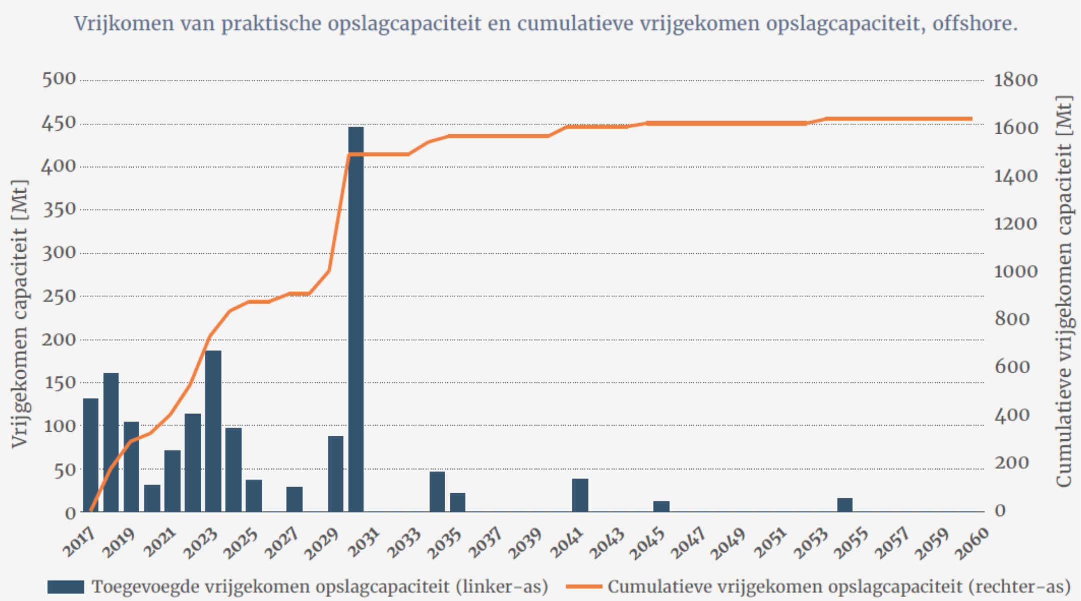
- Yellow spheres indicate fields that are in the list on slide 22, whereas green spheres are other fields that may be used but for which insufficient information is available in the public domain.
- Red arrows connect CO_2 source areas/collection points onshore to storage sites offshore.
- Porthos intends to start with filling P18 in 2024, followed by P15, both to be connected to sources in the PoR by pipeline.
- After P15, a pipeline connection to Q1 and/or K, L fields is required. Fields in P6 block (30-40Mt) could be used as a stepping stone, but are not currently included in published studies.
- Athos is initially targeting storage in Q, K, or L block, all of which have large storage capacities. Transport from capture sites onshore (IJmuiden, Amsterdam) by pipeline is probably the best option. Alternatively, CO_2 could be transported by ship to Den Helder if that is where the shipping terminal of the Aramis infrastructure would be located.
- Post-2045, additional capacity in other candidate fields in E, G, J, K, and L blocks can potentially be developed (green spheres, see also next slide).

Additional capacity is available in North Sea



Gasunie/EBN (2018)

- Gasunie/EBN (2018) concluded that the practical cumulative storage capacity of offshore fields is 1678Mt (see graph on the left). Their analysis was based on data (e.g. initial gas in place, volume of gas produced, estimates of ultimately recoverable reserves) from production status reports submitted in 2016.
- From this it can be concluded that about 1000Mt of additional offshore storage potential is available (above the 685Mt in the fields that are included in the roll-out plan).
- Furthermore, as can be seen in the graph, the expectation is that 900Mt of capacity will be available by 2025, increasing to 1500Mt by 2030.

Towards a coordinated longer-term vision for CCS

- CCS requires a transport and storage infrastructure to be developed in the North Sea to transport CO_2 from capture sites onshore to reservoirs offshore for permanent storage. In 2013, the CATO-2 project (deliverable D08*) already concluded that sharing transport and storage infrastructure is a cost-effective approach for CCS. Since CCS is anticipated to be financially supported by government funding (e.g. SDE subsidy scheme), a reduction of system costs for CCS achieved by sharing infrastructure would be of benefit to society.
- Sharing of infrastructure however requires coordination, if not orchestration, between (commercially-driven) development initiatives, and this is role is currently taken up by EBN.
- As an example, in the greater Port of Rotterdam (PoR) area, the Porthos project aims to develop infrastructure to transport CO2 to clusters of fields (P18, P15) that are 20-40 km offshore (see slide 24). However, the capacity of those clusters is limited (<80Mt in 5 fields of which 3 have less than 12Mt capacity, which may render them uneconomical to be developed) and under the assumptions made in this study, they would be full within 10 years after start of injection (see slide 22). Additional storage capacity for the greater PoR area could potentially be created in Q1 (150Mt capacity), or in the K and L blocks, requiring a transport pipeline of 100-150km length.
- However, other development projects (Athos, Aramis) are developing transport and storage infrastructure for customers looking to store captured CO2 from sites in the greater Port of Amsterdam (PoA) area, and sites further away (Zeeland, Eemshaven, NW Europe), and the design of this infrastructure (pipeline capacity, injection capacity) should already take into account the expected additional feed-in of CO2 from the PoR area to prevent a lock-in later that requires large investments to be resolved.
- In view of the above, a logical next step would be to develop longer-term vision on the development of transport and storage infrastructure that aligns and integrates ongoing commercial CCS initiatives in NL and the wider the North Sea region. Such an “international CCS infrastructure outlook” should explore (and exploit) synergies to reduce total system cost.

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

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CCS and Electrification

CCS infrastructure design considerations

- Transport of CO_2 from capture sites onshore to storage reservoirs offshore is most cost-effective when the CO_2 is transported in liquid or supercritical (dense) state. Supercritical CO_2 forms at temperatures above 31 °C and 74 bar, whereas liquid CO_2 requires pressures above approximately 40-50 bar at prevailing sea water temperatures (5-13 °C).
- Cost-effective transport therefore requires compression to transport the CO_2 in liquid or dense state. For reasons of economy of scale, compression will most likely be done in an onshore processing plant, which requires roughly 60MW per 15Mt/yr of CO_2 injected.
- Ideally the CO_2 would also be kept at temperatures above 31 °C to transport and inject it in its dense state (warm injection). However, because CO_2, when transported by subsea pipeline, cools down to sea water temperature when transported over longer distances (10s of km and more), even with insulated pipelines, heating would be required offshore for warm injection.
- In practice, reservoir injection strategies will be designed such that heating on platforms is avoided because it is very costly. Initially, the CO_2 will therefore be injected in the gaseous state at lower pressure and mass flow rate (Mt/yr), and temperatures of around 15 °C (cold injection) to avoid clogging of the near-well area of the reservoir due to freezing (Joule-Thomson effect). Should injection occur in liquid state at higher pressures (and Mt/yr rate) from the start then without heating of CO_2 before injection the large pressure difference with the reservoir pressure would cause the CO_2 to expand (and thus cool down) rapidly, leading to the Joule-Thomson effect and potentially clogging of the well by freezing.
- Once the reservoir pressure has increased sufficiently, injection can occur in liquid state at higher pressure and mass flow rate, and relatively low bottom-hole temperature.

CCS power requirements & supply options

- Without compression and heating on the platform, power requirements for CCS on a platform are limited to 50-200kW (for operating valves, metering, sensors, and lights), which is two orders of magnitude lower than those for natural gas production (10-40MW), mainly because the gas must be compressed prior to being fed into the pipeline for transport to shore.
- However, pressure loss occurs while the CO_2 flows from the onshore processing plant to the reservoirs, and for distances above 100km, boostering is required (1MW per 50km for 5Mt/yr). Therefore, the use of central offshore hubs is foreseen where the CO_2 pressure would be boostered to reach reservoirs that are more than 100km from shore. On platforms that serve as hubs, the power requirements would therefore be several MW.
- Still, these power requirements (range 50kW-10MW) are smaller that the typical power requirements for natural gas. A platform that is electrified for natural gas production, and which has a cable connection either to shore or to an offshore wind farm for power supply, would therefore also be a good candidate for use for CCS.
- Another important consideration for electrification is that transport and injection of CO_2 should operate continuously, and with as little interruption as possible, to minimize operational and economic risks. Security of power supply is therefore an important aspect.
- Reliable, cost-effective, non-emitting technologies for powering a platform autonomously, i.e., as an alternative to a cable connection to shore or to a wind farm, are not yet mature (e.g. floating wind or solar plus battery storage). Supplying power with very high reliability to a non-electrified platform to re-use it for CCS after production of natural gas ceases is therefore challenging.
- A business case for electrification solely for CCS should therefore take into account the value of “security of injectivity” offered by a power cable connection.

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Conclusions

Conclusions

- CCS scenario's have been compiled from up-to-date info on CCS development initiatives in the Netherlands. CCS rates per year range between 14-19Mt/yr in the period 2030-2050, which requires a storage capacity of ≈ 400Mt. These requirements can be met by the fields that are currently subject of published feasibility studies (in P, Q, K, L blocks).
- The additional amount of CCS required to support the production of blue H_2 is higly uncertain due to the uncertainty in a) future demand for hydrogen, and b) volumes of green hydrogen that can be economically produced or imported. To meet the projected mid-level H_2 demand from the Climate Accord in the period 2030-2050, about 100PJ/yr blue H_2 must be produced, and this lifts CCS rates per year to 19-27Mt/yr, requiring 532Mt CCS capacity until 2050. For this CCS demand scenario, the developed roll-out scenario, which includes the fields that are currently subject of published feasibility studies (in P, Q, K, L blocks), shows that CCS rates can only be supported until 2045. Post-2045, sufficient additional capacity can potentially be developed though in other fields offshore, in particular in the E, G, J, K, and L blocks.
- CCS power requirements are low compared to power required for natural gas production, and therefore re-use of a electrified platform for CCS after cessation of gas production greatly benefits the business case for CCS. Reliable, cost-effective, autonomous solutions for powering a platform are not straightforward, and therefore a business case for electrification solely for CCS should take into account the value of "security of injectivity" offered by a power cable connection.
- A longer-term vision on the development of transport and storage infrastructure should be developed that aligns and integrates ongoing commercial CCS initiatives in NL and the wider the North Sea region. Such an "international CCS infrastructure outlook" should explore (and exploit) synergies to reduce total system cost.

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