ROAD P18-4 - MONITORING PLAN

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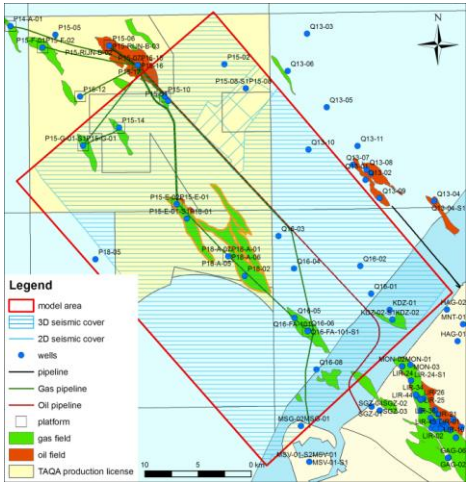
TNO innovation for life

OVERVIEW

- The ROAD project
- The P18 gas field
- **The monitoring plan**
  - Site characterisation
- **The corrective measures plan**
- Towards a stable situation
- Concluding remarks

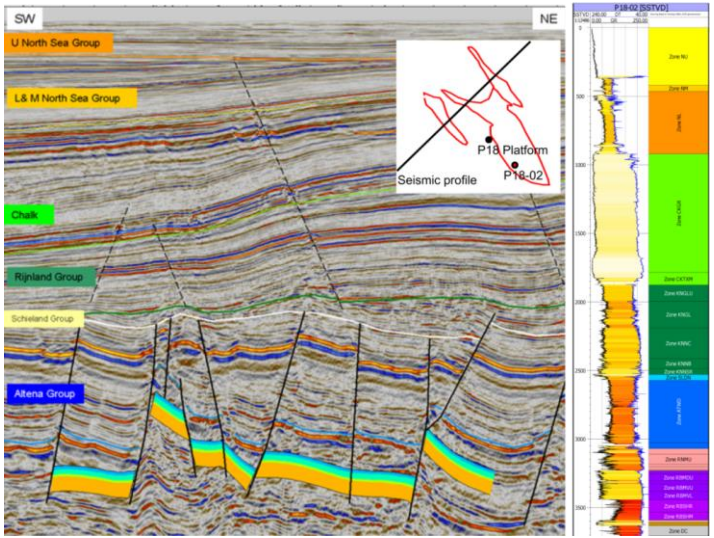
THE ROAD PROJECT

- **R**otterdam **O**pslag en **A**fvang **D**emonstratie – Rotterdam capture and storage demonstration
- E.ON Benelux, Electrabel & TAQA Energy, integrated CCS chain, 250 MW, post-combustion,
- Onshore capture, transport and off-shore, storage of ~1.1Mt of CO_2/year



THE ROAD PROJECT - P18-4

- P18-4 is a gas reservoir in clastic Triassic rocks at over 3 km depth, just offshore the Dutch coast
- One of three (four) compartments, faults of various generations



P18-4 MONITORING PLAN

- Monitoring and Corrective measures plans are part of the an EU storage permit

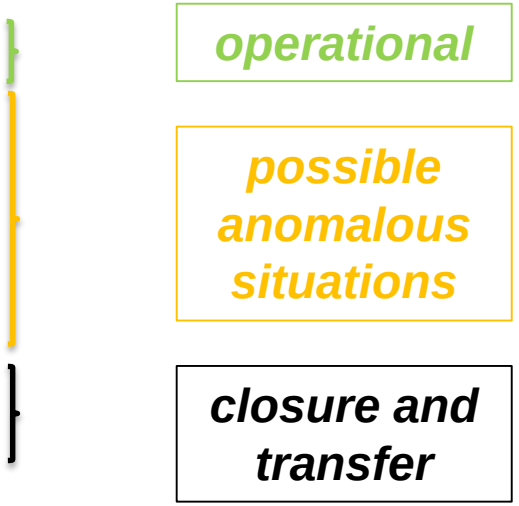
- For ROAD the monitoring plan needs to comply with:
  - Provisions in the EU CCS directive and implementation thereof in the Dutch Mining Act
  - Requirements of the EU Emissions Trading System (EU ETS)
  - Specific requirements to ROAD as a demonstration project

- Under the EU Storage Directive a monitoring plan has to provide details about monitoring like:
  - Parameters to be monitored
  - Monitoring technology employed and justification for technology choice
  - Monitoring locations and spatial sampling rationale
  - Frequency of application and temporal sampling rationale

MONITORING PLAN REQUIREMENTS EU DIRECTIVE

Comply with EU Storage Directive:

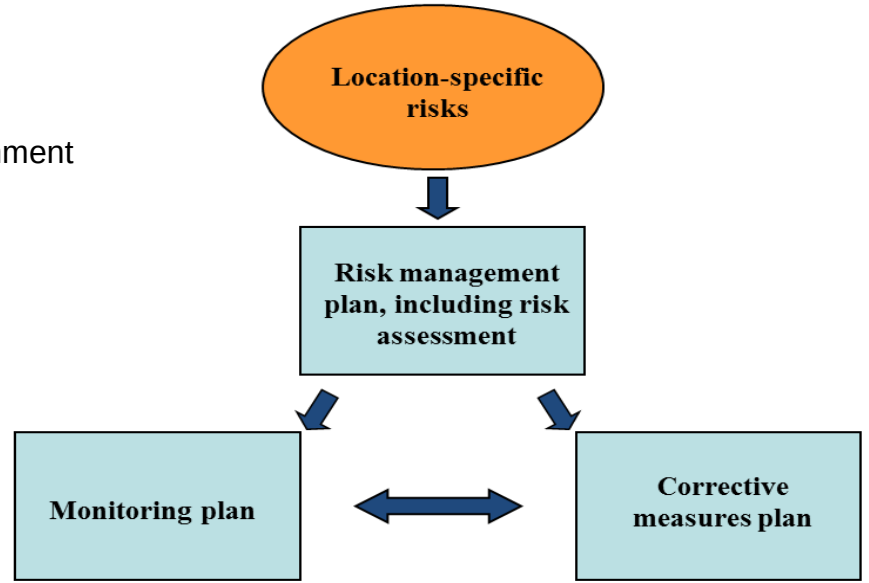
- Compare actual and modelled behaviour of CO_2 and brine
- Detection of significant irregularities
- Detection of CO_2 migration
- Detection of CO_2 leakage
- Detection of significant negative effects for environment, drinking water, nearby residents, the biosphere
- Evaluation of effectiveness of corrective measures
- Prove safety and integrity of the storage complex, including the assessment of complete and permanent storage



P18-4 MONITORING APPROACH – RISK BASED

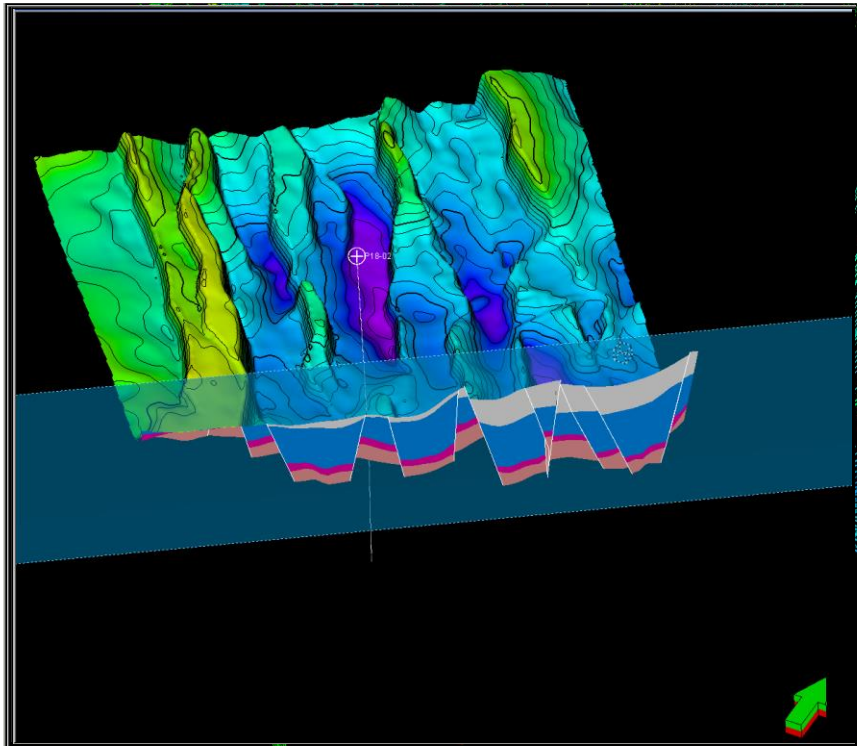
- Risk-based monitoring plan
  - Ensures safety and integrity storage complex
  - Necessary information for transfer responsibility to government
  - Additional learning with respect to large-scale CCS
  - Prove effectiveness of corrective measures
  - Balance between efficiency and costs

- Consistency between:
  - Monitoring plan
  - Corrective measures plan
  - Other plans & assesments…



P18-4 – SITE CHARACTERISATION

- Geological modelling
- Dynamic flow modelling
- Geomechanical modelling
- Geochemical modelling
- Well investigations
- Migration studies



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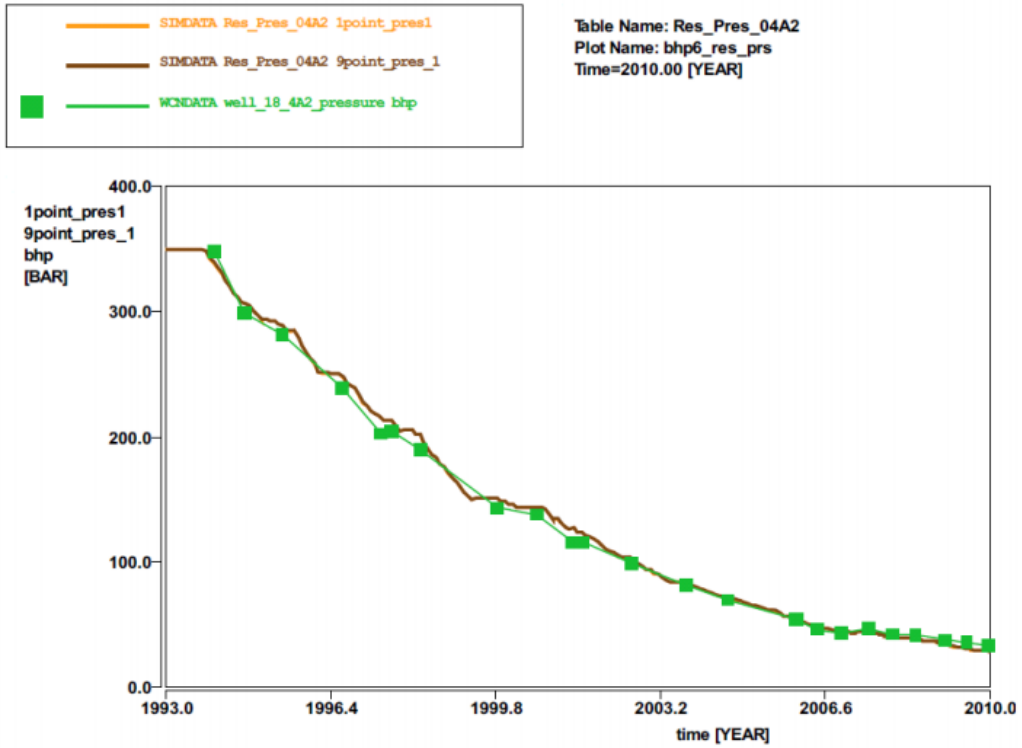

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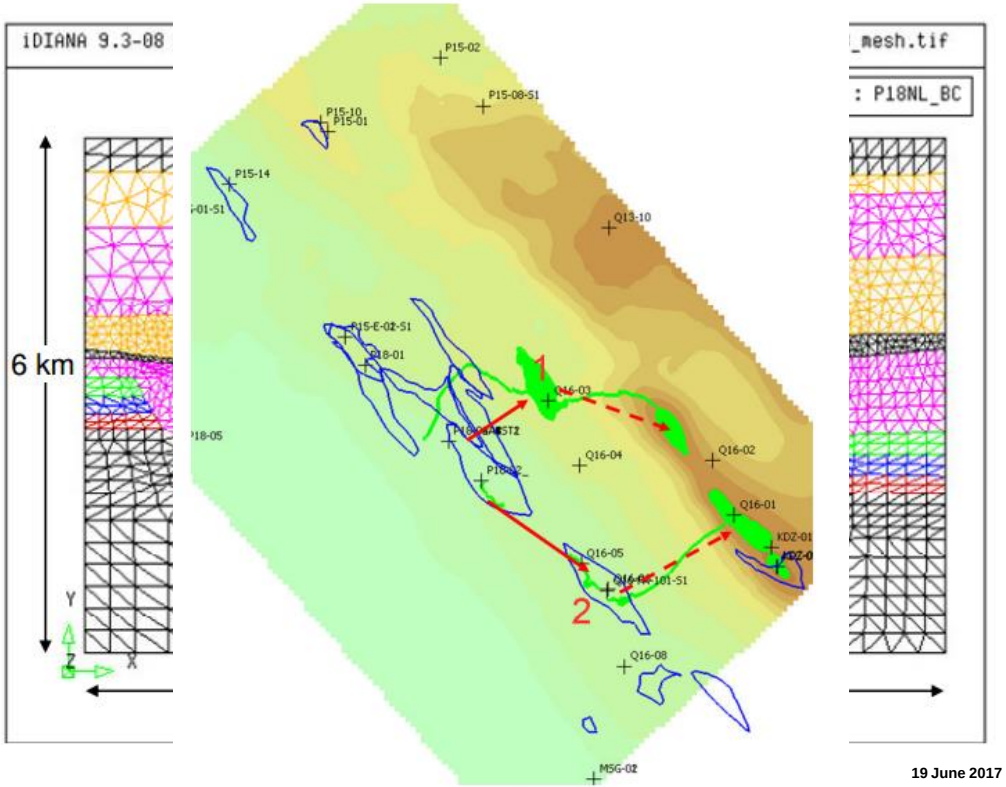
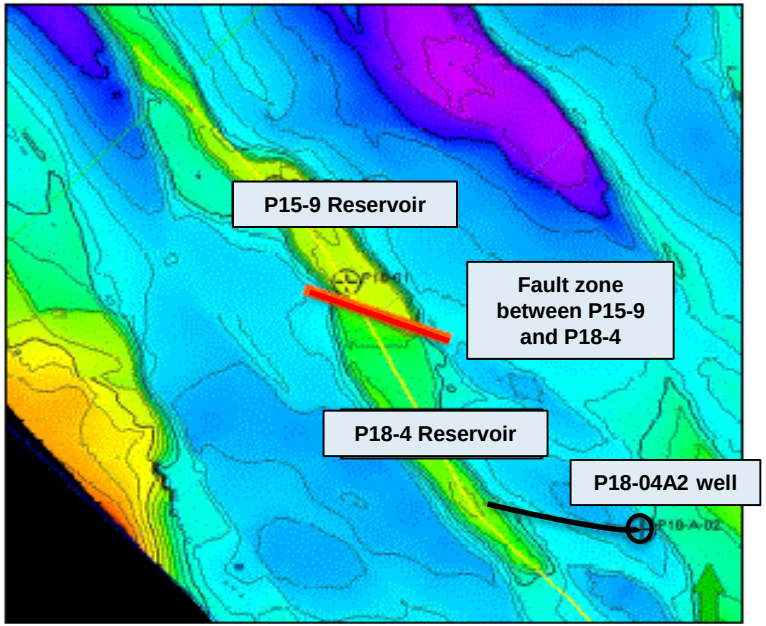
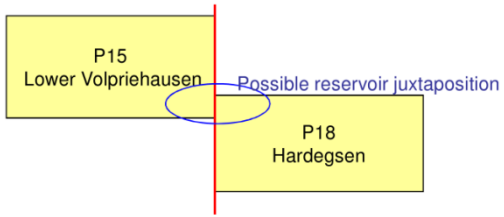


P18-4 - SITE CHARACTERISATION

- Focus on reservoir integrity and behaviour
- Important unknown: sealing capacity of fault P18-4/P15-9



Lower Volpriehausen P15
Phi: 5% k: 0.1 mD
Hardegsen P18
Phi: 12% k: 200 mD



P18-4 - SITE CHARACTERISATION

- The extensive site characterisation could not bring forward any show stoppers.
- It was concluded that the P18-4 reservoir is suitable for CO_2 storage.
- Some key factors:
  - Knowledge obtained during exploration and production indicates the a reservoir with a tight seal
  - The produced & under pressured reservoir will be brought back close to its original stable (hydrostatic) pressure
  - The reservoir held natural gas for millions of years, indirectly proving the quality of the storage site

P18-4 MONITORING PLAN

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- Designed to:
  - verify CO_2 containment and reservoir integrity during operation
  - to demonstrate long-term stability after the operational phase

- This is achieved by:
  - **Measuring the absence of any leakage through direct detection methods (e.g. at the wells)**
  - **Verifying indirectly that the CO_2 is behaving as expected through reservoir pressures**

- The current monitoring plan includes therefore collection of data such as:
  - Pressure, composition, flow and temperature monitoring
  - Well integrity monitoring (repeated) logging, measuring annuli pressures and checking of annuli fluids
  - Time-lapse seismic surveys (contingency monitoring), in case of irregularities
  - Monitoring of shallow overburden, to indicate absence of migration to the seabed

P18-4 MONITORING PLAN

Parameter	Pre-inj.	Injection	Post-inj.	Post-aban.	Post-transfer
Injection rate (flow meter)					
Well head p, T (pressure device, DTS)					
CO_2 composition (gas samples)					
p, T reservoir (downhole device, DTS)					
Stabilised p, T in reservoir (+ well shut-in)					
Well integrity (logging)					
Plug integrity (p test, inspection, fluid sample)					
Sea-bed pock marks (echo sounding)					
Pressure in adjacent reservoir (pressure device)					
Seismic survey (overburden, sideburden)					
Gas analysis at pock marks (gas samples)					

Monitoring type
Regular – mandatory
Regular – required (prelim. estimate)
Optional – contingency

MONITORING PHILOSOPHY – TRAFFIC LIGHT

Measured values have to match values predicted by models

- Green
  - Monitoring data fall within expected range
  - Monitoring frequency gradually decreased
- Yellow
  - Deviations in monitoring data – no corrective measures yet
  - Explain deviation & update models
  - Possibly additional measurements
- Red
  - Data outside pre-defined bandwidth
  - Take corrective measures
  - Scale up intensity of monitoring

Data bandwidths defined prior to start of injection

P18-4 CORRECTIVE MEASURES PLAN

The corrective measures plan defines the actions, measures or activities taken to correct significant irregularities and is like the monitoring plan, site specific.

- Communication with stake holders and reporting to authorities
- Additional monitoring like:
  - Monitoring in neighbouring wells
  - Seismic survey (e.g. when migration out of reservoir suggested by monitoring data)
- Adjust injection (pressure, rate)
- Large-scale intervention
  - In case of well damage
  - In case of problems on platform (venting procedures)

P18-4 LARGE SCALE INTERVENTION

- In case of leakage into neighbouring gas field P15-9:
  - Cease injection at P18-4, in case neighbouring gas field qualifies for CCS, continuation of injection after successful request for storage licence
  - Well work overs
  - Termination of injection
  - Venting activities

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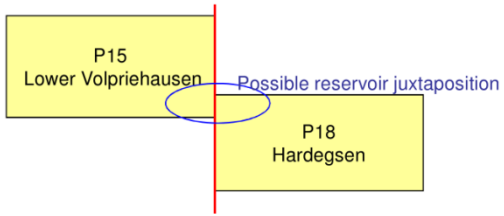
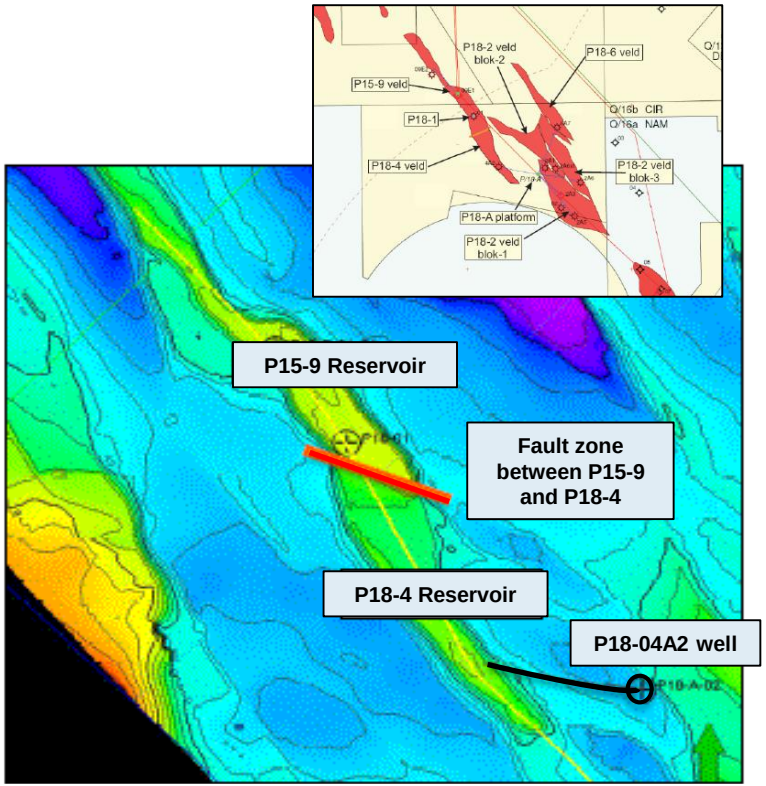




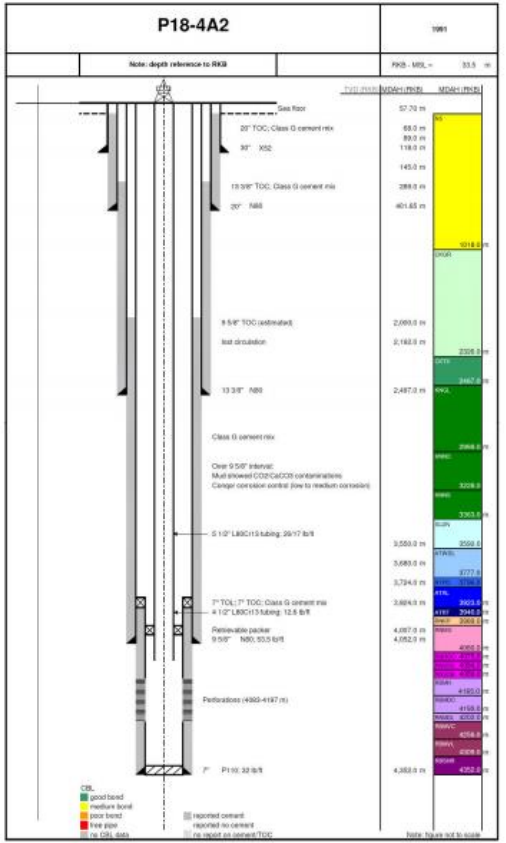
P18-4 EVENTS VS. CORRECTIVE MEASURES

Event	Corrective measure
CO_2 outside complex	
To overburden	Additional well monitoring; repair cement job
From well to biosphere	Additional well monitoring; repair cement job
From reservoir to biosphere	Additional monitoring; cease injection
To adjacent gas field	Monitoring adjacent field; fix wells in adjacent field
Induced seismic activity	
Re-activated fault(s)	Additional monitoring; cease injection
Failure / Damage	
Well damage	Repair well
Cap rock, reservoir damage	Additional monitoring; cease injection
Monitoring	
Technical failure monitoring system	Cease injection; adjust monitoring
Conceptual failure monitoring system	Cease injection; adjust monitoring
Entire system behaves differently	
Limited injection rate capacity	Adjust p, T; adjust monitoring
Unpredicted behaviour in well or reservoir	Cease injection; adjust p, T; adjust monitoring

TOWARDS A STABLE SITUATION

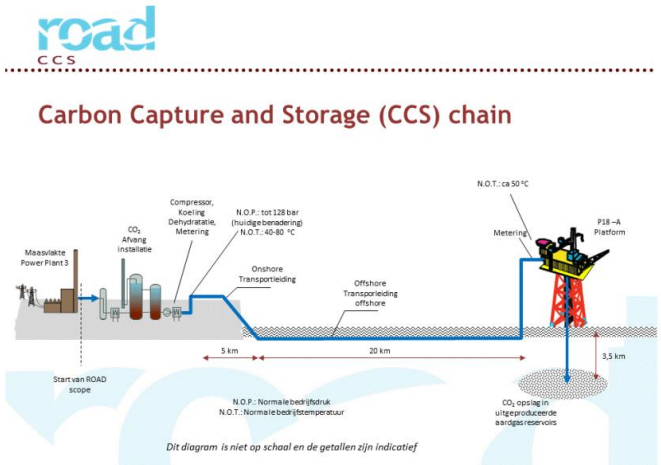
- Prediction of post injection pressures
- Indicate well integrity
- Assure complete/permanent storage of CO_2

- According to regulations, we need:
  - All available data to suggest complete and permanent storage
  - Show that for a certain period since end of injection
    - E.g. 20 years, that storage is complete and permanent, but may be shorter if Competent Authorities are convinced
  - Plug and abandone wells, removed injection facilities, etc.



CONCLUDING REMARKS

- ROAD monitoring and corrective measures plans addresses the requirements of the EU CCS directive in a relatively simple and straightforward approach
- Compact monitoring plan is mainly possible due to the site being a depleted gas field:
  - Large body of knowledge and experience available
  - Proven seal, limited monitoring effort needed to verify containment
- Traffic light model to describe site conformance – flexible and adjustable when new data and models become available
- Final version of monitoring plan after detailed site design completed

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