CO_2 transport and storage: R&D projects

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CO_2 transport and storage R&D @ TNO

Storage (ongoing)

- Monitoring, conformance assessment (CETP Ramonco) – geological uncertainty, defining conformance
- Aquifer storage (TKI New Gas) – providing the basis for aquifer storage NL offshore
- Well integrity, leakage along wells (JIP Eloquence) – tool to estimate migration along wells
- RCSG – ongoing testing of CCS facilities in Rijswijk lab

Under development:

- CLARITY – Collaborative Lessons for Advancing Responsible Improvement in CO2 Transport and storage
- POSEIMON - Porthos seismic monitoring Offshore Netherlands

Waiting for evaluation results:

- H-EU CO2SITE - CO2 Storage Investment Atlas for Europe
- H-EU SPECS - Impurities Impacts and Management for CO_2 Storage

Transport

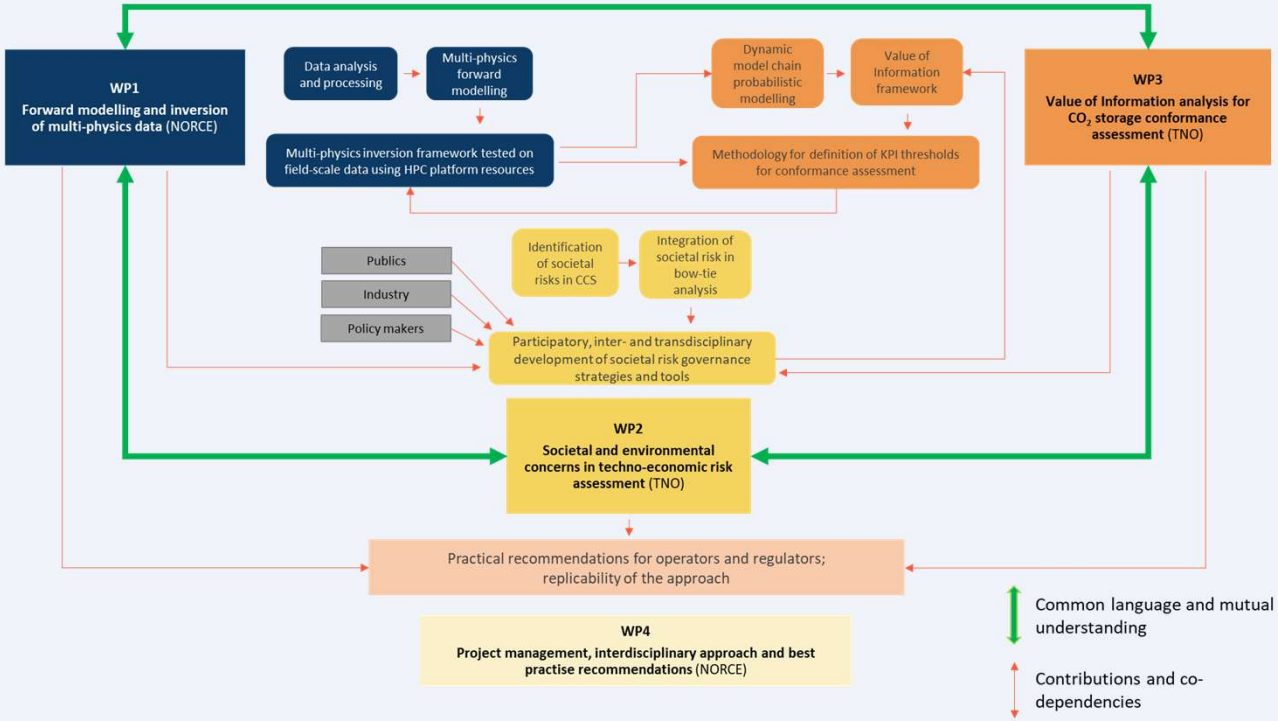
- CO_2 flow loop (ENCASE, CO_2Time) – building and using the new CO_2 flow loop

TNO innovation for life

Ongoing Storage R&D Projects

CETP Ramonco - Risk-based framework for assessing CO_2 storage monitoring

- **Conformance monitoring & assessment**
  - Ensemble based history matching
  - Quantitative conformance assessment
  - Monitoring system design
- **Joint inversion seismic and gravity data**
  - 3D images of CO_2 saturation in subsurface



CETP Ramonco - Risk-based framework for assessing CO_2 storage monitoring

WP2- Societal and environmental concerns in tecno-economic risk assessment

Public surveys

Representative Norway (N=1032); Germany (N=1049); The Netherlands (N=1014). Romania under analysis and Greece upcoming

Qualitative and Quantitaive covering the CCS chain

Identifying prefered level of participation

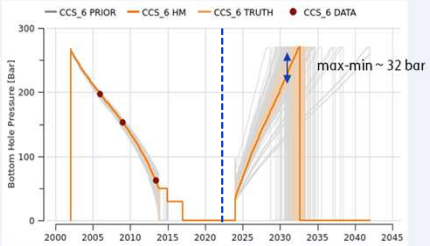
Focus groups

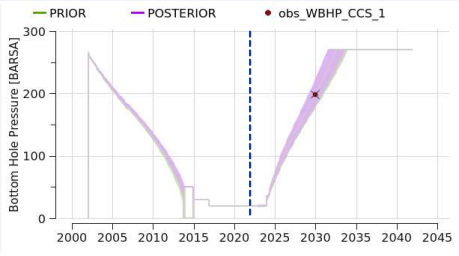
2 focus groups per country

Representatives from industry, governments, NGO's

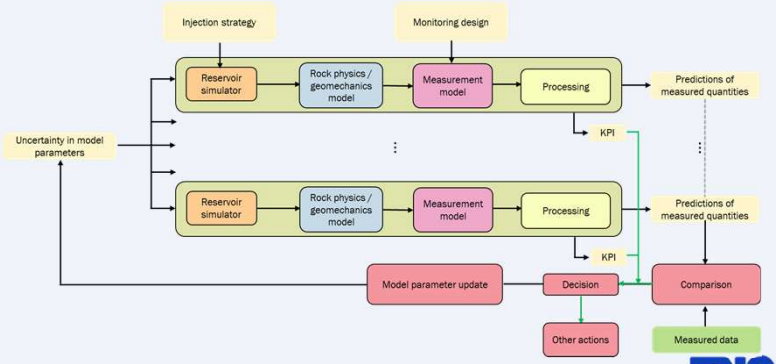
Outcomes to influence a bow-tie development

WP3- Value information analysis for CO_2 storage conformance assessment





The impact of large leaks could not be distinguished from geological uncertainty using forward and inverse UQ approaches (GET 2025).



TKI CO_2 storage in aquifers

Objective:

- For relevant aquifer storage plays in Dutch offshore:
  - **explore the relation between pressure limit, storage capacity, and risk of loss of containment**

Topic(s):

- Use typical storage 'plays': compartmentalised (i.e., relatively small) aquifer structures, or aquifer structures containing a depleted fields
- defining guidelines for maximum pressure definition
- loss-of-containment risk *vs* storage capacity *vs* maximum pressure

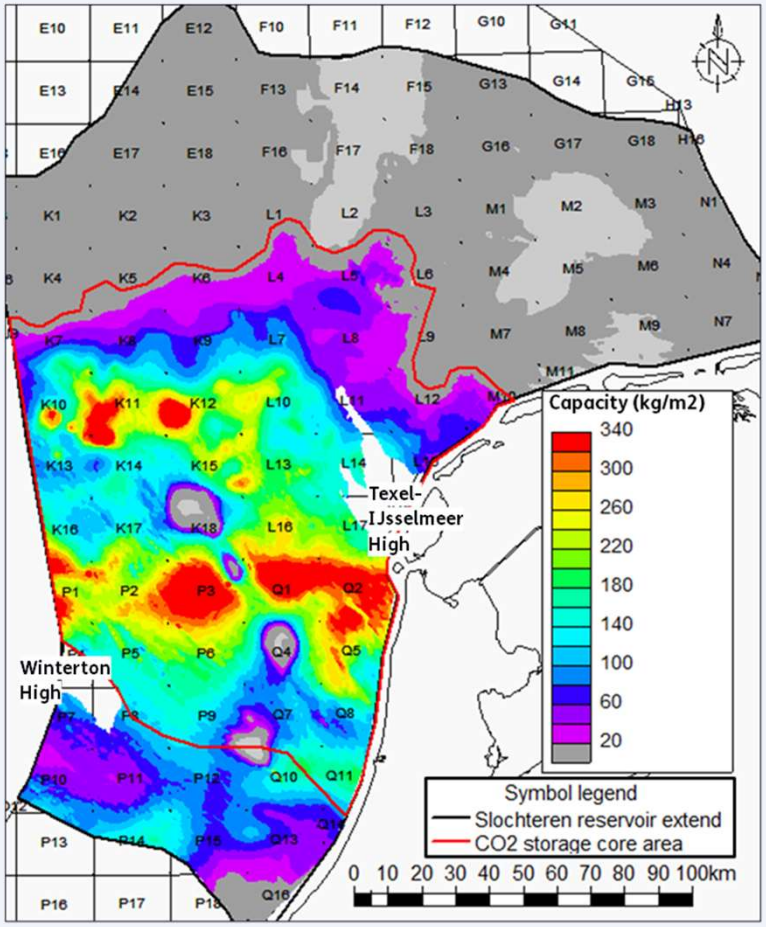
Product / result

- **Material for policy to enable aquifer storage on Dutch continental shelf**

Partners: operators in Dutch offshore

- ENI, TotalEnergies, Shell, Petrogas, One-Dyas, EBN

- Timeline: start Q1 2025, duration 2 years

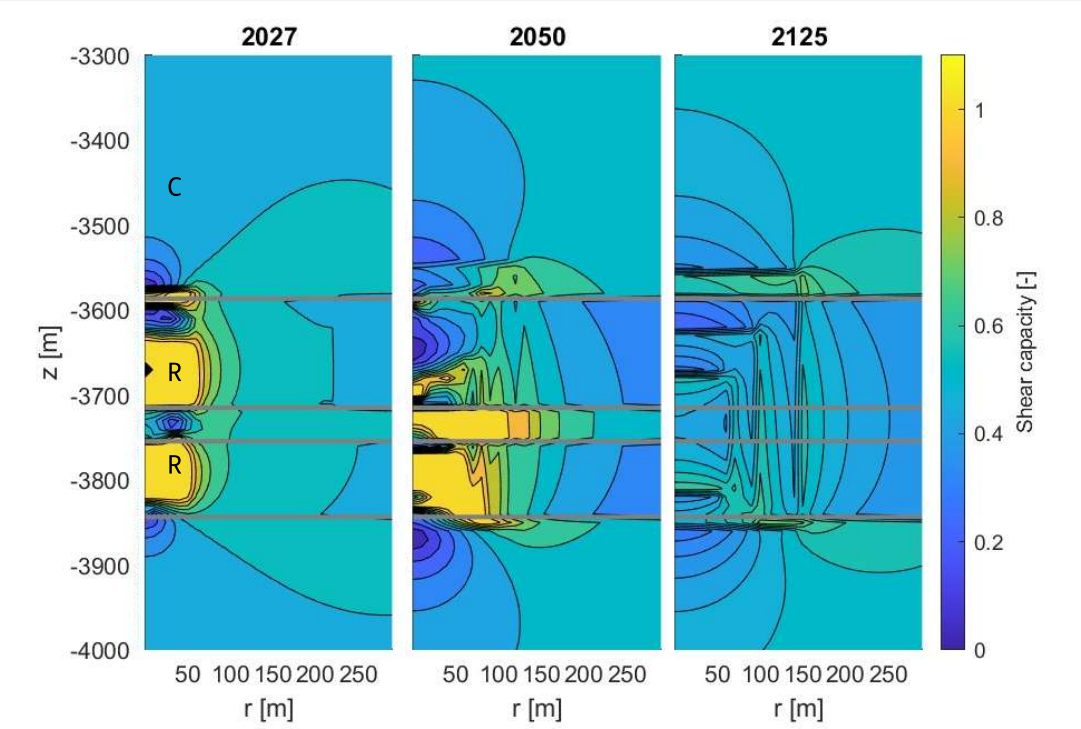


SCADSA study, TNO, 2024

TKI CO_2 storage in aquifers

- Study risks of loss of containment, as function of pressure in the storage reservoir
- **Aim: illustrate the impact of various possible choices for pressure (*) constraints on storage capacity and risk level**
  - The project does not suggest which choice to make
- Several typical storage 'plays' in the Dutch offshore
- First case study (Rotliegend reservoirs) being finalised
- Two more case studies to be done in 2026
- Project finalised end 2026

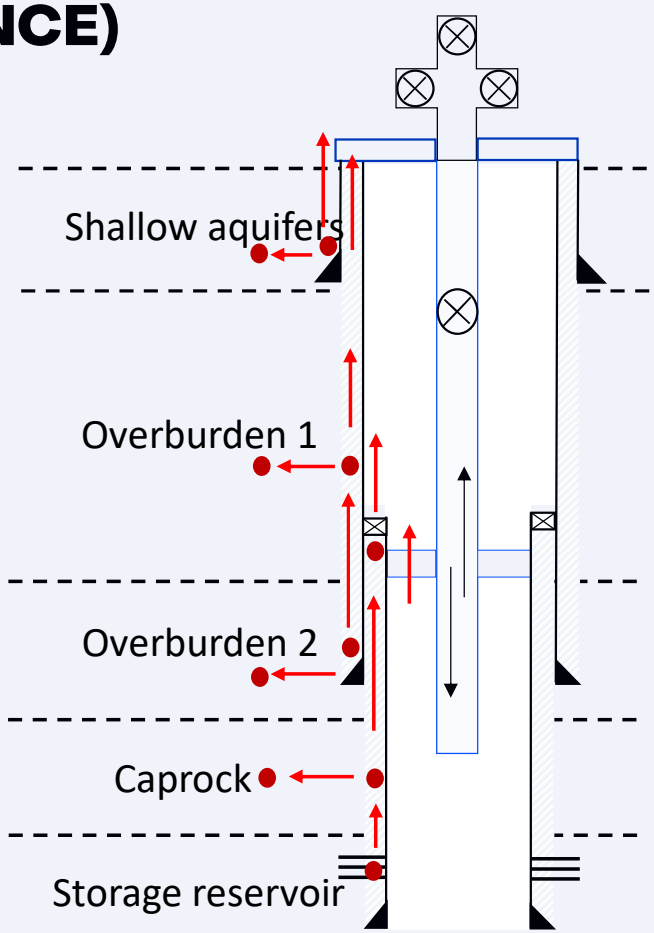
(*) *better would be to use 'stress constraints', as temperature effects must be included*



Example showing geomechanical stability, over time, due to CO_2 injection in two reservoir layers ('R') and caprock ('C'), during ('2027'), after ('2050') and long after '2050') injection

Development of a tool for quantitative leakage assessment of legacy wells for abandonment and reuse (ELOQUENCE)

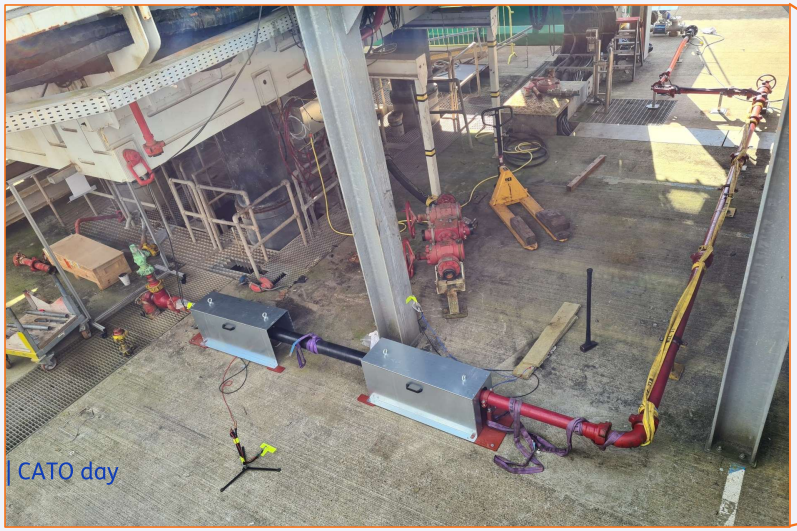
- Holistic leakage assessment tool that considers the entire well path and aims to predict the most likely leakage pathway as well as the leakage rate.
- The tool provides as assessment of the expected quality of the cement sheath (microannuli size) based on operational and in-situ conditions
- Such a tool facilitates quantitative leakage assessment of legacy wells for abandonment and reuse purposes
- The tool will incorporate results from lab experiments and will be verified by field cases (based in Norway, Netherlands or other regions of interest).



RCSG labs

Testing CCS downhole tools at RCSG

- Successful tests of a downhole tool to be applied in CO_2 injection wells to control the wellhead injection pressure and the phase change behaviour
- Testing performance using RCSG's rig and mud circulation system
- Tool tested in the test well at ~300 m depth



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CSS Storage R&D Projects – Under development

Under development

CLARITY - Collaborative Lessons for Advancing Responsible Improvement in CO2 Transport and storage

Identify most important lessons learnt from Porthos:

- Reduce technical uncertainties
- Conducted independently and reliably with no commercial interest
- Cover pre-operational, commissioning and operational stages (3 to 4 years)
- Permitting assessment is out of scope

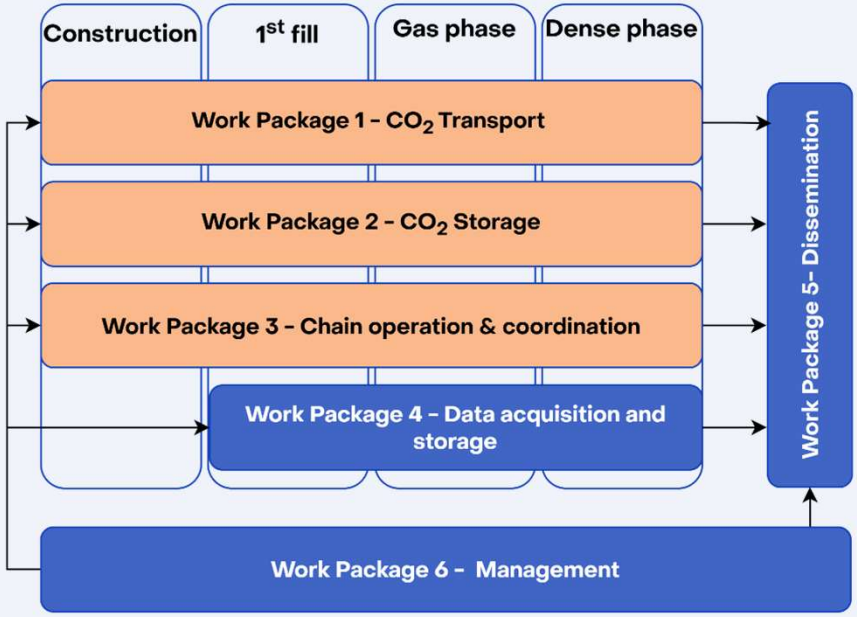


Figure 7: Technical work packages (WP1 -3) and data work package (WP4) relationship with dissemination work package (WP5).

Under development

CLARITY –Governance and dissemination vision

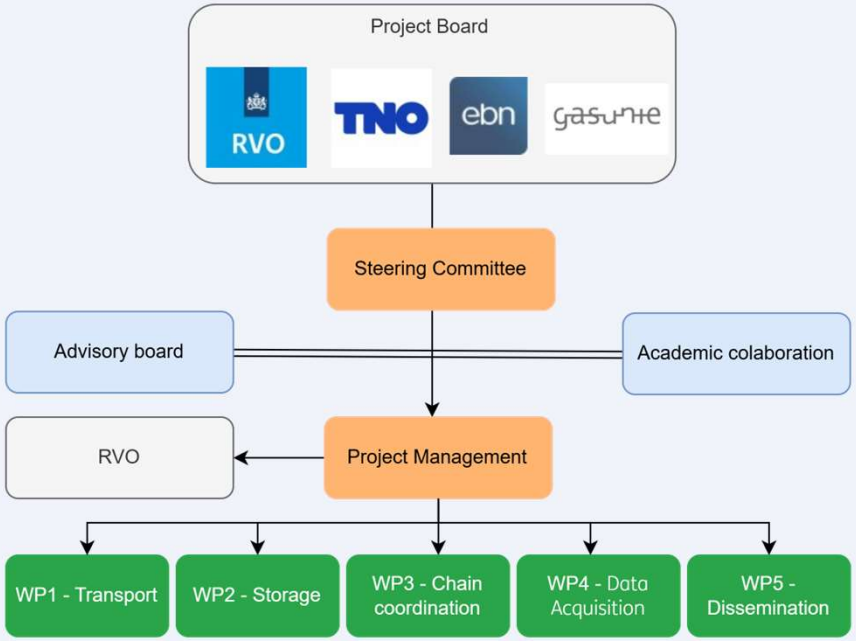


Figure 9: Project hierarchy.

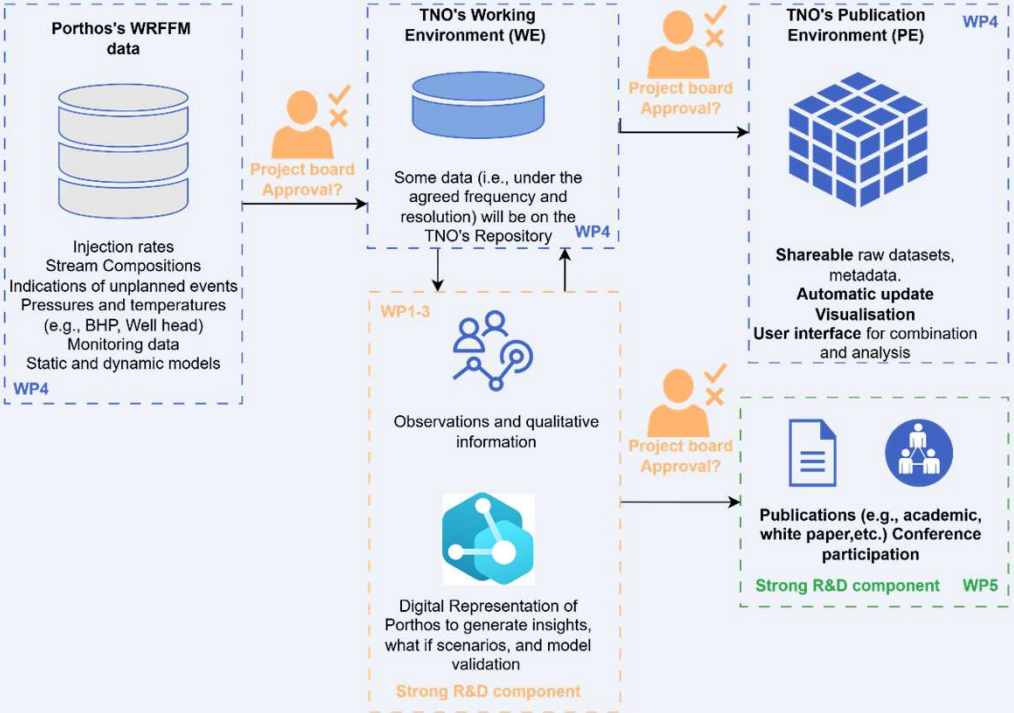


Figure 8:Information flow from Porthos's WRFFM and Technical WPs towards dissemination, including the required approvals. R&D content is highlighted along with WPs interfaces.

Under development

POSEIMON–I

Research program POSEIMON-I

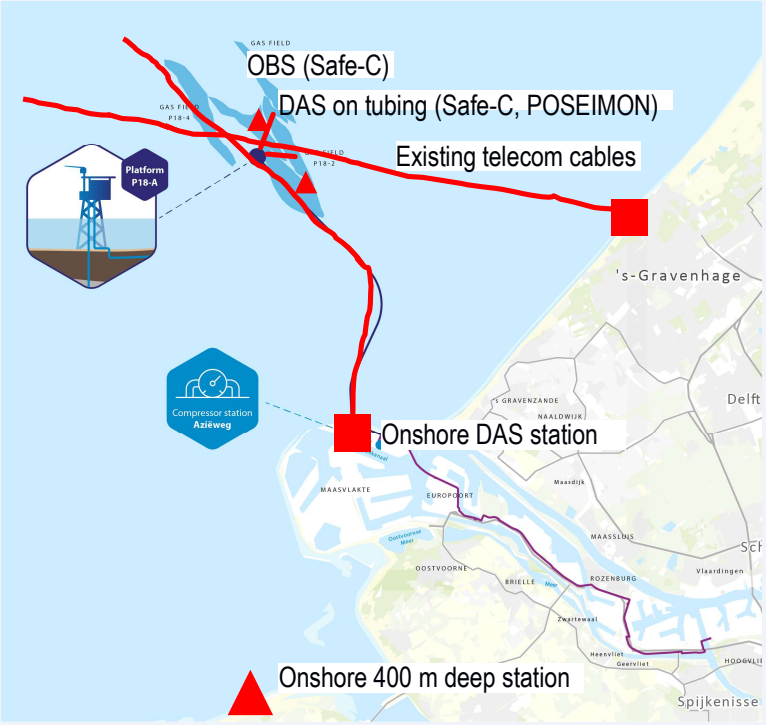
Assess cost-effective monitoring & gain understanding of (micro)seismicity due to CCS. Preparation for POSEIMON-II

Why important?

- Social license to operate
- Microseismicity as diagnostic tool for field behavior/leakage
- Input seismic hazard models
- Utilizing Porthos for learning as first CCS in depleted gasfield

Objectives

- Assess cost-effectiveness of offshore (micro)seismic monitoring techniques + recommendations future CCS projects. (aligning with Safe-C)
- Gain understanding of CCS microseismicity in relation to conformance and leakage detection
- Design POSEIMON-II network



- Duration: 2025 – 2031 (6 years)
- Partners: TNO (lead), KNMI, UT, TUD, Porthos, EBN

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CSS Storage R&D Projects – Waiting for evaluation

CO2SITE - CO_2 Storage Investment Atlas for Europe

2006–2008 EU Geocapacity
Assess the European capacity for geological storage of CO_2

2010 CO2STOP, EGDI SCOPE
Created a database (CO2STOP) of locations of geological formations in Europe that could be used to store CO_2. Asses the use cases, datasets, functional and technical requirements to provide geological information in Europe (EDGI SCOPE).

2015 GeoERA
The establishment of the "European Geological Surveys Research Area"

2016 EGDI
Launch of the platform to provide geological information in Europe

2021 EGS
Strategic Research and Innovation Agenda (SRIA)

2022 GSEU
The entry into a permanent collaborative network of European geological survey organisations

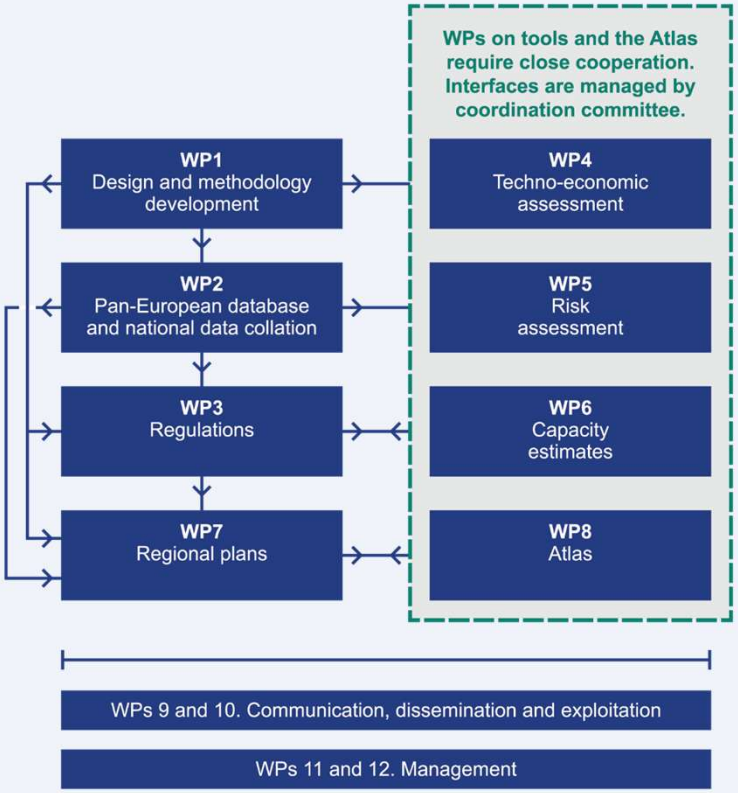
2024 NZIA
Net-Zero Industry Act (NZIA) entered into force

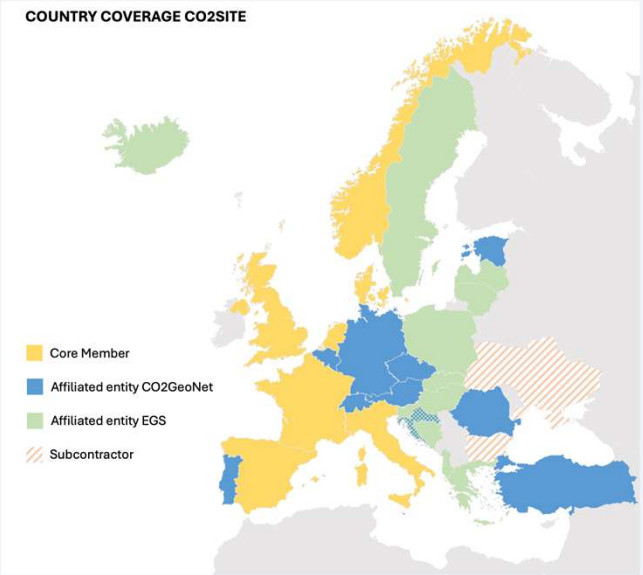
2025 EGS – SRIA update
Establish a permanent Geological Service for Europe (GSE) to enable sustainable use and management of Europe's geological resources

2026 CO2SITE
Enhanced transparency, open access to updated geological data and advanced tools to assess investabilty of potential CO_2 storage sites

proposal

2027 onwards GSE
Update and maintain the EGDI platform





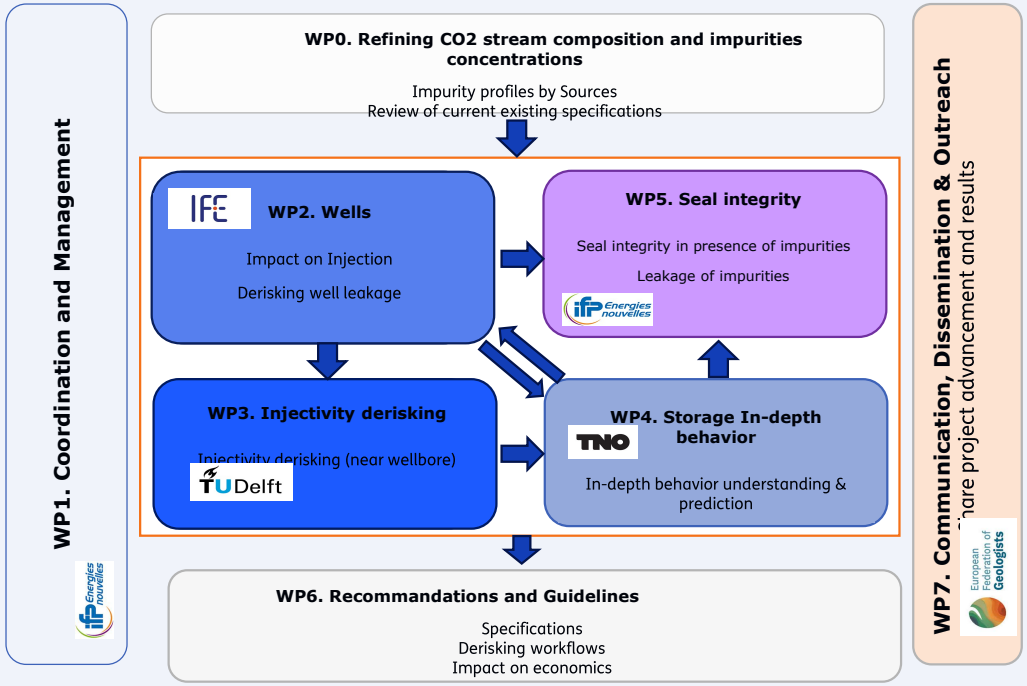
H-EU SPECS

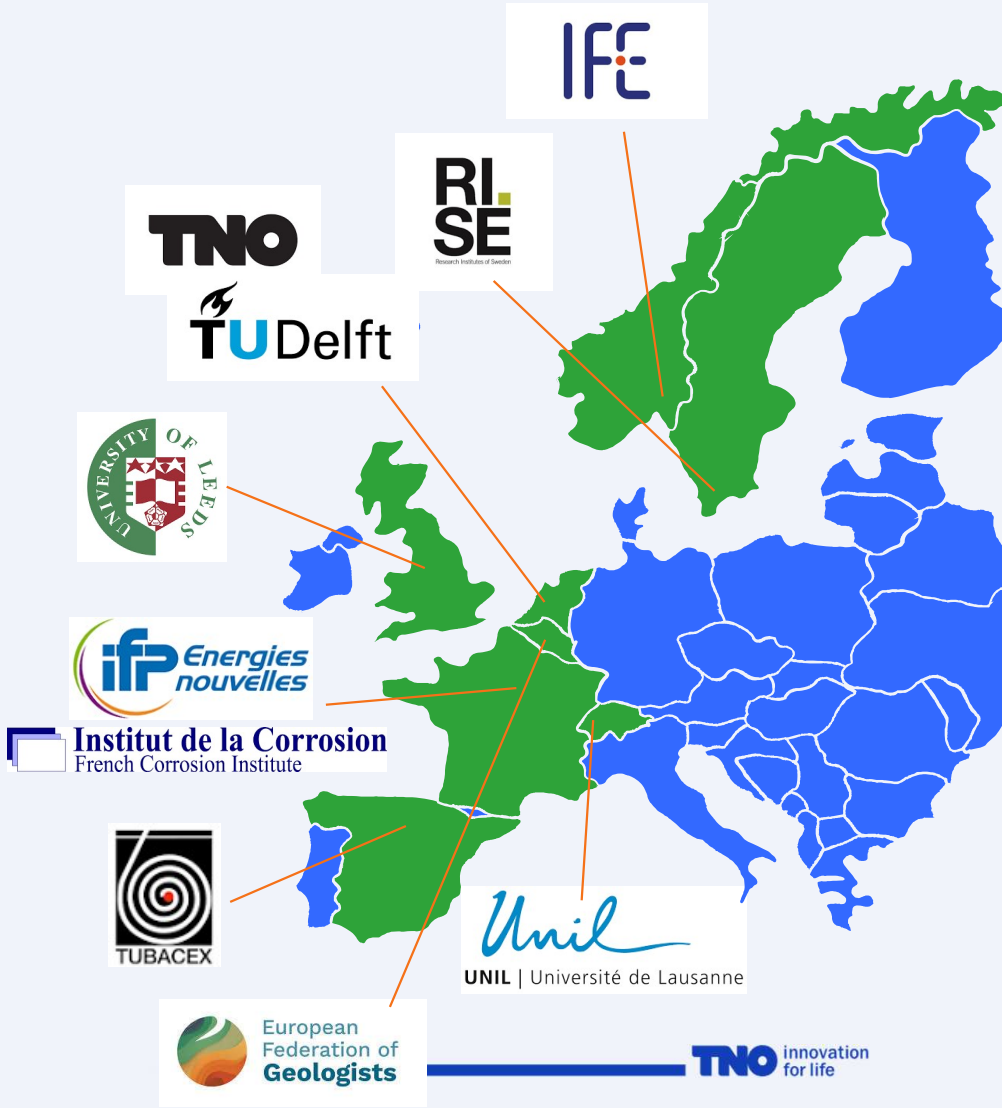
Unravelling CO2 impurities impacts on Storage

Enhanced faster risk identification and assessment of injectivity and integrity

Provide guidelines on CO2 stream specifications

Facilitate access to storage for more CO2 sources





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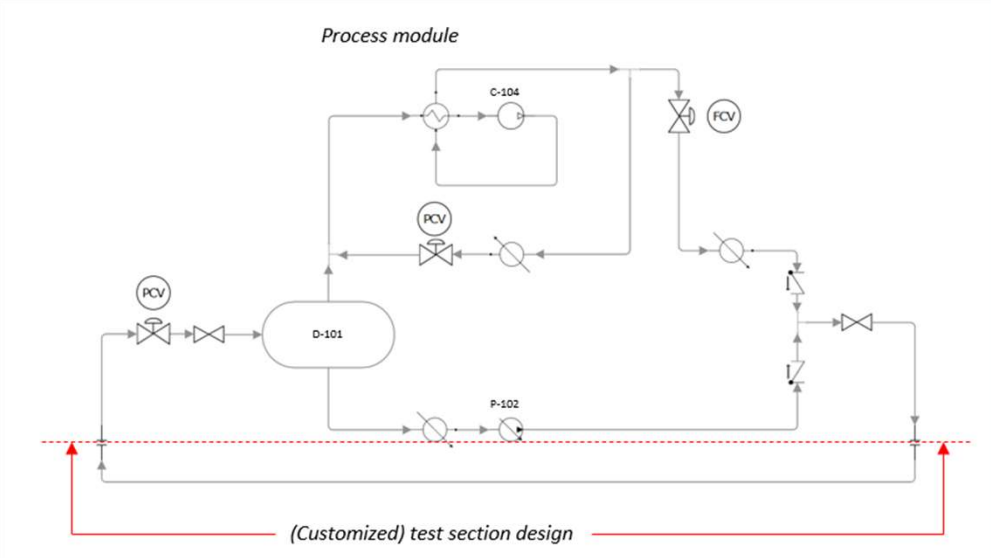
CSS Transport R&D Projects

Colorado flow loop

- Test section ID of ½”-1”
- Flow conditions

	Min	Max
Flow rate gas		20 m/s (1/2” pipe), 5 m/s (1”)
Flow rate liquid		1-2 m/s
Pressure		100 bar
Pressure drop		75 bar
Temperature	-50 °C	+ 40 °C

- Pure CO_2 / CO_2 with impurities
- Default test section: horizontal section followed by a vertical downwards section (both > 100 diameters long for fully developed flow)
- Flexible and modular facility **to investigate CO_2 behaviour for e.g. bends, valves, chokes, instruments , other vertical & horizontal appendages, porous media**.



CO_2 flow loop

JIP with EBN, Shell, TotalEnergies, ENI and Harbour Energy

Objectives:

- Impurities
- Forces on Bends
- Flow through valves
- Flow though porous media (with TNO Utrecht)
- Flow through orifices (to be extended for CO2 with impurities in H-EU project)

H-EU ENCASE

Horizon Europe project with 5 Research Institutes on CO_2 transport

Lead: IFE (Norway)

January 2023 – June 2026

- Key activities in the project:
- Build the experimental capacity of the research institutes (TNO further develops the Colorado flow loop)
- Measuring and simulating the thermo-physical properties of CO_2 with impurities
- Developing measurement and control techniques
- Investigating the safety of CO_2 transport (TNO to perform vapour collapse measurement)
- Social innovation and co-creation (TNO to develop exhibit in collaboration with the Energy Cave)

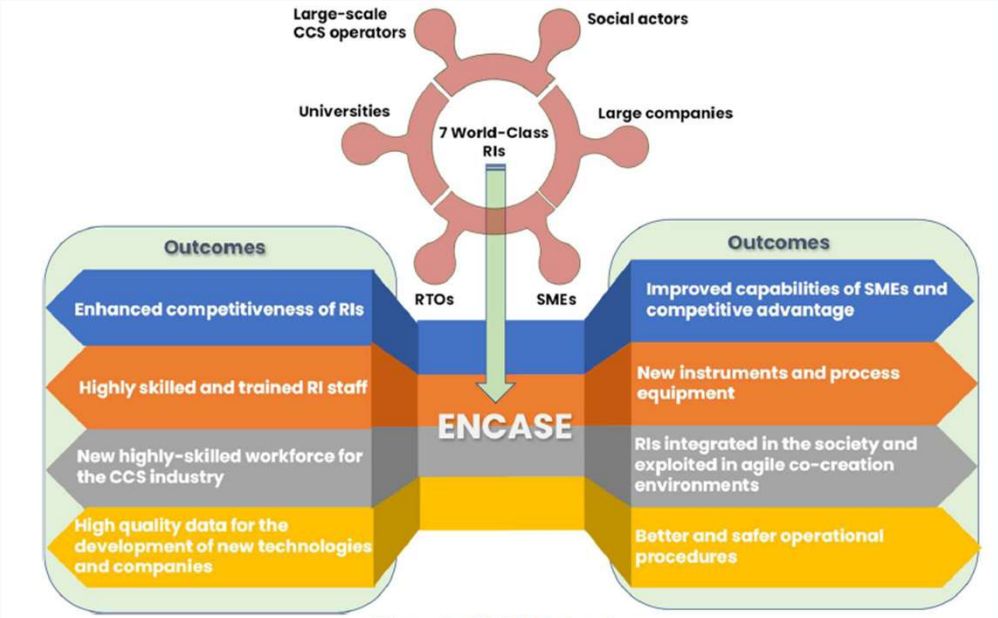


Figure 1. ENCASE at a glance

https://www.encase-eu.com/

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