CO_2 TRANSPORT AND STORAGE

CATO DAY, JUNE 26, 2019

Dr. F.P. Neele

innovation for life

CCS – 2019
EUROPE, NETHERLANDS

- Projects of Common Interest - PCIs
- London Protocol
- Activities in The Netherlands
- Ongoing work
- Way ahead

PROJECTS OF COMMON INTEREST (PCI)

EU PROJECTS OF COMMON INTEREST

- Key cross border infrastructure projects that link the energy systems of EU countries

- PCIs may benefit from:
  - accelerated planning and permit granting
  - a single national authority for obtaining permits
  - improved (streamlined) regulatory conditions
  - lower administrative costs due to streamlined environmental assessment processes
  - increased public participation via consultations, and increased visibility to investors.

- PCIs have the right to apply for funding from the Connecting Europe Facility (CEF).

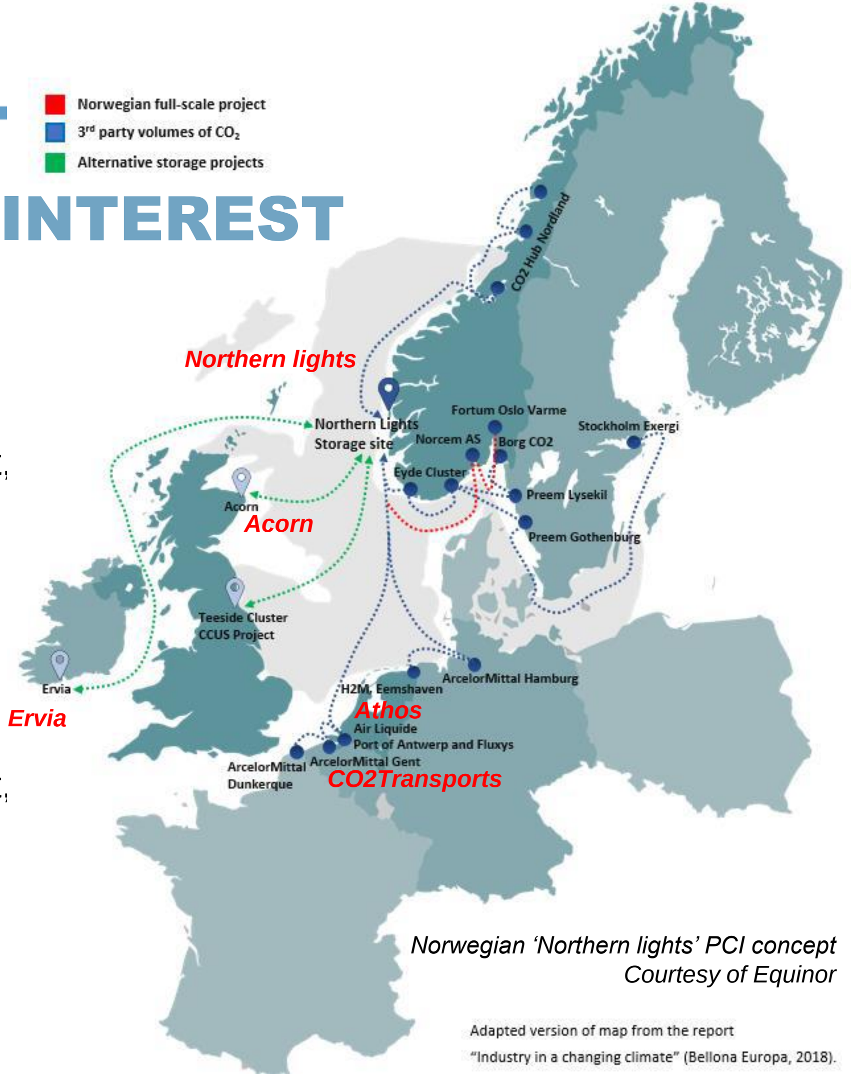
- CO_2 transport projects applicable to apply for PCI status from 2017

CO_2 PROJECTS OF COMMON INTEREST

- 2017: first round of CO_2 PCIs – 4 projects
  - Northern Lights (Norway + UK)
  - Rotterdam Nucleus (Netherlands + UK)
  - CO2 SAPLING (transport element of ACORN project,
  - Teesside (UK + NO)

- 2019: second round of CO_2 PCIs – 5 projects
  - Northern Lights (Norway + UK + NL + EI)
  - CO2TransPorts (Netherlands + Belgium)
  - CO2 SAPLING (transport element of ACORN project,
  - ERVIA (Ireland + NL + UK + NO)
  - Athos (Netherlands + Ireland)

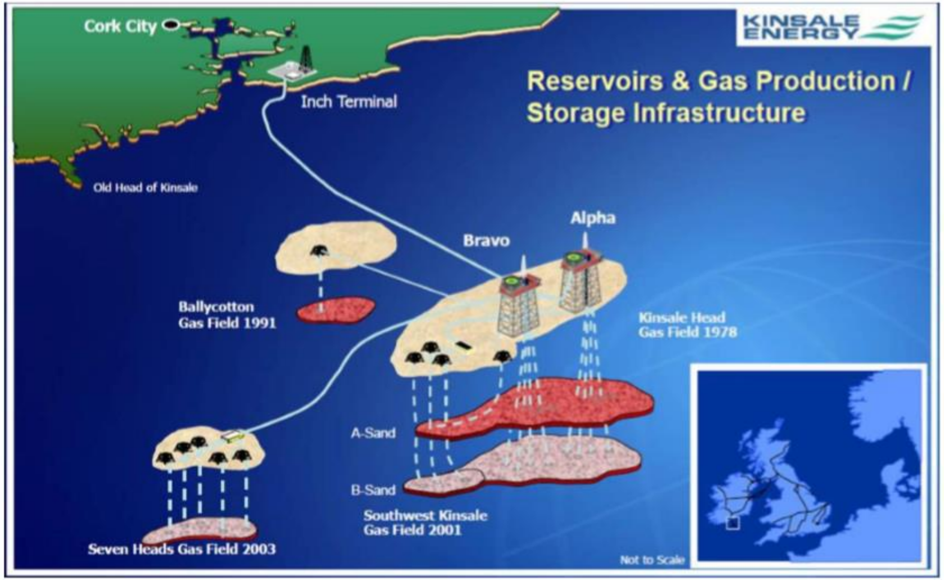
(https://ec.europa.eu/info/sites/info/files/detailed_information_regarding_the_candidate_projects_in_co2_network_0.pdf)

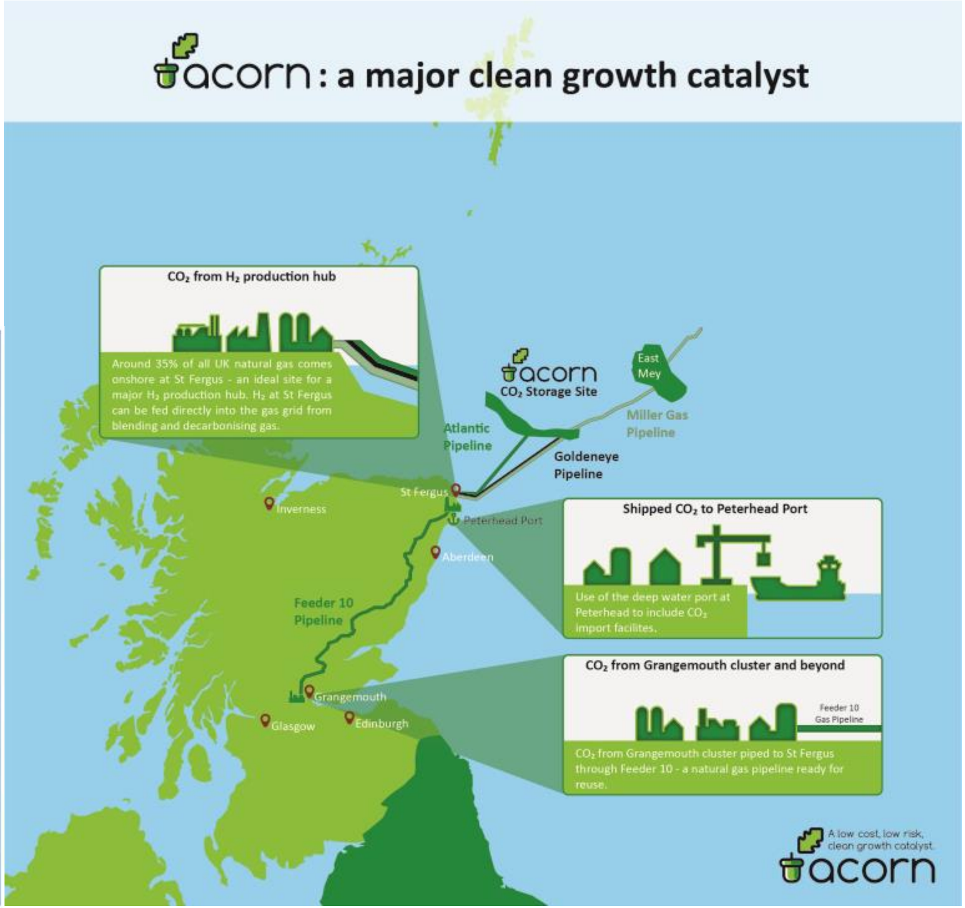


Norwegian 'Northern lights' PCI concept
Courtesy of Equinor

CO_2 PCI PROJECTS

- 2018: second round of CO_2 PCIs – 5 projects
  - ACORN, UK
  - ERVIA, Ireland

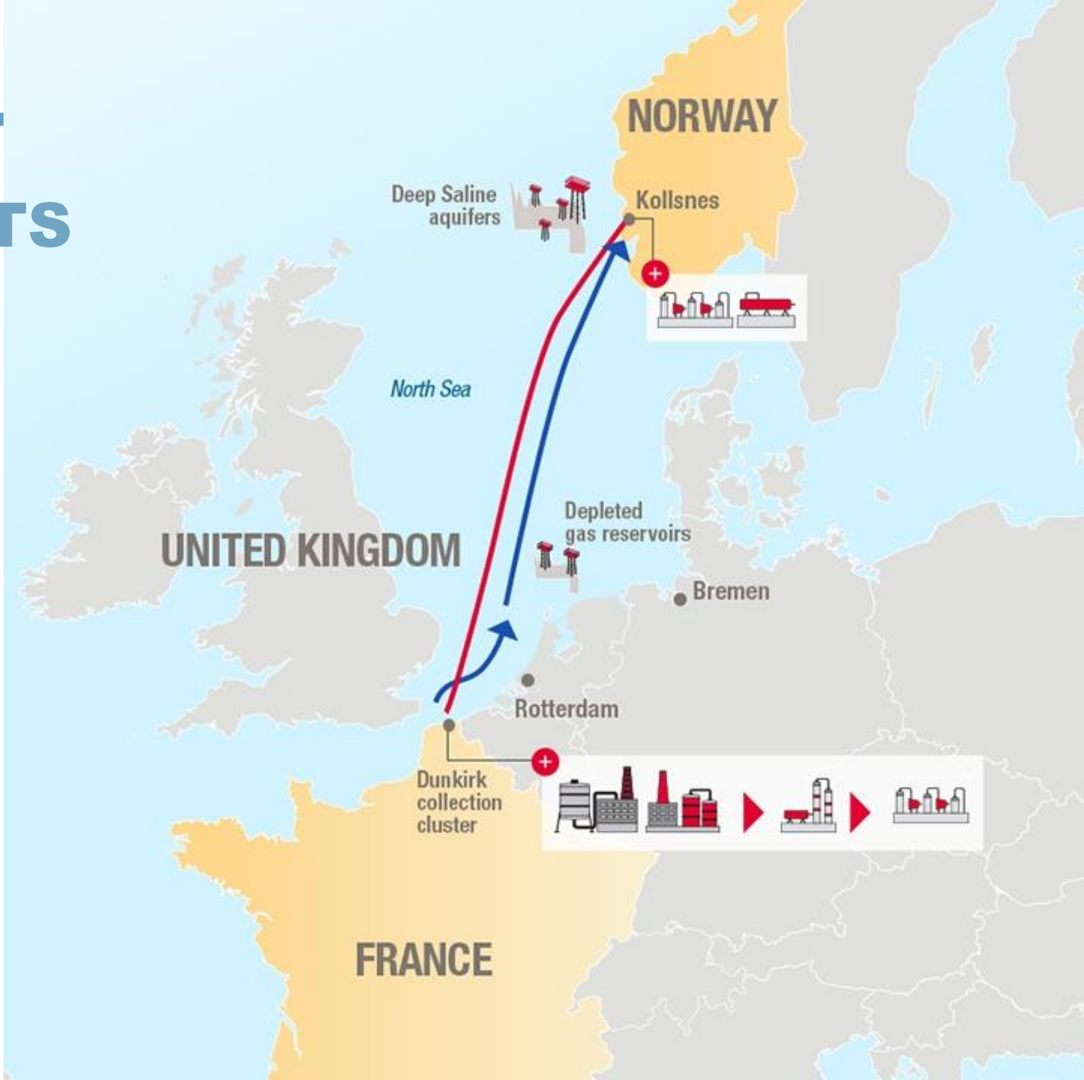




OTHER DEVELOPMENTS

- France: “*3D project for CCS*”
- 11 stakeholders
  - A.o., ArcelorMittal, Total, IFPEN

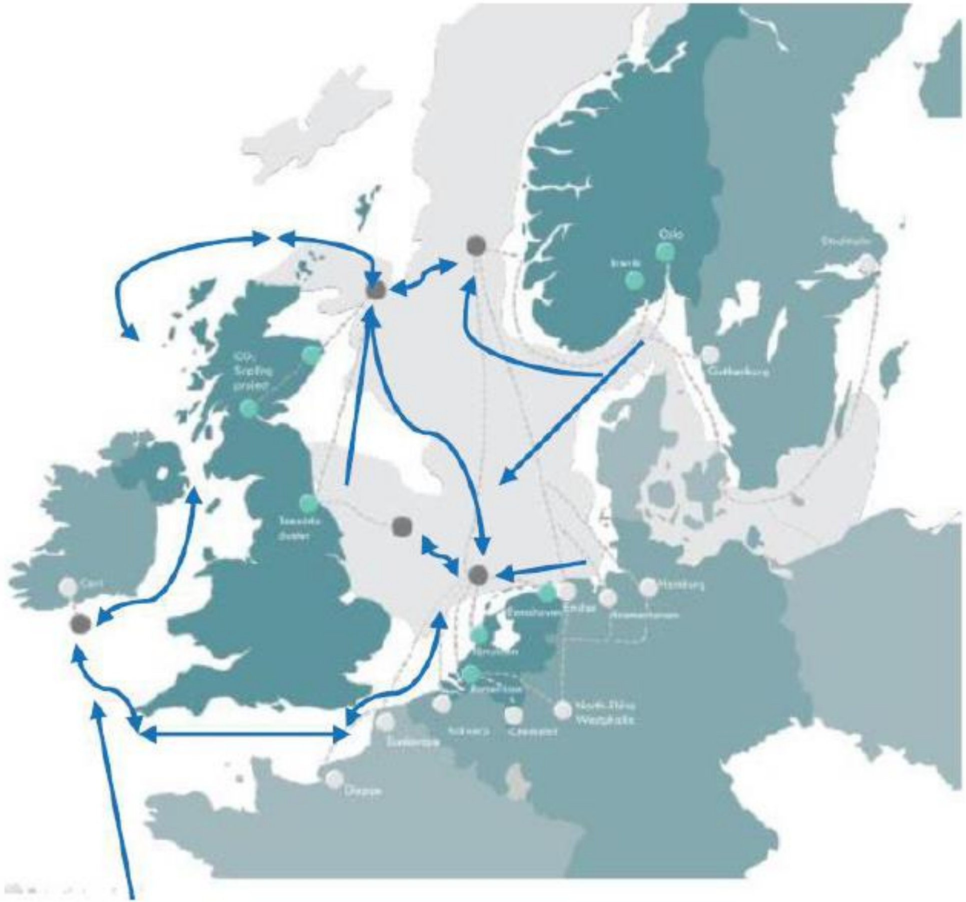
- **D**MXTM: new solvent
  - IFPEN development
  - 35% reduction in capture energy need
- **D**evelop **D**unkirk cluster
  - 10 Mt/yr of CO_2
  - Operational by 2035
  - Storage in North Sea



LARGE-SCALE CCS

- Huge capacity for storing CO_2 in North Sea
- First elements of transport infrastructure being designed / developed

- Access to storage for other countries
  - Germany – Northrein Westphalia
  - Belgium
  - France
  - Baltic countries
  - …



LONDON PROTOCOL

LONDON PROTOCOL

- The Protocol promotes the protection of the marine environment by prohibiting the dumping of wastes and other matter into the sea (1972/1996)
- In 2007, an amendment entered into force which permitted CO_2 streams to be considered for dumping under the London Protocol.
- However, currently the LP:
  - Allows cross-border transport of CO_2
    - … as feedstock
  - Does not allow cross-border transport of CO_2
    - …for storage

- Norway will submit proposal to adapt the LP to accept bi-lateral agreements between countries to allow cross-border transport with the intention to store below the North Sea (Q2 2019)

CCS ACTIVITIES IN NL

CCS ACTIVITIES NL

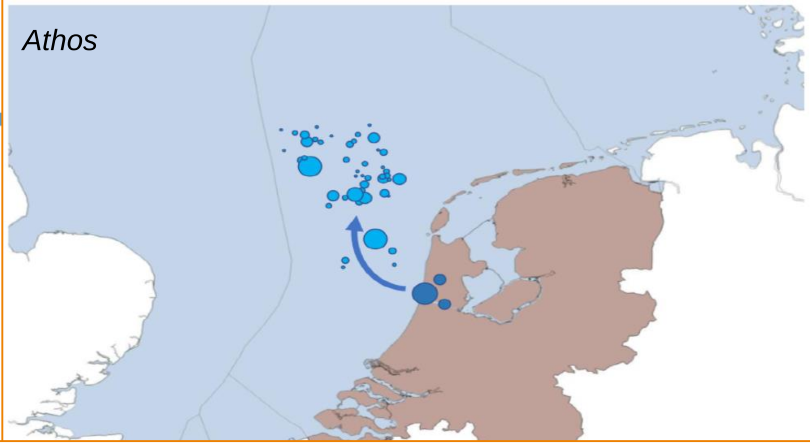
- Porthos, Rotterdam
  - 4-5 Mt/yr by 2030
  - Multi-user network, multi-store network
  - Links with Antwerp, Terneuzen, through PCI
  - Offshore P18 cluster: first target for storage
  - First injection 2023

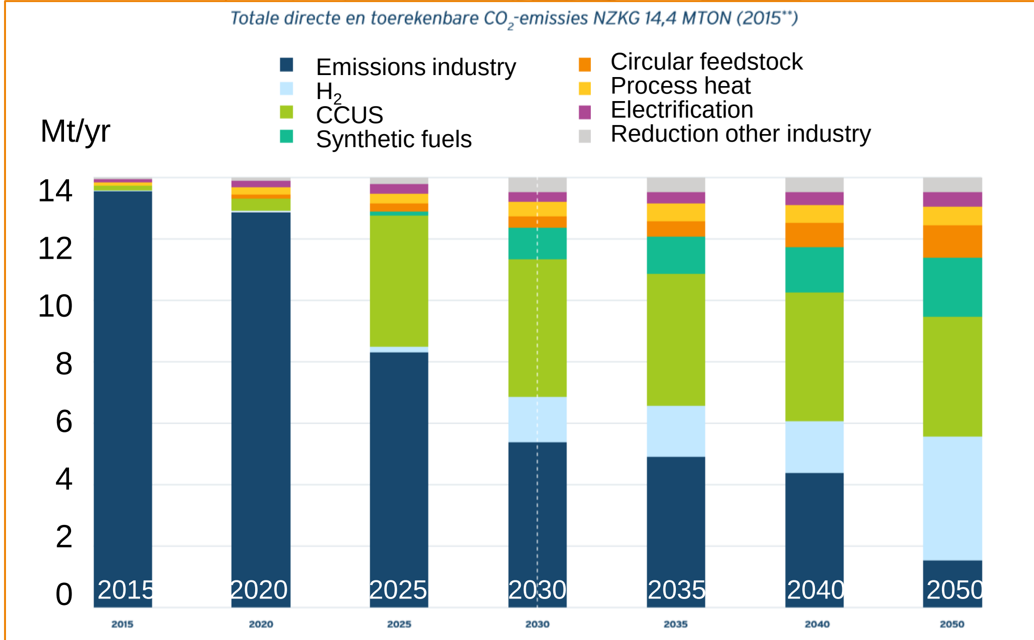
Rotterdam Nucleus: on first PCI list

https://www.rotterdamccus.nl/

CCS ACTIVITIES NL

- Athos, IJmond
  - 4-5 Mt/yr, post 2025
  - Multi-user network, multi-store network
  - Tata, DOW
  - First injection 2027
  - AEB (CCU: e.g., greenhouses)





https://www.portofamsterdam.com/sites/poa/files/nzkg_vliegwiel_voor_een_duurzame_toekomst_0.pdf

CCS ACTIVITIES NL

- Aramis, Den Helder
  - Start date and volume: to be defined
  - Import by ship and / or pipeline
  - Storage in K and L blocks

- H-vision, Rotterdam
  - Blue hydrogen: H_2 from gas, with CCS
  - H_2 as fuel and feedstock
  - 2025: 2 Mt/yr; 2030: 5-6 Mt/yr
  - Link with Porthos for storage

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

CCS ACTIVITIES NL

- H2M, Eemshaven
  - Blue H_2 from natural gas from Norway
  - CO_2 by ship to Norway (Northern Lights)
  - H_2 as fuel and / or feedstock (e.g., Magnum power plant)
  - FID 2021, start H_2 production (with CCS) 2024
  - Volumes: not given

- BioCCS, Eemshaven
  - 250 MW bioCCS demo plant
  - Start 2030 (with CCS), but possibly earlier with CCU

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

CCS ACTIVITIES NL

- Chemelot, Geleen
  - Target: 0.5 – 0.8 Mt/yr by 2025
  - OCI: 0.5 Mt/yr of pure CO_2
  - Transport: liquid CO_2 by barge – to Rotterdam / Porthos?
    - Barges to be developed and regulated
  - Timing uncertain

- Zeeland, North Sea Port
  - Implementation CCS by 2030
  - 1.7 Mt/yr, increasing to 3.1 Mt/yr by 2040 then decrease due to use of blue H_2
  - Pipelines to Rotterdam

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

ONGOING WORK

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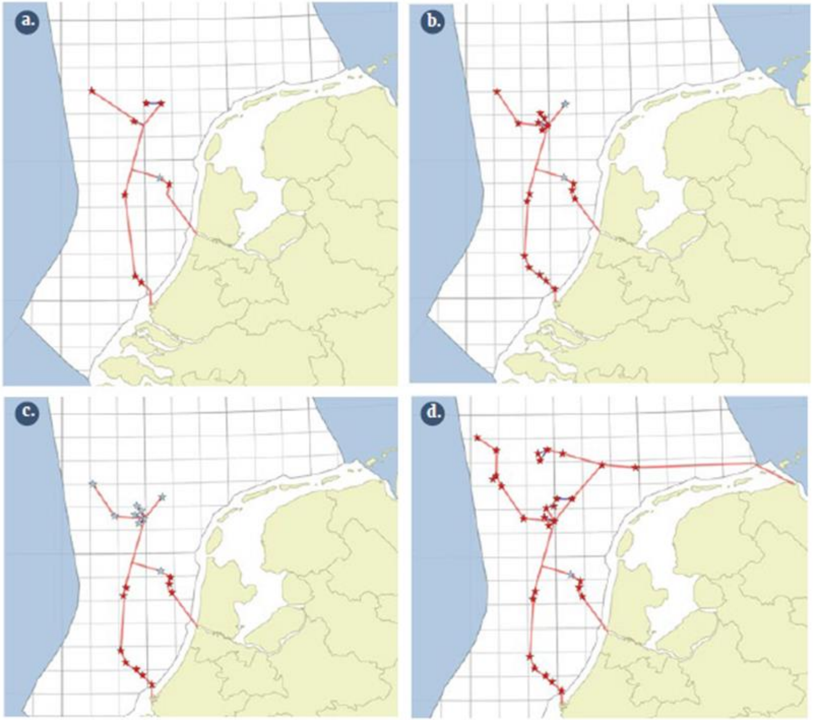
EBN-Gasunie, Transport and storage of CO_2 in NL, 2017



- Network development
  - Three consortia counting on NL offshore storage capacity
  - Belgium, France, Germany assuming storage in NL offshore
  - ➢ Which are the potential development scenarios?

- Storage in depleted gas fields
  - Available infrastructure, proven storage capacity, proven seal
  - ➢ How to handle pressure drop between transport pipelines and reservoir?

ALIGN - CCUS
DEVELOPING CAPACITY

- Abundant storage capacity, but how to develop it?
  - Potential timeline of field development
  - Ranking of options – unit storage cost, location, capacity, etc.

DGF: depleted gas field

DSF: deep saline formation

Several clusters in central DCS

K14-K15 cluster Several fields

Q1 cluster DGF, DSF

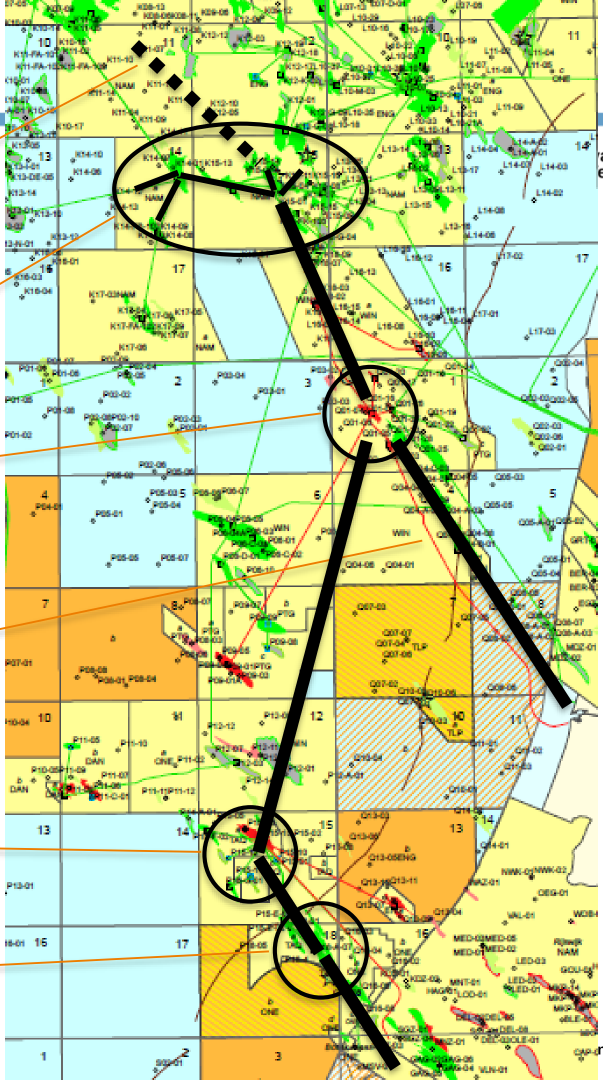
Re-use oil pipeline? (~75 km)

Second choice? (~20 km)

P15 cluster 35 Mt

First choice (~25 km dist.)

P18 cluster 35 Mt



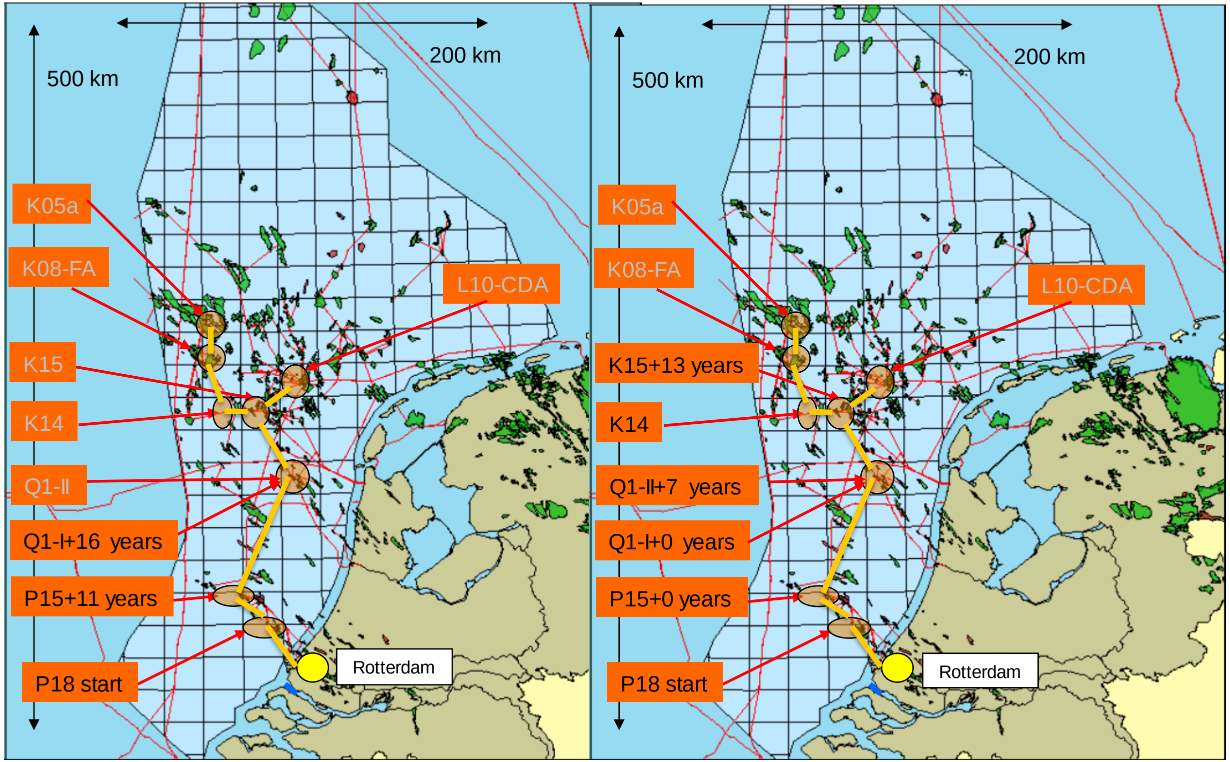
POTENTIAL NETWORK DEVELOPMENT SCENARIO

- CO_2 supply from Rotterdam region
- First element ('A') currently being designed
- Design element 'A' depends on choices made for later elements

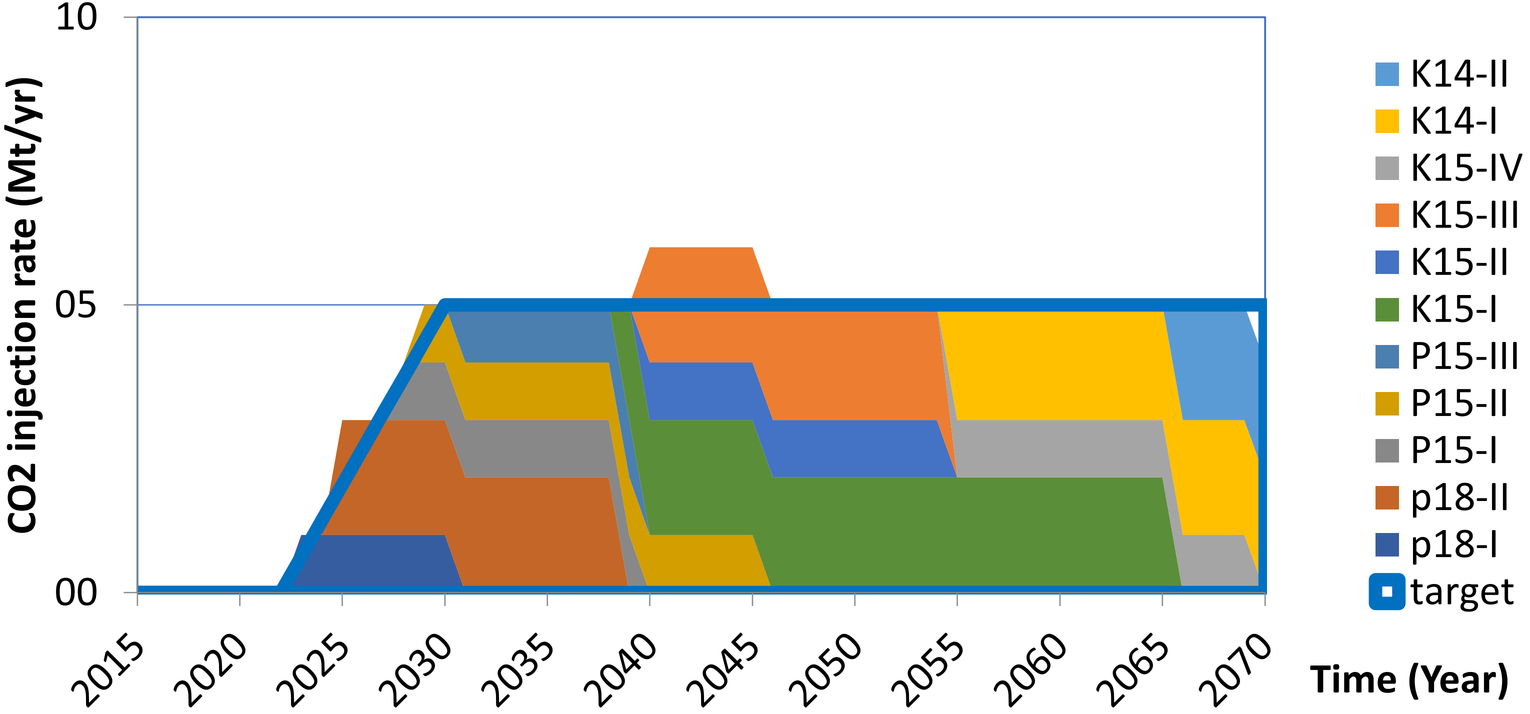
- Network development depends on:
  - Unit costs of storage and transport
  - Risk assessment of clusters and fields
  - Availability of fields, platforms & wells
  - Storage capacity & injection rates

H-VISION
ROTTERDAM

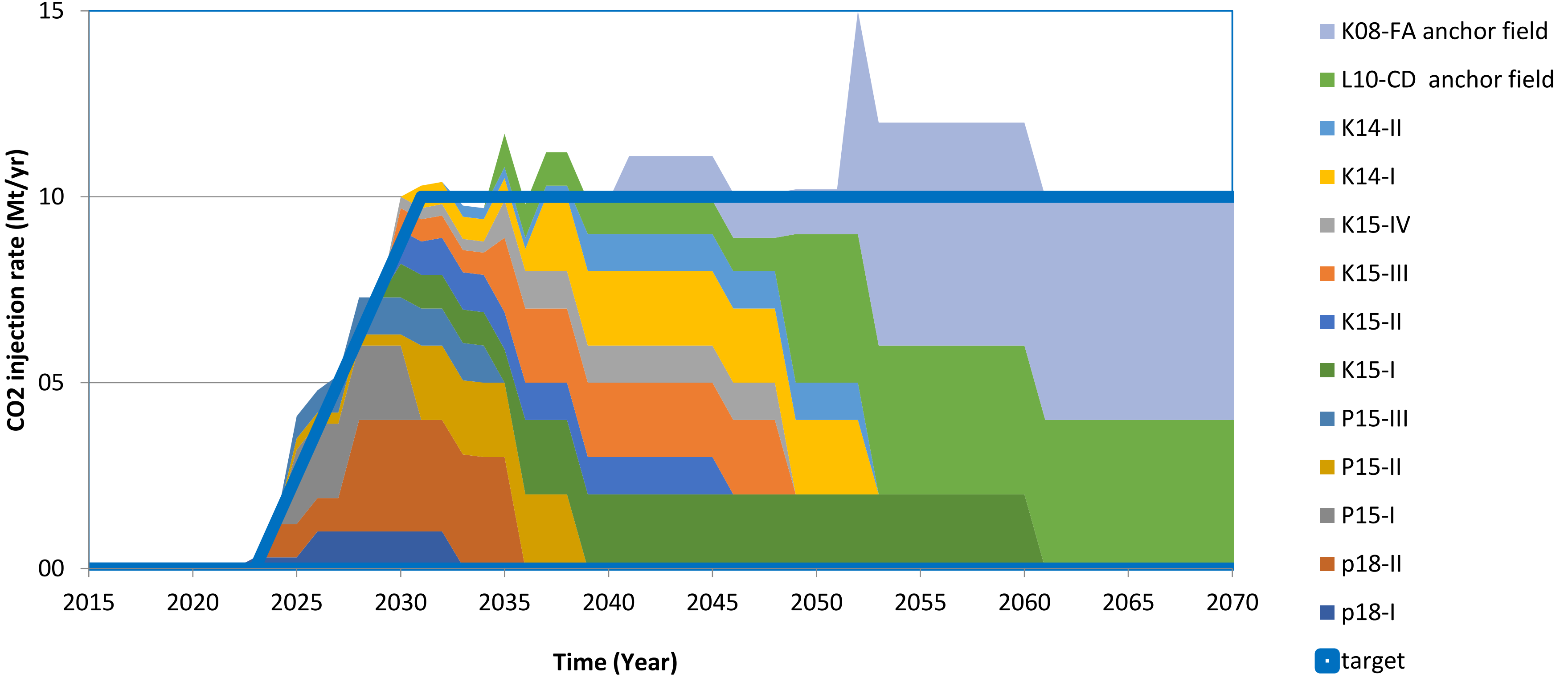
- Two scenarios
  - ‘Porthos only’ (no H_2)
    - 4 Mtpa
    - 80 Mt total
  - ‘Porthos’ + H_2
    - 4 + 10 Mtpa
    - 290 Mt total
- Scenario duration 25 yr
  - ~ 2025 – 2050
- Total capacity offshore: 1600 Mt (EBN-Gasunie, 2017)



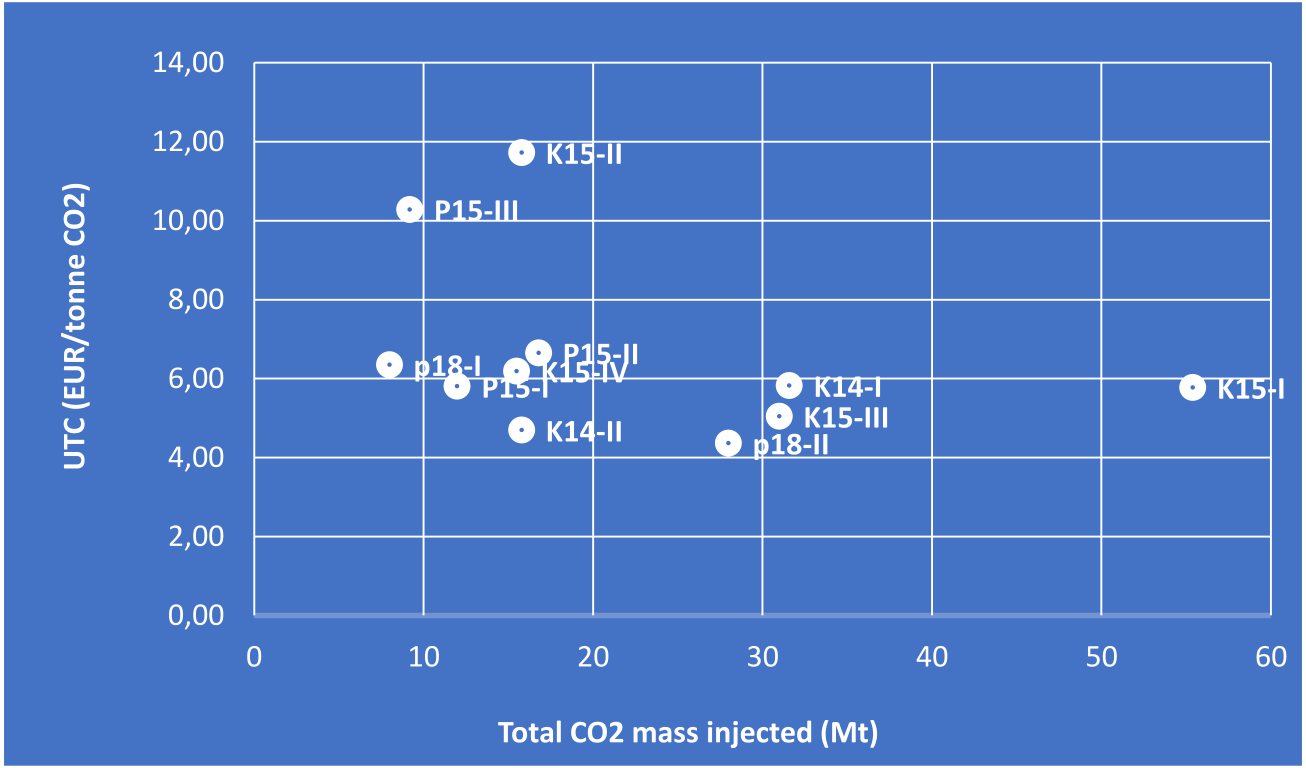
5 MTPA SCENARIO CAN BE EASILY ACCOMMODATED



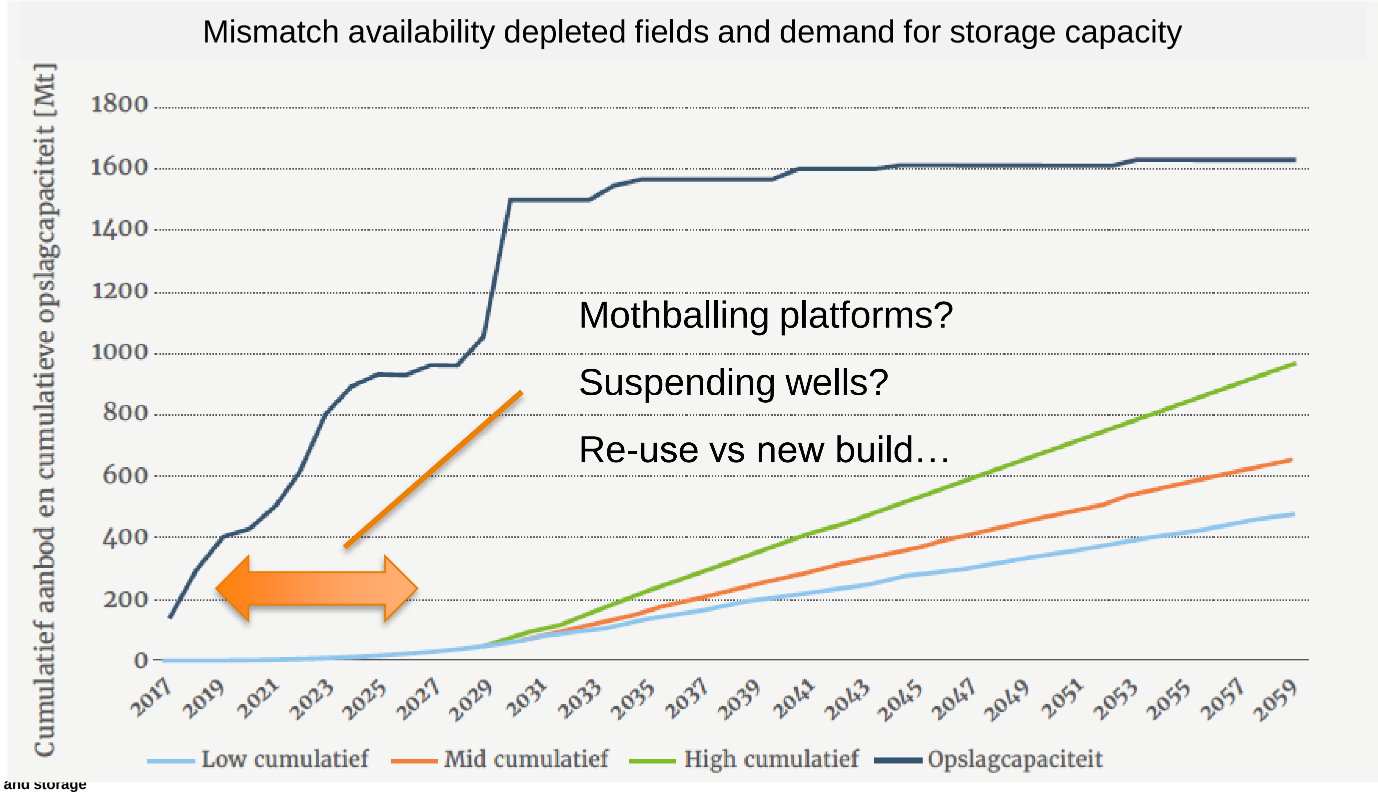
10 MTPA WITH CONSTRAINED INJECTION RATE



UNIT TECHNICAL COSTS OF STORAGE (EUR/TONNE CO_2)



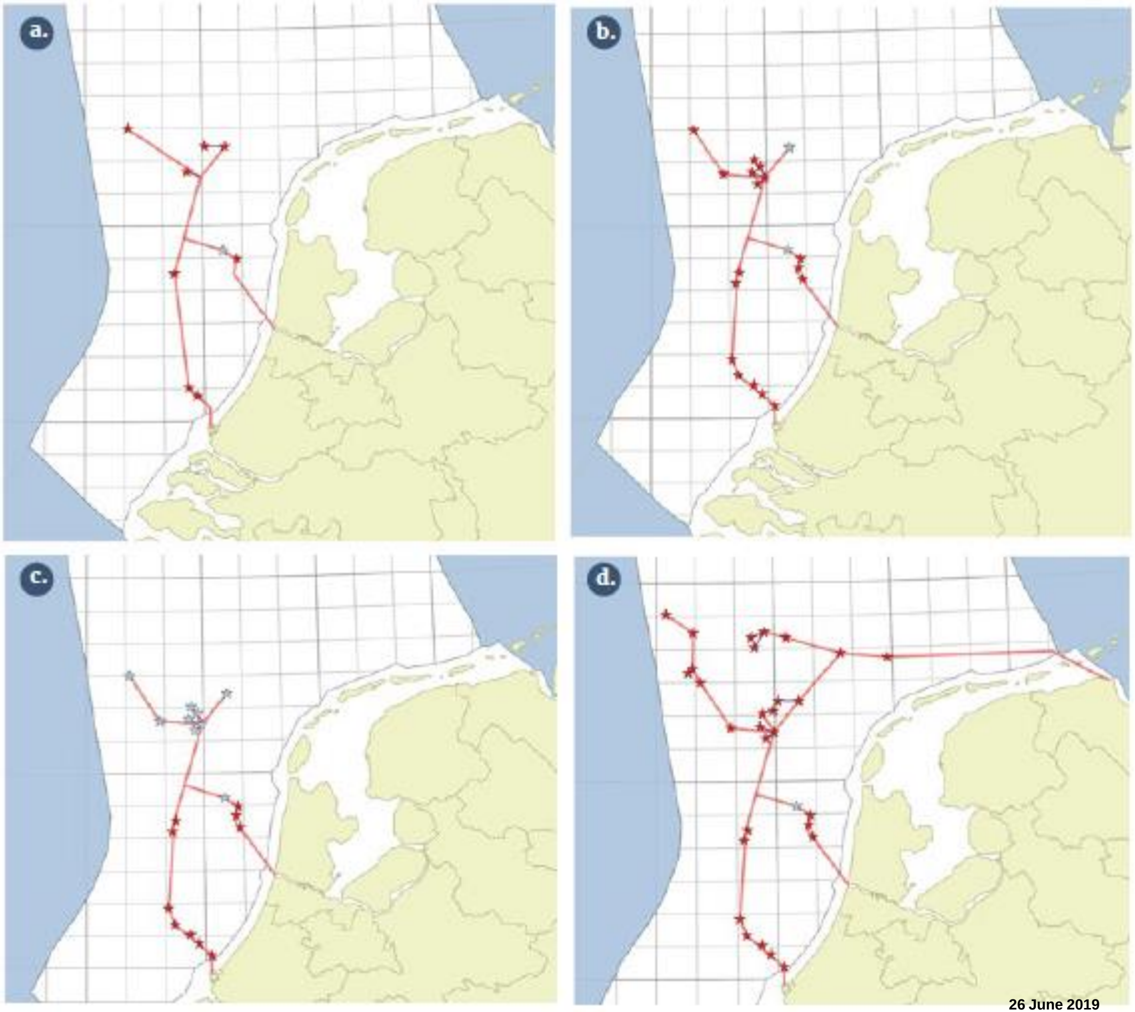
CO_2 SUPPLY VS. STORAGE CAPACITY



Source: EBN-Gasunie, 2017

POTENTIAL CCS DEVELOPMENT

A. Low case, re-use
B. Mid case, re-use
C. Mid case, new
D. High case, re-use

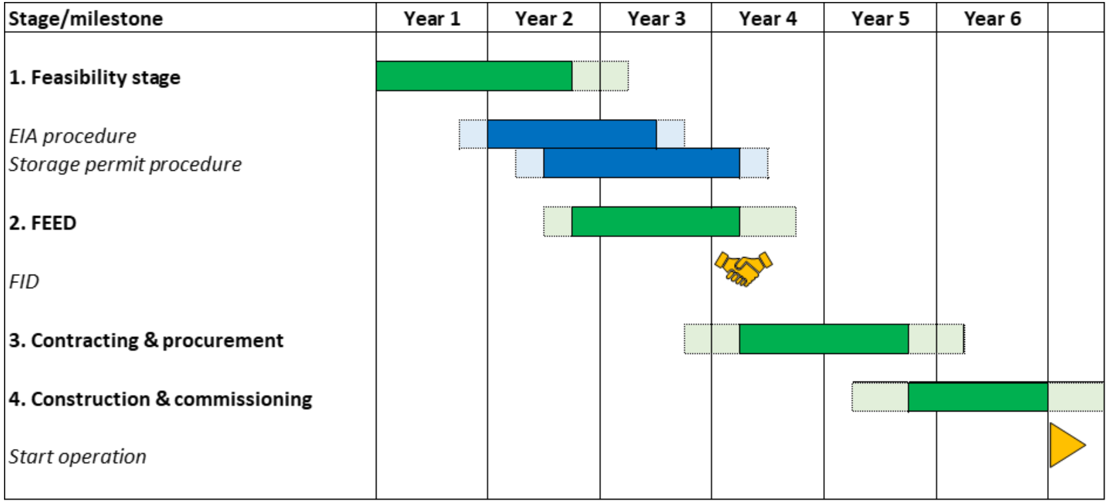


Source: EBN-Gasunie, 2017

STORAGE DEVELOPMENT LEAD TIMES

- Re-using platforms, wells
- New build pipelines

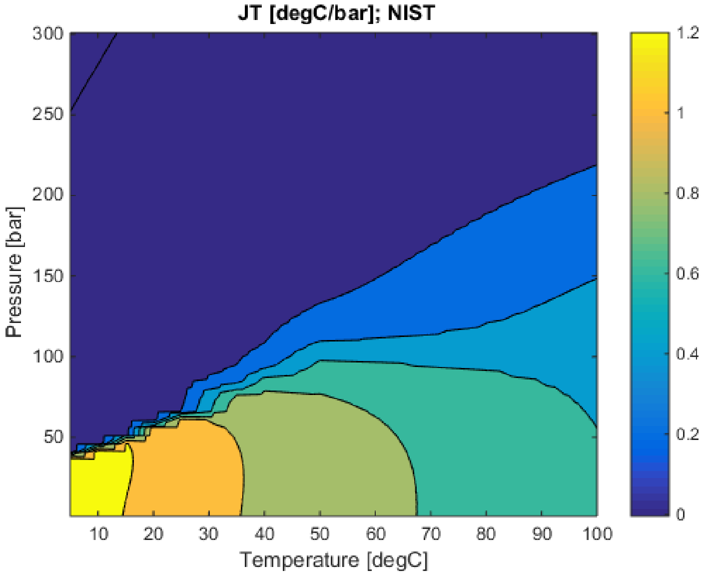
- Developing a depleted gas field into a CO_2 storage site takes at least 6 years



OPERATIONAL CONDITIONS
OFFSHORE T&S NETWORKS

- Transport trunklines: **high pressure** for efficiency
  - 80 – 100 bar, liquid CO_2, single phase
  - Temperature 5 – 10 °C (sea water temperature)

- NL reservoirs often at **low pressure** after production
  - 20 bar or lower not uncommon
  - Temperature typically >100 °C, > 2.5 – 3 km depth

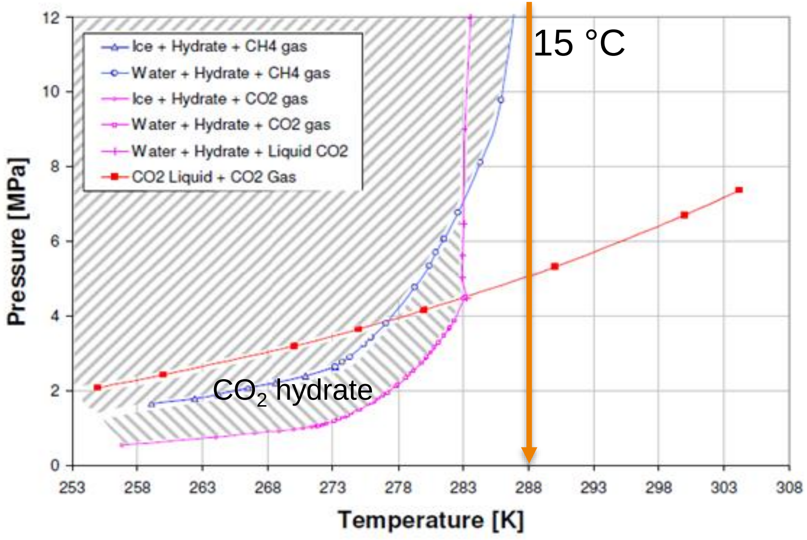


RE-USING DEPLETED FIELDS
(AND THE WELLS)

- Safe storage
  - Well integrity maintained during operations
    - Injection on – off: temperature cycling in well
    - **Wellhead: T > -10 °C** (material constraint)
  - Reservoir and cap rock integrity preserved
    - Large contrast temperature CO_2 - reservoir

- Maintain operability of reservoir
  - Avoid salt deposition and hydrate formation
  - Hydrates: **bottomhole T > 15 °C**

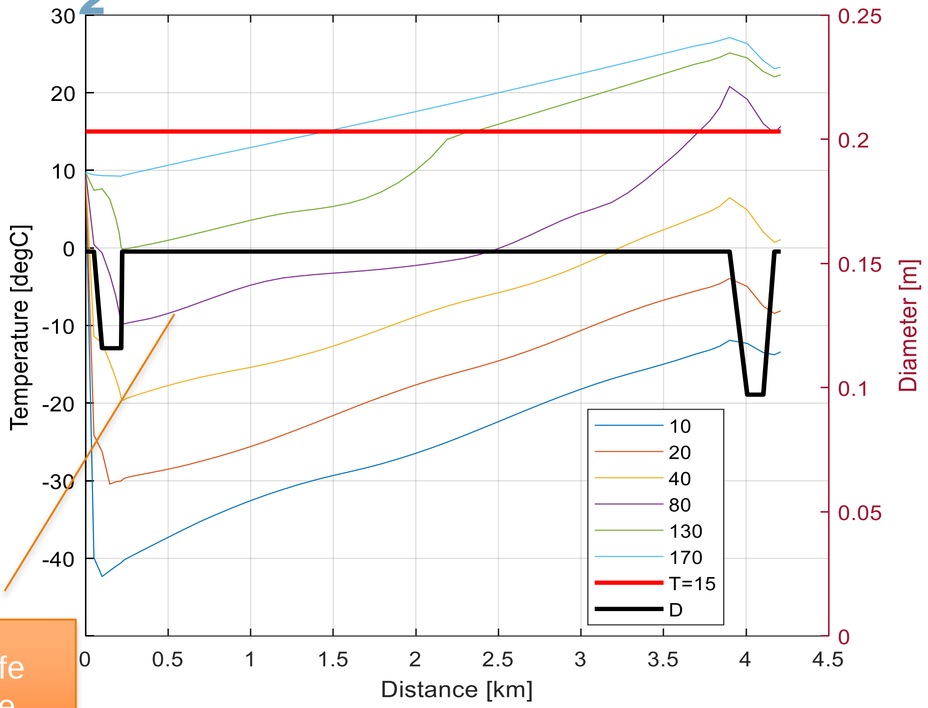
- Flow rates through well: limits due to erosion, vibration



Need water…

EXAMPLE: LIQUID, COLD CO_2
CONDITIONS ALONG WELL

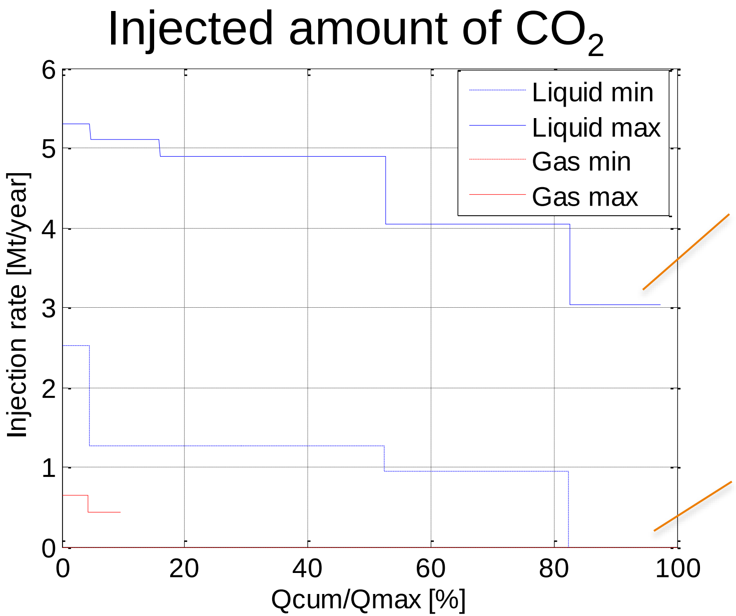
- TVD ~ 3.5 km (deviated well)
- At wellhead:
  - Massflow: 10 - 170 kg/s
  - Pipeline pressure 100 bar
  - Wellhead temperature: 10 °C
- Near bottom of well:
  - Reservoir pressure: 20 bar
  - Reservoir temperature: 120 °C



Results depend on well completion, reservoir properties, etc.: system design to take these phenomena into account

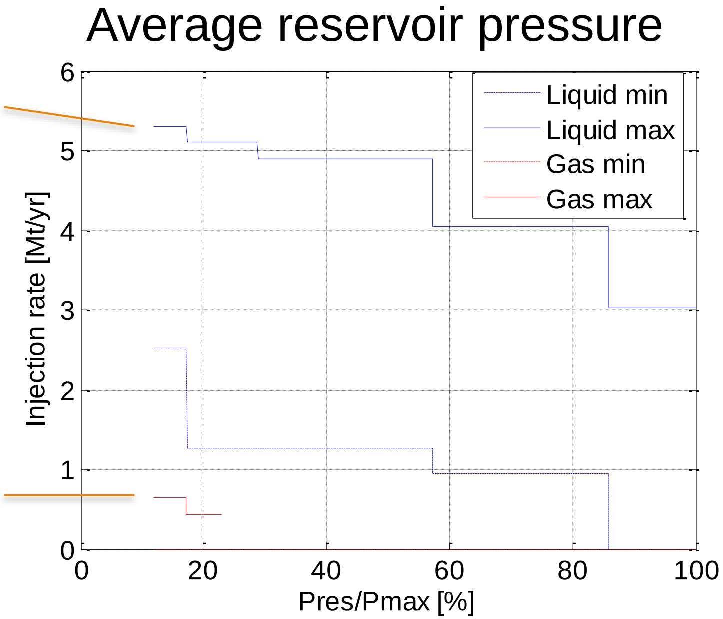
Minimum safe injection rate
70 kg/s (~2 Mtpa)

SAFE OPERATION WINDOWS
DESIGN IMPLICATIONS



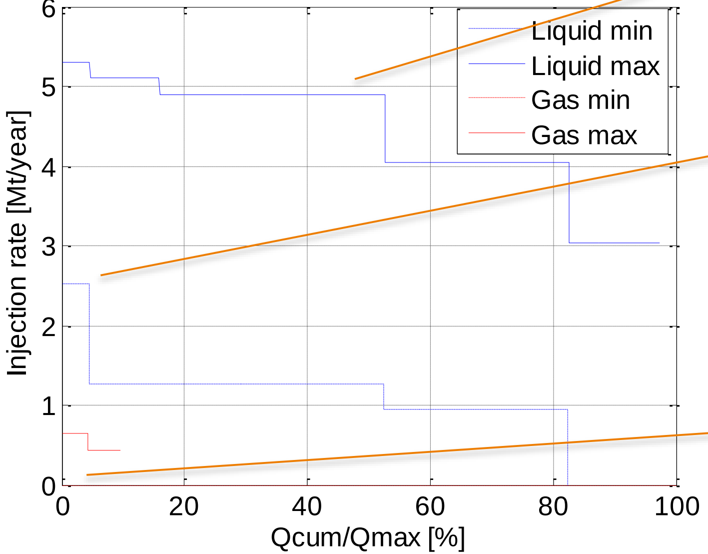
Liquid CO_2 at wellhead
High p pipeline

Gaseous CO_2 at wellhead
Low pressure in pipeline



SAFE OPERATION WINDOWS
DESIGN IMPLICATIONS

Injected amount of CO_2

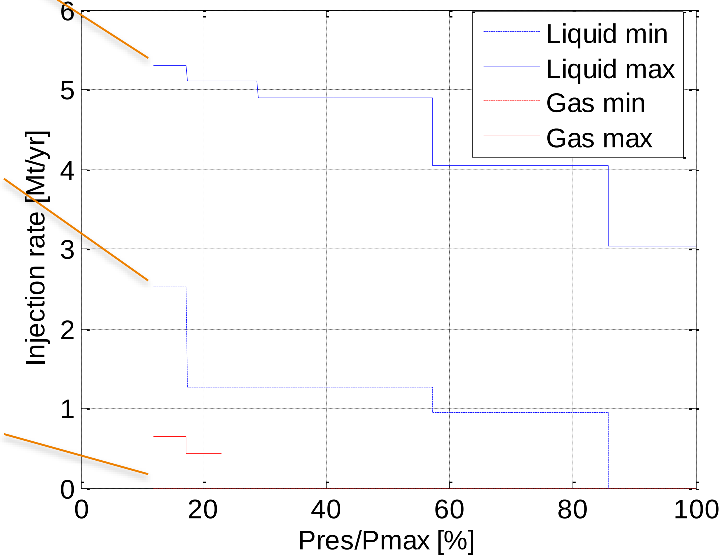


Maximum flow: erosion and vibration issues

Liquid CO_2 at wellhead: Minimum flow!

Gaseous CO_2 at wellhead No minimum flow

Average reservoir pressure



NETWORK DEVELOPMENT
IMPLICATIONS OF USING DEPLETED FIELDS (1/2)

- Near-shore: injecting warm CO_2 is an option
  - ROAD project: insulated pipeline, no cooling after compression
  - Wellhead temperature up to 60 °C, gas phase (30-40 bar)
- Further out offshore: CO_2 is cold
  - Insulated pipelines not an option
  - Likely solution for initial phase: gaseous (lower rates)
    - Liquid injection leads to high minimum rate - limited operational flexibility

NETWORK DEVELOPMENT
IMPLICATIONS OF USING DEPLETED FIELDS (2/2)

- Source of CO_2: determines approach in filling reservoirs
  - Low-pressure pipeline, gas phase, open flow: can accommodate low-rate of highly variable supply
  - High-pressure pipeline, controlled flow, with high minimum rate: requires high-volume, steady supply

- Timeline
  - Initial phase (until pressure in reservoir is about 50 bar): gaseous CO_2
    - Lower rates for first 1 – 2 years (depends on reservoir capacity)
  - Then switch system (pipeline – wells – reservoir) to liquid injection

Must get clarity on hydrate formation: will it occur in depleted gas fields?

- Re-use of platforms
  - Limited equipment needed: valves, metering, monitoring (no compression, no pumps)

IMPLICATIONS FOR OFFSHORE CCS DEVELOPMENT

- Field availability, pipeline re-usability, status of wells (legacy P&A wells!)
  - Impact network development routes
  - Need DCS-wide facility-specific dataset and re-use plan?

- Storage development timeline:
  - Depends on rate of supply
  - Affected by characteristics of supply: intermittent vs ‘base load’, low vs high volume
    - Gaseous vs liquid injection & lead time to reach 50 bar reservoir pressure

- Re-use vs new build
  - Interval between CoP and start of injection
  - Age, status of facilities, …

WAY AHEAD

WAY AHEAD

- Networks
  - Network development
  - Choice of fields
    - Plan / field selection
  - Network flexibility
  - Impact variable supply & storage

- Operational plan(s)
  - Defining the operational window
    - Managing temperature in system
  - Risk management plan

- Monitoring & modelling uncertainties
  - Geological uncertainty, monitoring accuracy
  - Verification
  - Effective, efficient monitoring systems
  - Proving storage system performance
  - Closure, handover: storage system stability

- Various
  - Hydrates

THANK YOU FOR YOUR ATTENTION

TNO.NL/ECNPARTOFTNO