DETECT

INTEGRATED GEOLOGICAL CO_2 LEAKAGE RISK ASSESSMENT

DETECT

Determining the risk of CO_2 leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach

Project Update - ACT Knowledge Sharing Workshop

November 13, 2018

Shell Global Solutions International BV: **Marcella Dean,** Project Manager & WP4 Lead, Jeroen Snippe, WP3 Lead

Heriot Watt University: Andreas Busch, WP2 Lead

RWTH Aachen University: Pieter Bertier

Risktec Solutions B.V.: Sheryl Hurst, WP5 Lead

Accelerating CCS Technologies

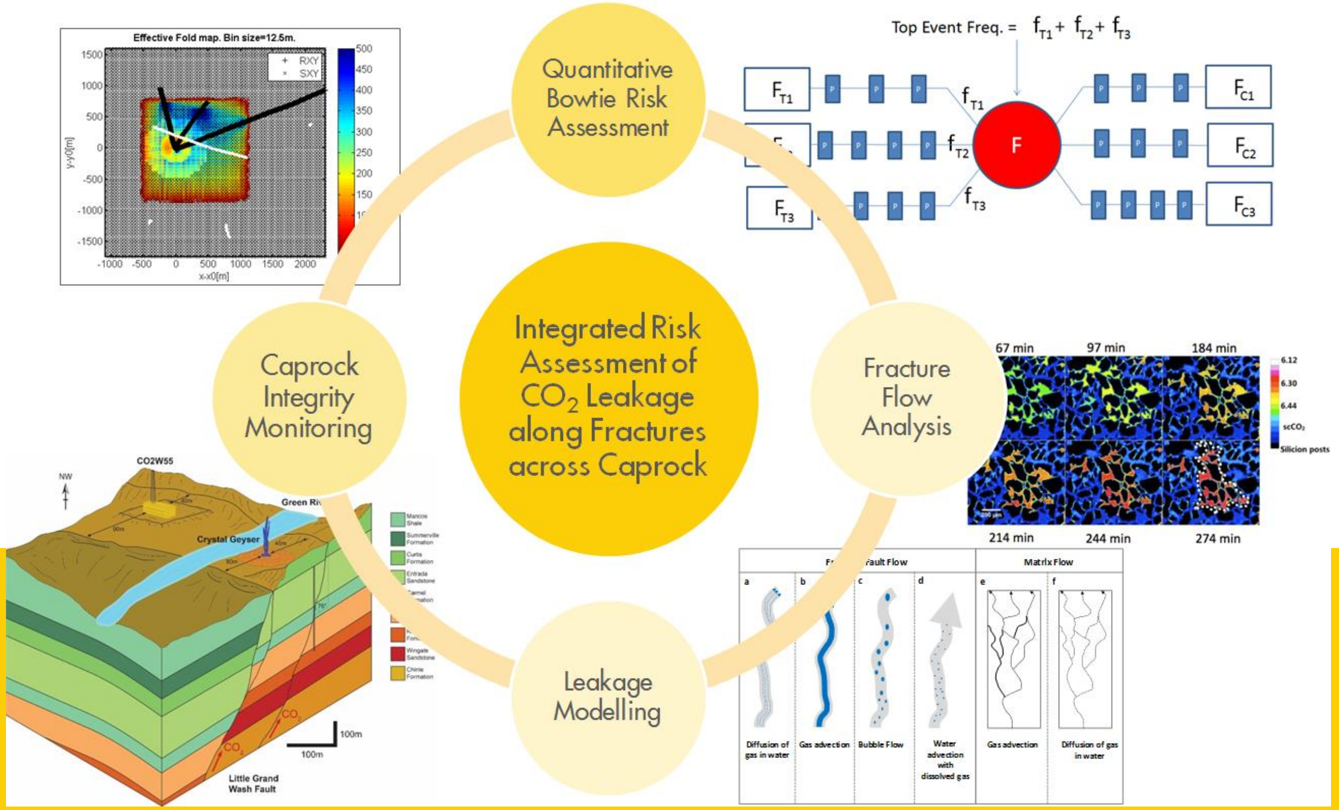
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

D E T E C T

INTEGRATED GEOLOGICAL CO_2
LEAKAGE RISK ASSESSMENT

DETECT Project

Overview



The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

DETECT Integrated geological CO_2 leakage risk assessment

Determining the risk of CO_2 leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach

DETECT

INTEGRATED GEOLOGICAL CO_2 LEAKAGE RISK ASSESSMENT

Objectives

- Shell-led consortium will generate CCS industry leading guidance for managing geological CO_2 storage risks allowing stakeholders to:
  - RISK ASSESSMENT Perform effective caprock and seal integrity risk assessment
  - INTEGRATED MODELLING Select realistic and efficient leakage rate modelling approaches
  - LEAKAGE RATES Understand realistic leakage rates and related implications
  - MONITORING Select cost effective and innovative containment monitoring technologies
  - COMMUNICATION Communicate clearly and logically assessed caprock risks

Collaboration

- WP1 Project Management
  - Shell
- WP2 Fracture Characterisation
  - Heriot-Watt University
  - RWTH Aachen University
- WP3 Hydro-mechanical and hydro-chemical modelling
  - Shell
  - Heriot-Watt University
- WP4 Containment Monitoring
  - Shell
- WP5: Risk Assessment
  - Risktec Solutions

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

D E T E C T

INTEGRATED GEOLOGICAL CO_2
LEAKAGE RISK ASSESSMENT

WP1 – Project Management

Update

2

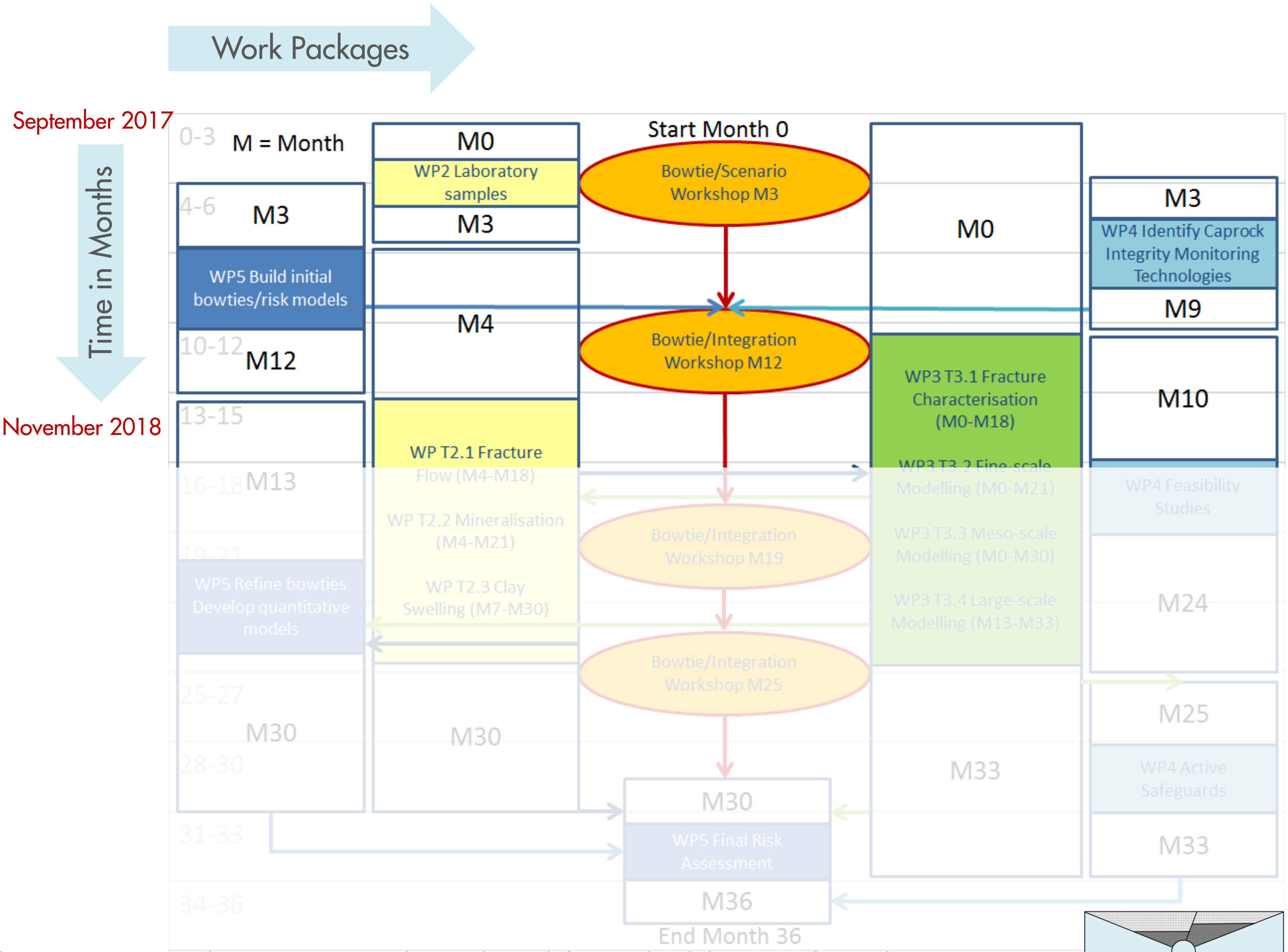
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

Accelerating CCS Technologies

Project Status

Status

1. **On Track with Deliverables**
   - No major delays or issues
2. **Excellent Collaboration**
   - Regular virtual meetings and email contact among all partners:
     - WP3 biweekly progress meeting Shell with HW
     - WP3 and WP5 every three weeks progress meeting
   - Regular F2F meetings:
     - Shell visits to partners
     - 3 meetings/workshops, 4th planned in January



The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

D E T E C T

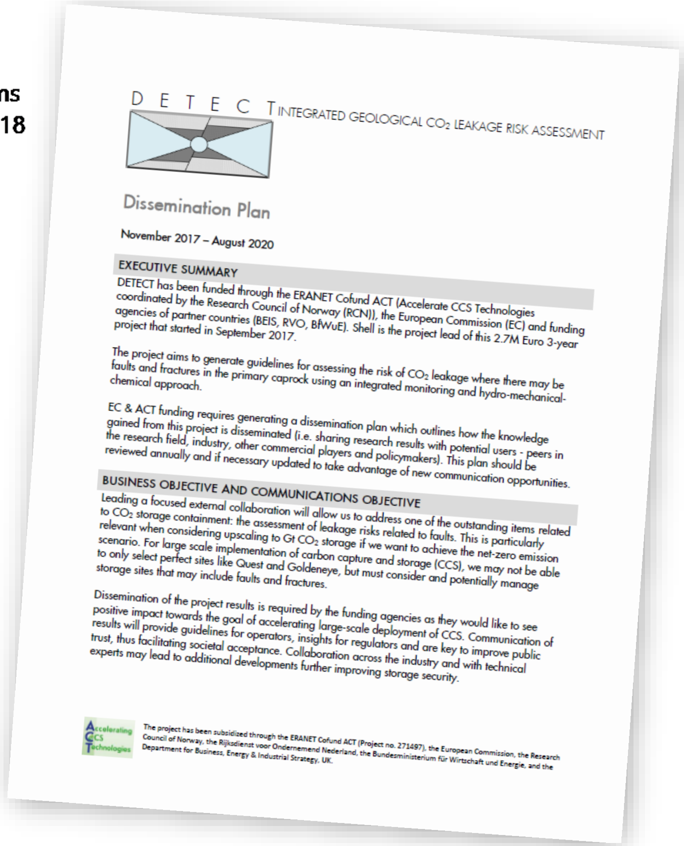
INTEGRATED GEOLOGICAL CO_2
LEAKAGE RISK ASSESSMENT

WP1 Project Management

Deliverables

- D1.1. Dissemination plan and (completed first edition)
- Traffic Light Reports 1-4 to RVO submitted on time, no major issues
- D1.2. First annual meeting report completed

DETECT Comms Plan March 2018


D E T E C T INTEGRATED GEOLOGICAL CO_2 LEAKAGE RISK ASSESSMENT

Dissemination Plan

November 2017 – August 2020

EXECUTIVE SUMMARY

DETECT has been funded through the ERANET Cofund ACT (Accelerate CCS Technologies coordinated by the Research Council of Norway (RCN)), the European Commission (EC) and funding agencies of partner countries (BEIS, RVO, BMWiE). Shell is the project lead of this 2.7M Euro 3-year project that started in September 2017.

The project aims to generate guidelines for assessing the risk of CO_2 leakage where there may be faults and fractures in the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach.

EC & ACT funding requires generating a dissemination plan which outlines how the knowledge gained from this project is disseminated (i.e. sharing research results with potential users - peers in the research field, industry, other commercial players and policymakers). This plan should be reviewed annually and if necessary updated to take advantage of new communication opportunities.

BUSINESS OBJECTIVE AND COMMUNICATIONS OBJECTIVE

Leading a focused external collaboration will allow us to address one of the outstanding items related to CO_2 storage containment: the assessment of leakage risks related to faults. This is particularly relevant when considering upscaling to Gt CO_2 storage if we want to achieve the net-zero emission scenario. For large scale implementation of carbon capture and storage (CCS), we may not be able to only select perfect sites like Quest and Goldeneye, but must consider and potentially manage storage sites that may include faults and fractures.

Dissemination of the project results is required by the funding agencies as they would like to see positive impact towards the goal of accelerating large-scale deployment of CCS. Communication of results will provide guidelines for operators, insights for regulators and are key to improve public trust, thus facilitating societal acceptance. Collaboration across the industry and with technical experts may lead to additional developments further improving storage security.

Workshops/Meetings

- **September 14th, 2017:** Kick-off meeting September 14th, 2017 at Shell Technology Centre Amsterdam
- **November 14th, 2017:** 1st bowtie/Integration workshop in at Risktec in Manchester
- **April 17-18, 2018:** 2nd bowtie/Integration workshop and first SAB meeting at Heriot-Watt University in Edinburgh
- **January 21-22, 2019:** Planned Integration workshop in Aachen

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

DETECT

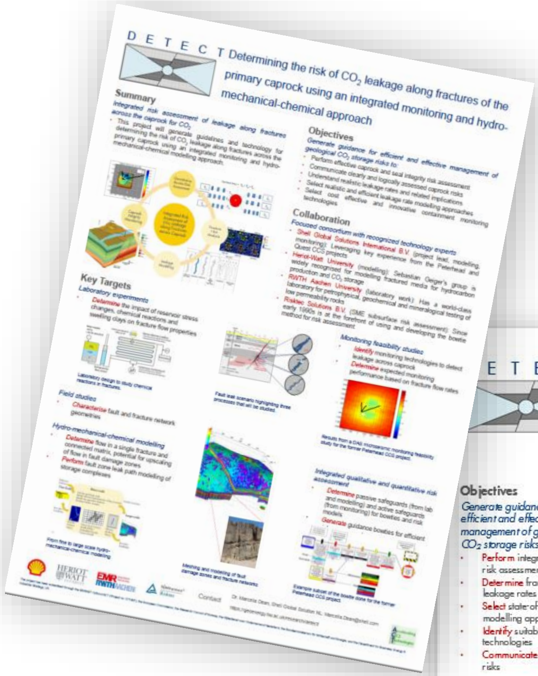
INTEGRATED GEOLOGICAL CO_2 LEAKAGE RISK ASSESSMENT

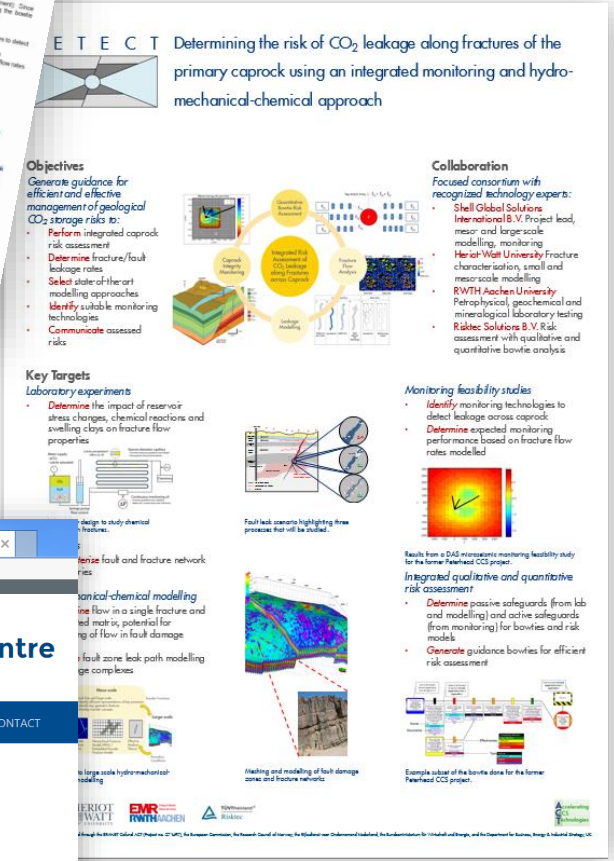
WP1 Project Management

Dissemination Activities

Workshops/Industry Conferences

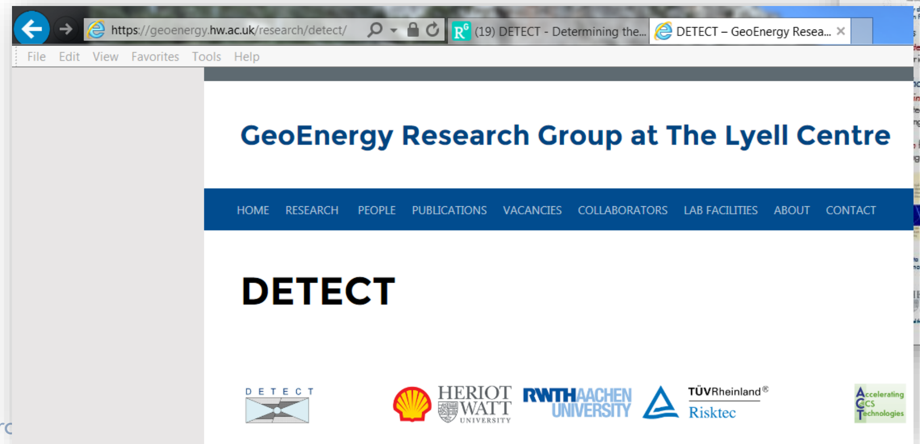
- Marcella Dean (Shell) ACT knowledge sharing workshop (October 24th, 2017, Bucharest)
- EERA-CCS Joint Program Steering Committee meeting
- Andreas Busch, Stephanie Zihms (HW) poster at the EGU meeting (April 12th 2018, Vienna)
- Florian Doster (HW) talk at PROTECT workshop (April 2018, Geilo, Norway)
- Marcella Dean (Shell) year1 poster: 1) at GHGT-14, 2) at Curtin University and CSIRO; 3) at Shell Geophysics Conference
- Niko Kampman and Kevin Bisdom (Shell) will present at EAGE CO2 Storage Workshop in Utrecht 21-23 November 20018





Online Presence

- DETECT page on Research Gate website:
  ResearchGate 371 READS!
- DETECT website via HWU website:
  https://geoenergy.hw.ac.uk/research/detect/
- Press release on DETECT by HWU in January 2018

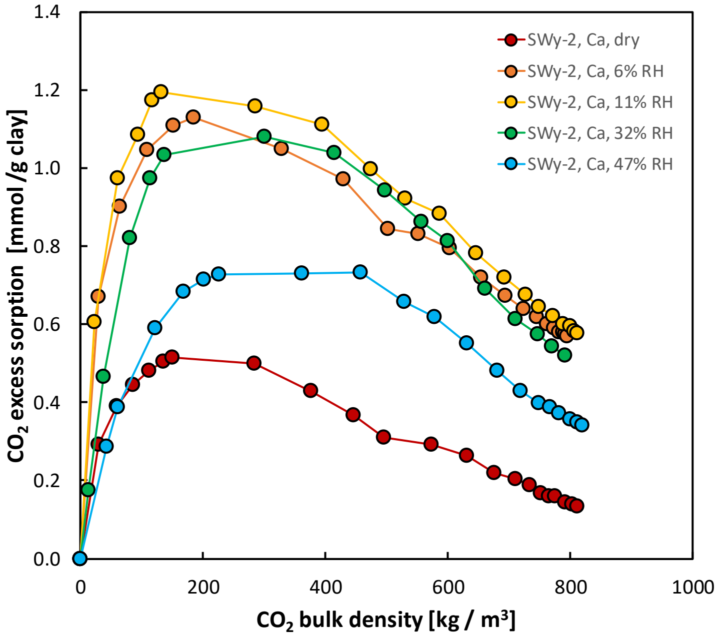


The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the Eurc
Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

DETECT
INTEGRATED GEOLOGICAL CO_2
LEAKAGE RISK ASSESSMENT

WP2 – Fracture Flow, Mineralisation, Clay Swelling

3



The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

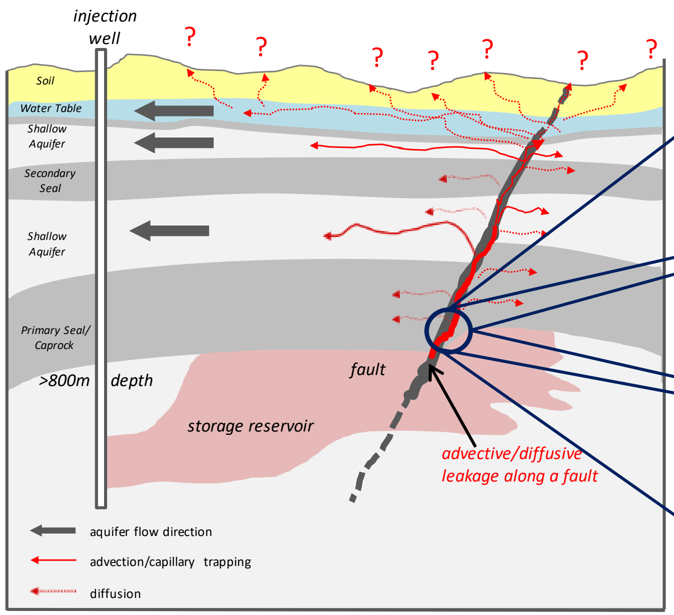
Accelerating CCS Technologies

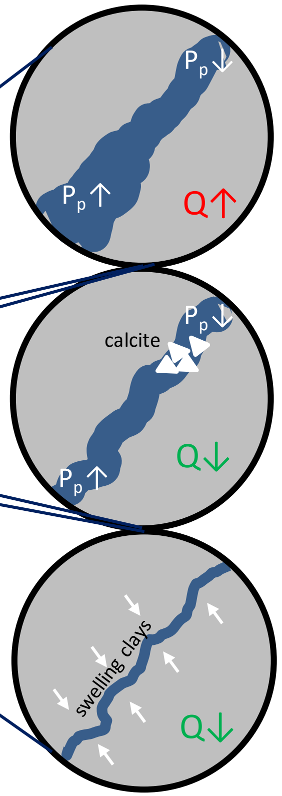
WP2 Lead: Andreas Busch, HWU

WP2 – Fracture Flow, Mineralisation, Clay Swelling

WP2 will test sensitivities of leakage rates along fracture networks or fault damage zones to fluid pressure, chemistry, mineral reaction rates, saturation changes and effective stress changes to generate the necessary input parameter for leakage modelling in WP3.

- **Objectives**
  - Identify and analyse factors controlling fracture flow as a function of temperature, pore pressure, confining stress, mineralogy or strength parameters
  - Significantly improve fundamental understanding of the impact of CO_2 induced expansion of swelling clays in fractures
  - Determine effects of CO_2-induced water-rock interactions on transport through fractures
- **Collaboration**
  - Heriot-Watt University, RWTH Aachen University, Shell IRD





Fault leak scenario highlighting three processes that will be studied.

WP2.T1. Fracture Flow: stress-permeability relations

WP2.T2. Mineralisation: mineralisation in fractures

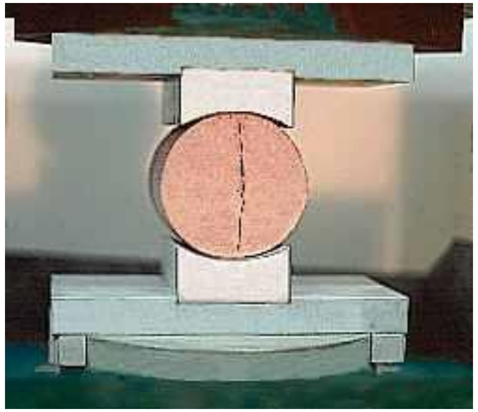
WP2.T3. Clay Swelling: clay swelling affecting fracture apertures

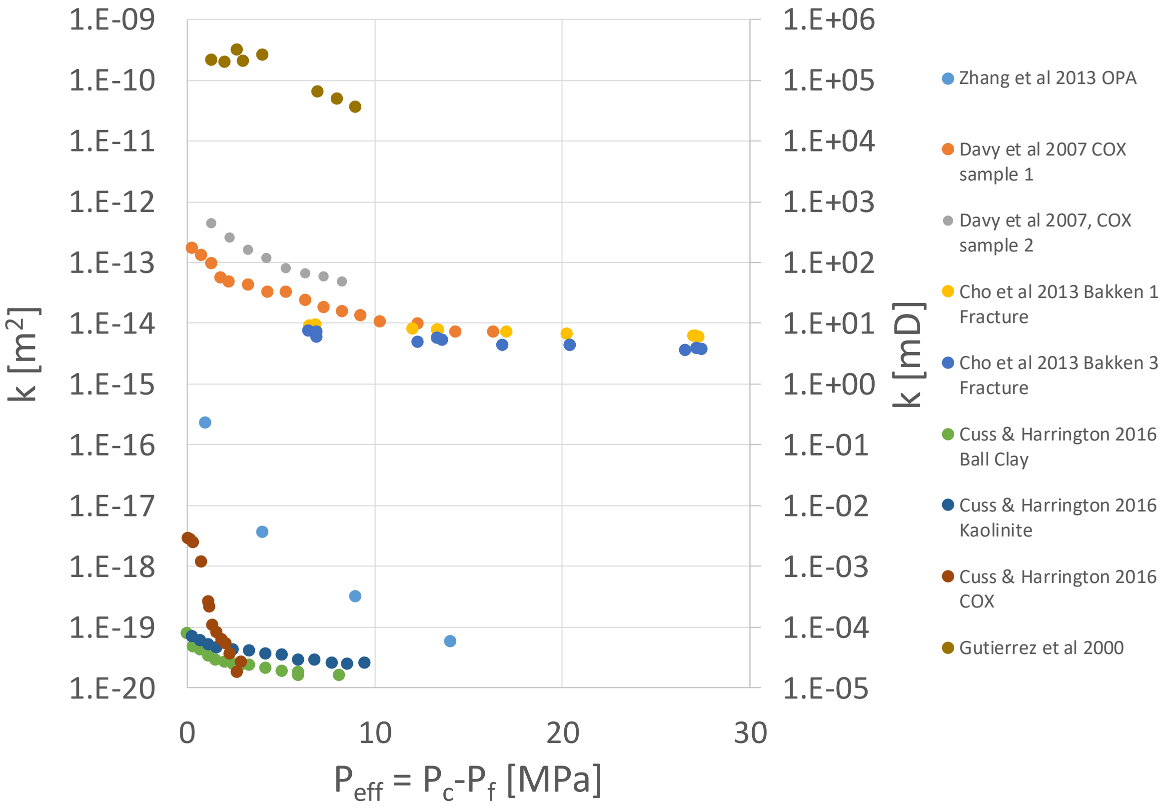
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

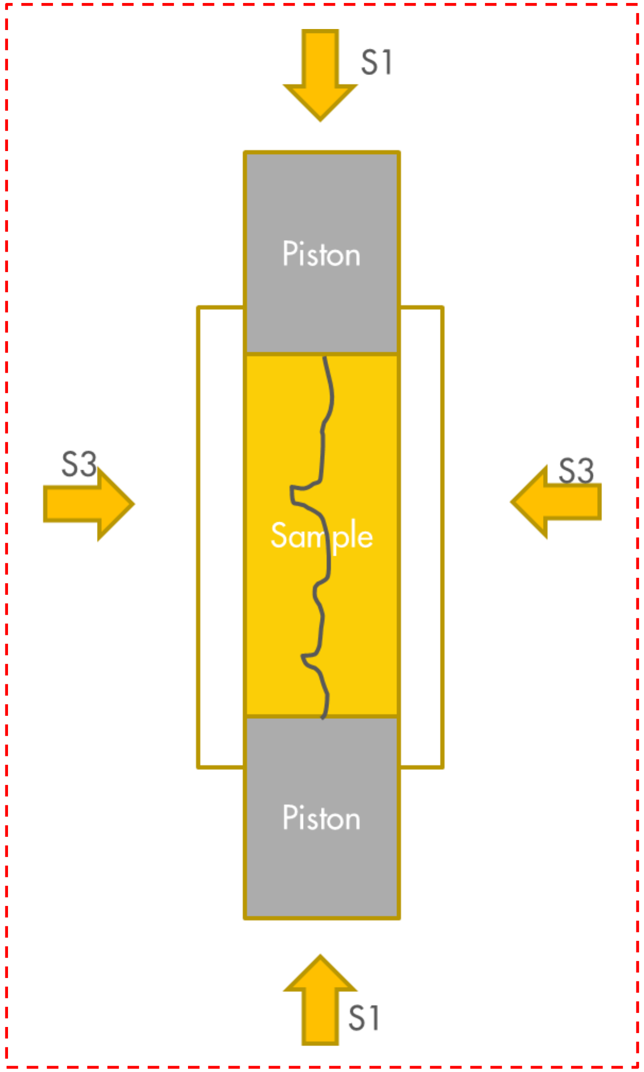
WP2 – Fracture Flow, Mineralisation, Clay Swelling

T2.1. Fracture Flow Experiments Isotropic and triaxial cell measurements of brine and CO_2 flow in fractured mudrocks as a function of effective stress

- Parameterize stress-perm relationships for numerical simulations

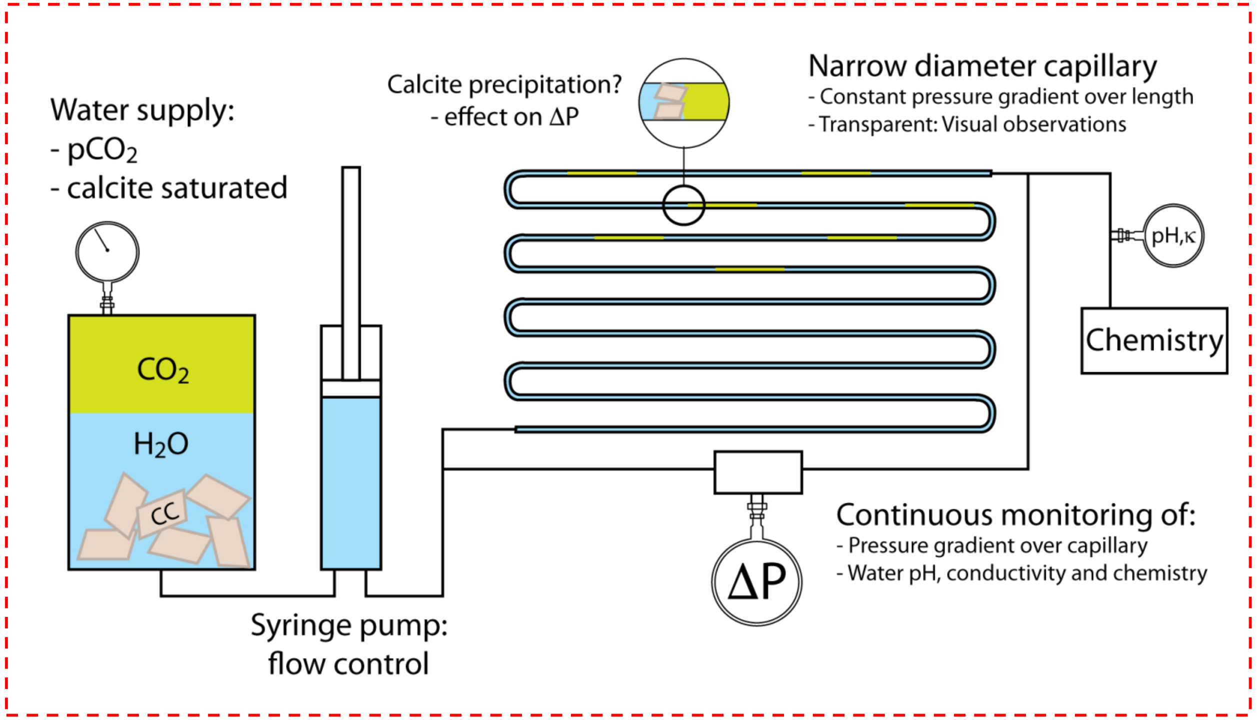






The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP2 – Fracture Flow, Mineralisation, Clay Swelling

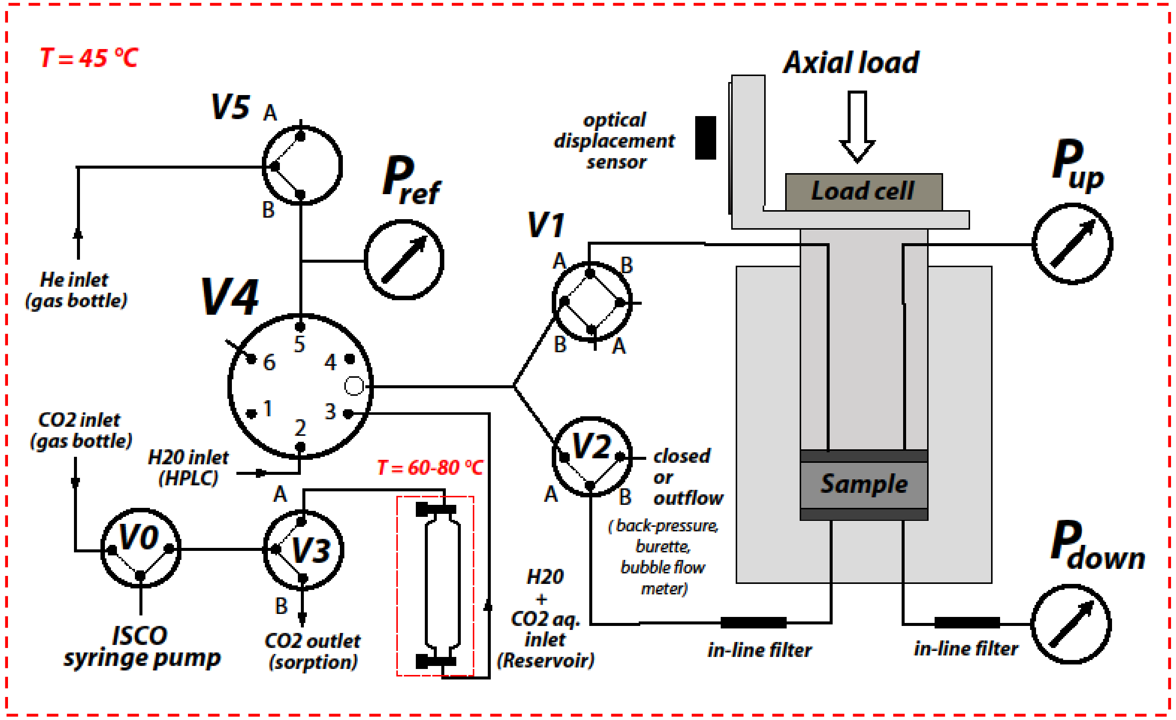


T2.2. Mineralisation Experiments

Study impact of CO_2 promoted corrosion and mineralization on fracture self sealing behaviour.

- Understand controls on mineralisation (e.g. nucleation, saturation)

Critical supersaturation required for precipitation (nucleation)



T2.3. Clay Swelling Experiments

Study effect of CO_2 promoted clay swelling on fluid transport in smectitic mudrocks.

- What parameters control CO_2 swelling?

Flow rate = f(sample composition, fluid phase, pressure, temperature)

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

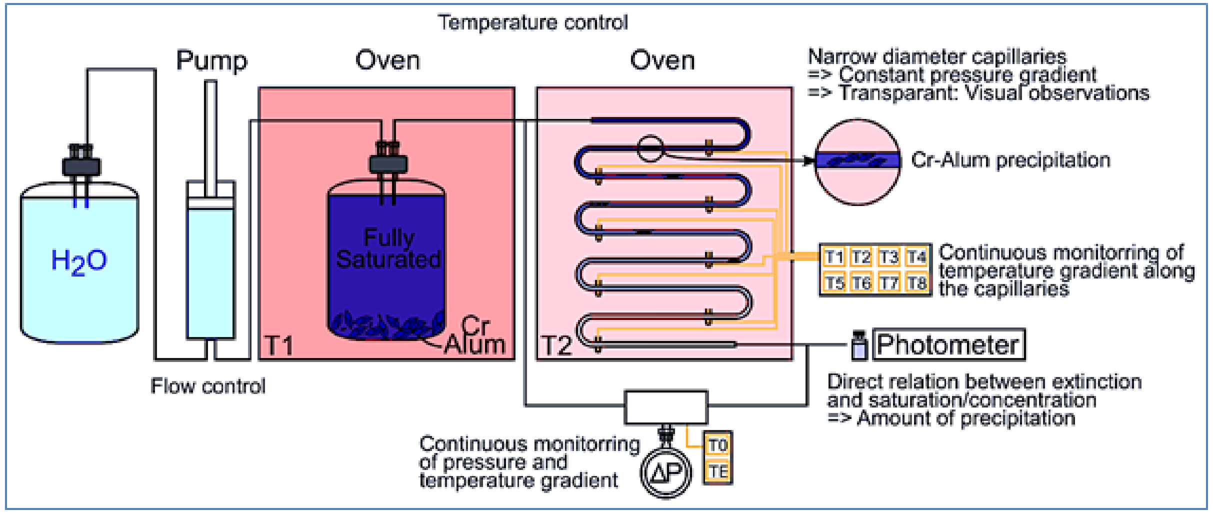
WP2 – Status 1st November 2018

Status

T2.1: Fracture Flow Experiments on track

Triaxial cell delivered; currently setup and testing.

All testing samples identified, and samples collected from most case studies

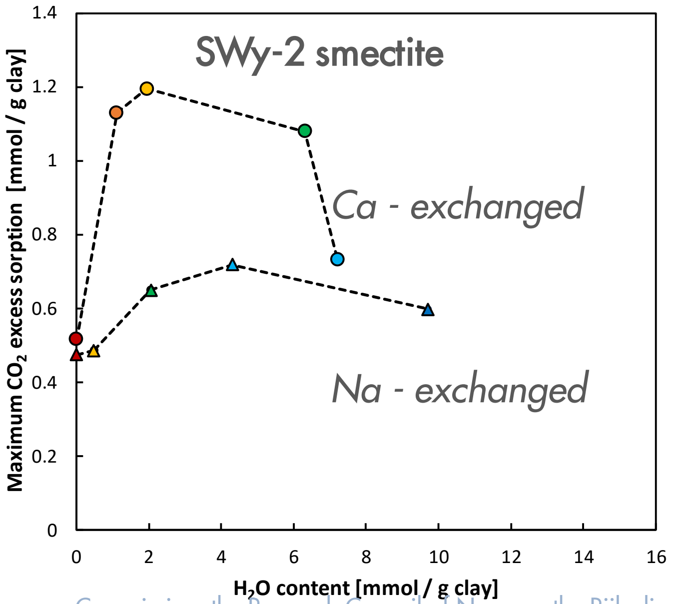


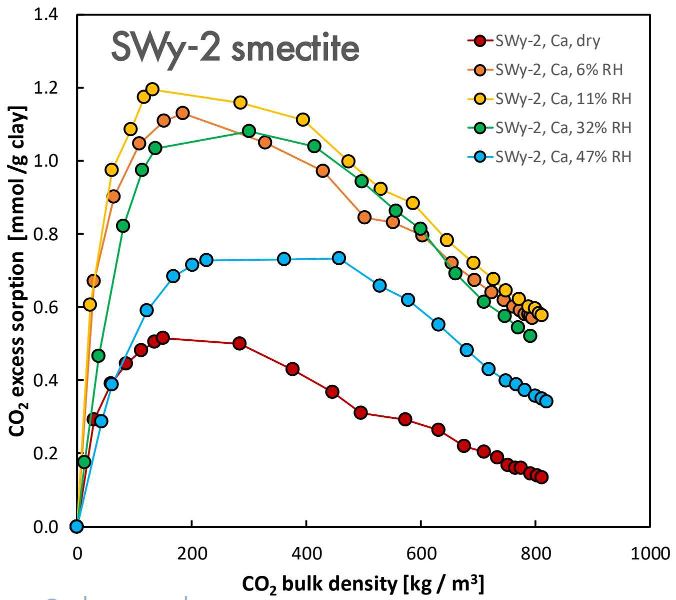
T2.2: Mineralisation Experiments on track

Phase One capillary experimental set-up built and experiments on-going

T2.3: Clay Swelling Experiments on track

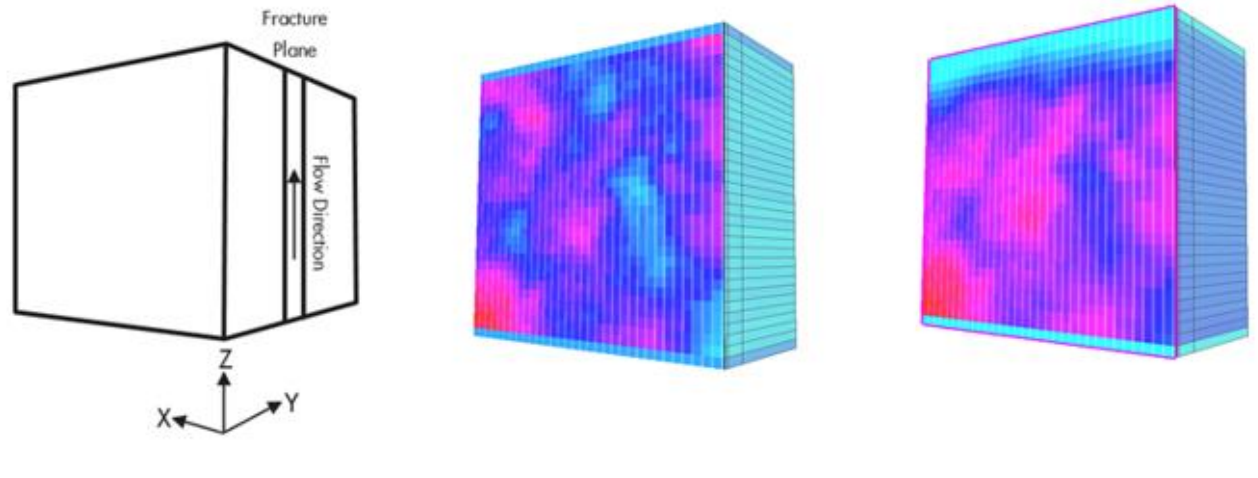
CO_2 sorption as a function of water content finished, experimental set-ups for flow measurements built and experiments underway





The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP3 – Fracture Characterisation and Modelling



Fracture geometry Original aperture map Calcite precipitation map

4

DETECT
INTEGRATED GEOLOGICAL CO_2 LEAKAGE RISK ASSESSMENT

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

Accelerating CCS Technologies

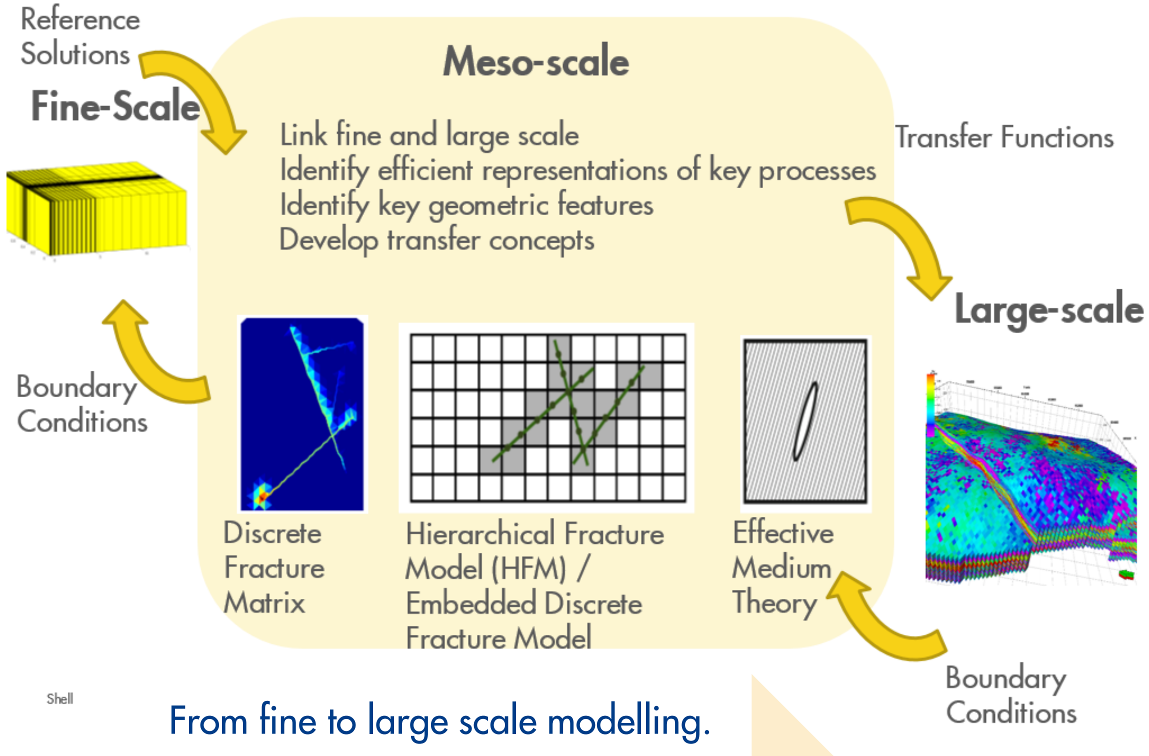
WP3 – Fracture Characterisation and Modelling

WP3 will characterise 2D/3D fracture network pattern for flow modelling. It will also perform innovative hydro-mechanical-chemical CO_2 and brine leakage modelling at fine-scale, meso-scale and large-scale. Results inform WP4 and WP5.

- **Objectives**

1. Develop and apply a predictive modelling workflow for realistic CO_2 and brine leakage rates along realistic fault/fracture damage zones through the primary caprock and continuing into shallower formations
2. Incorporating effects on fracture aperture of mineral dissolution/precipitation and clay swelling

- **Collaboration**
  - Shell IRD, Heriot-Watt University, University of Cambridge



From fine to large scale modelling.

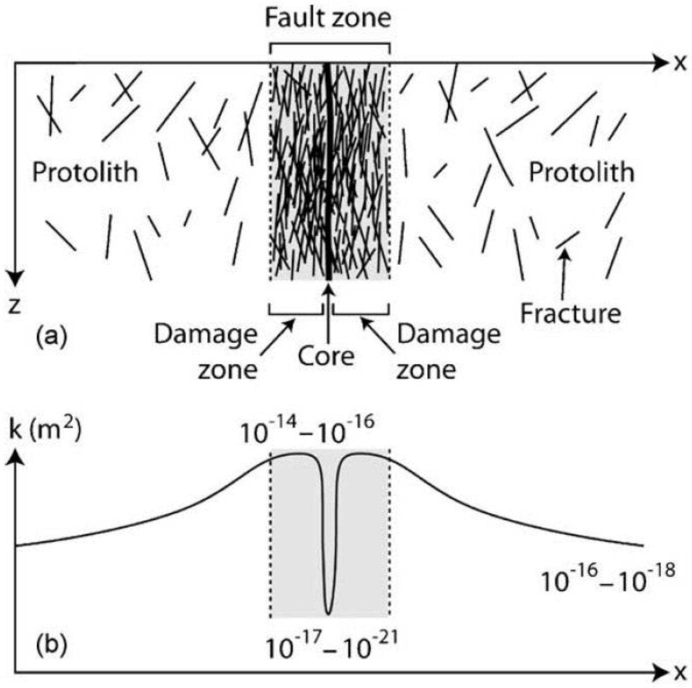
WP3.T1. 2D/3D fracture network pattern characterisation for flow modelling	WP3.T2. Fine-scale modelling of flow in a single facture and connected matrix	WP3.T3. Meso-scale modelling and upscaling of flow in fault damage zones	T3.4. Large-scale fault zone leak path modelling of storage complexes

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP3 – Fracture Characterisation and Modelling

T3.1. 2D/3D fracture network pattern characterisation (HWU)

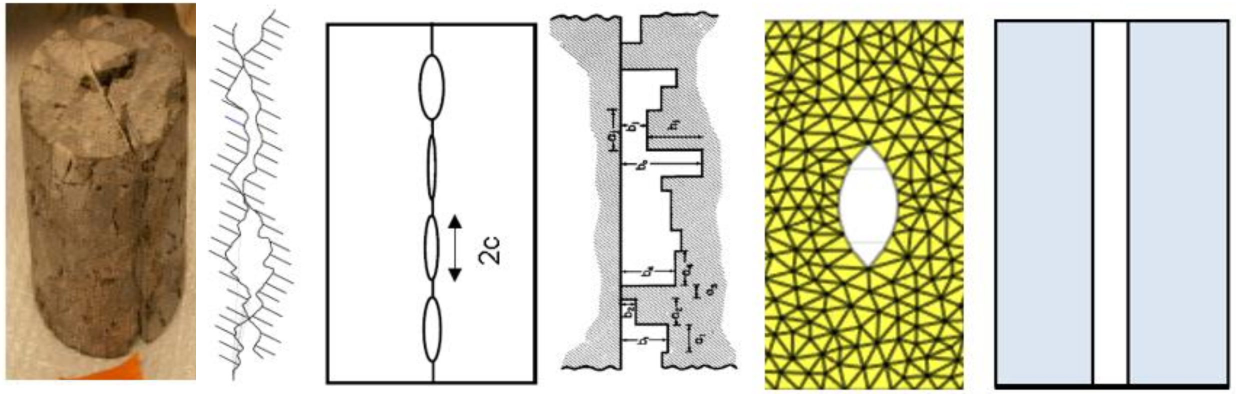
Establish database for fault attributes and map fault damage zones for flow modelling



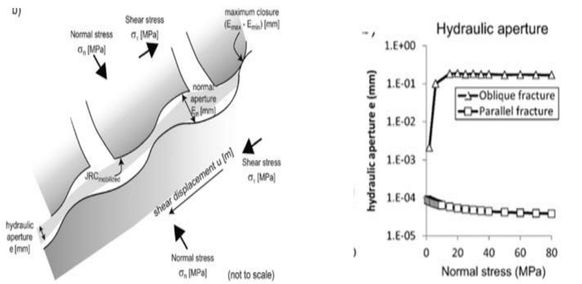
T3.2. Fine-scale modelling of flow in a single fracture and connected matrix (HWU)

Implementation of the constitutive stress-fracture permeability relations derived from laboratory experiments into fine-scale hydro-mechanical model for single fractures considering RTM and clay swelling

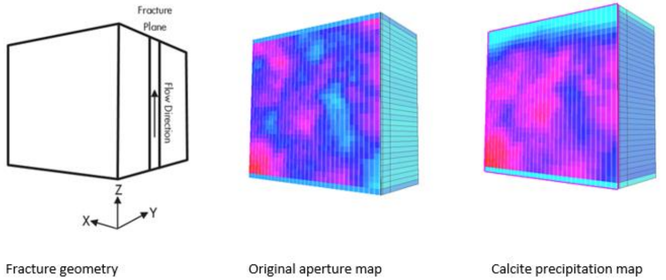
Fracture roughness representations



Flow-stress impact



Reactivity impact

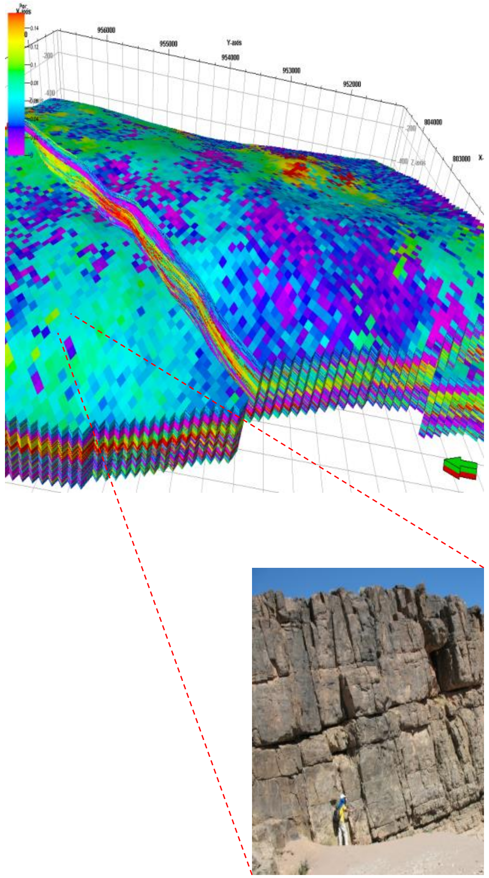


The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP3 – Fracture Characterisation and Modelling

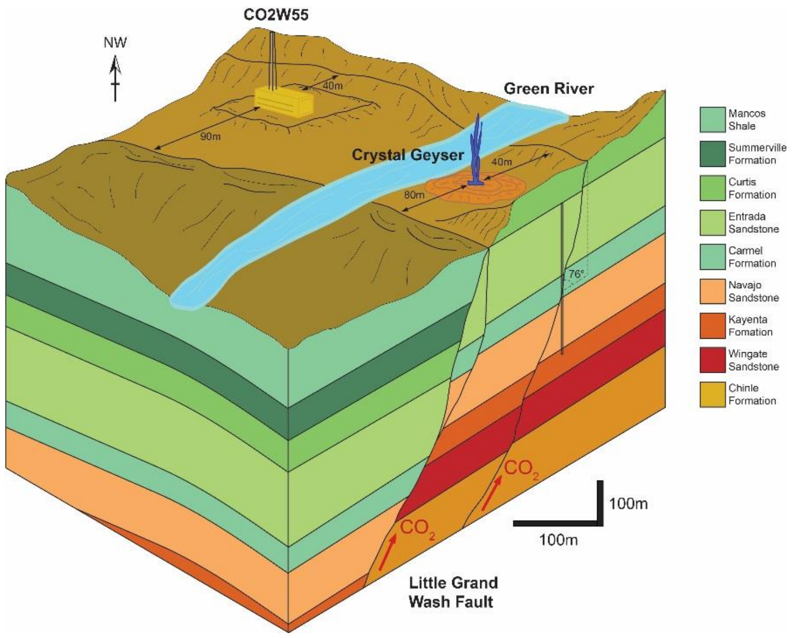
T3.3. Meso-scale modelling and upscaling of flow in fault damage zones (HWU)

Meshing and modelling of fault damage zones and fracture networks to simulate flow of CO_2 through fractured and faulted caprock



T3.4. Large-scale fault zone leak path modelling of storage complexes (Shell)

Modelling of CO_2 and brine flow in fault/fracture systems in storage complexes



The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP3 status 1st November 2018

Status

T3.1.: Fracture network pattern characterisation, sample collection and experiments on track

Close working relationship WP2-WP3 to design experiments that will constrain the models

T3.2 – T3.4: Integrated fine-scale to large-scale modelling workflow design completed

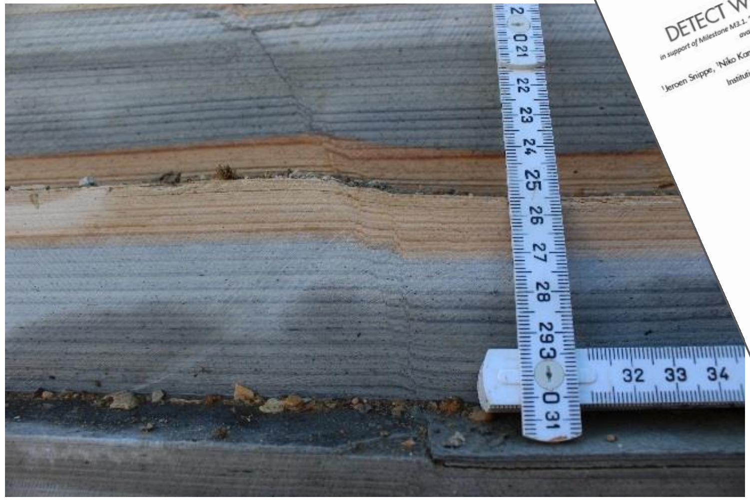
Agreement on representation of all considered physical-chemical processes at all three model scales

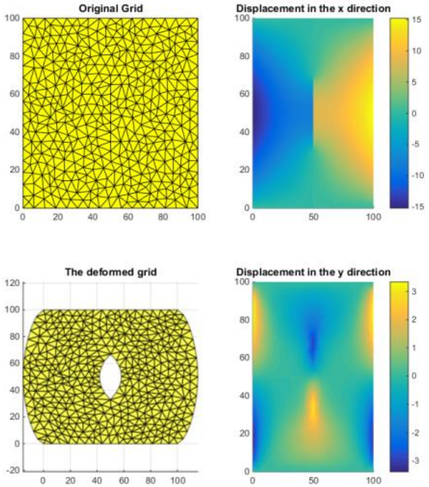
Model implementation on track

Working models at all scales. Physical-chemical processes and realistic fracture geometries gradually being included

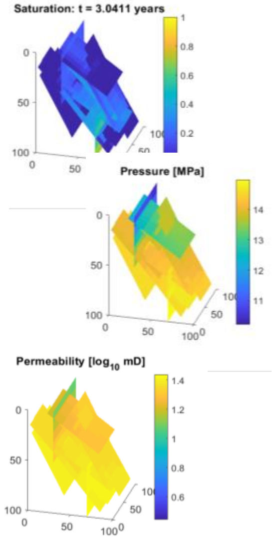
Close interaction with Risktec (WP5)

Ensure consistency with quantitative risk assessment models

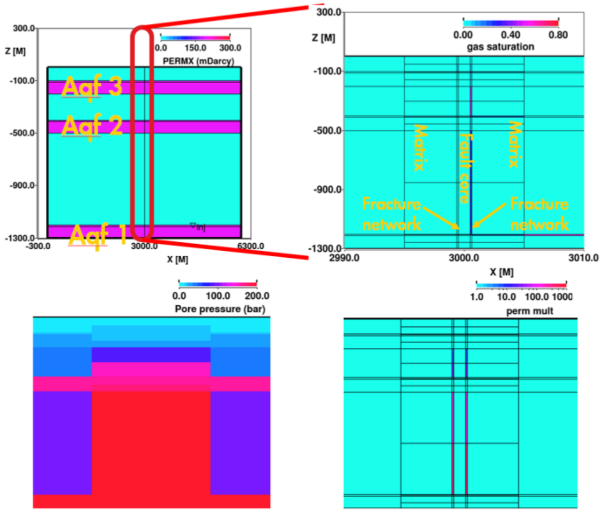




Fine



Meso

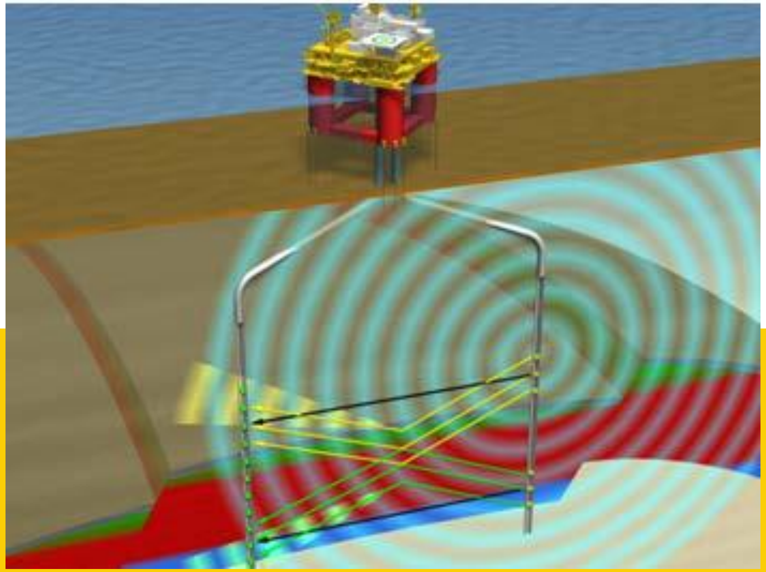


Large

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP4 – Containment Monitoring for Caprock Integrity

5



The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

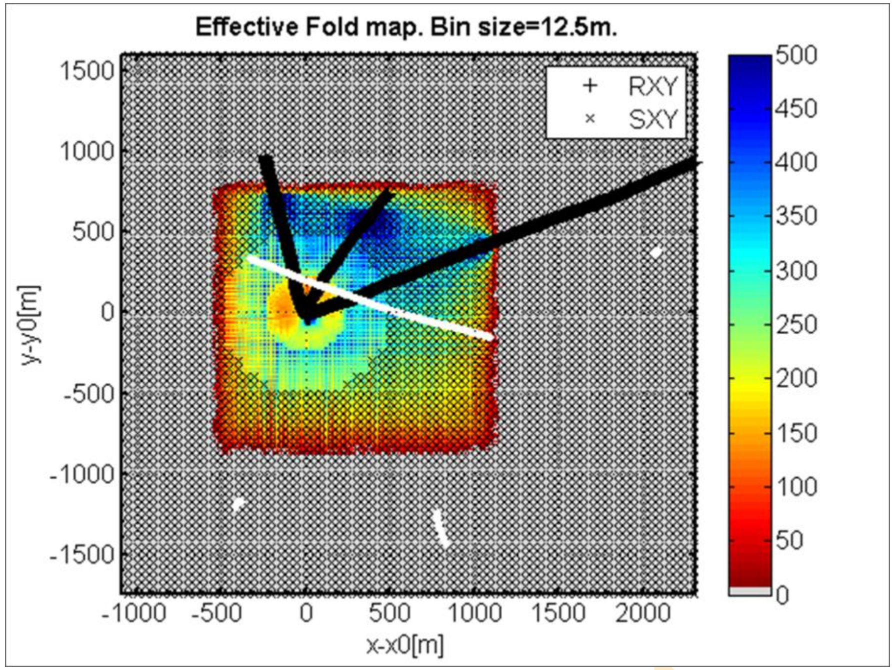
WP4 – Containment Monitoring for Caprock Integrity

WP4 will select cost-efficient and effective caprock monitoring technologies which will be incorporated as active safeguards in bowties and quantitative risk assessment models (WP5).

- **Objectives**

1. Identify which containment monitoring technologies can act as effective and efficient barriers to the risks posed by CO_2 leakage along fractures of the caprock
2. Give a comprehensive overview of selected containment monitoring technologies with their respective detection threshold ranges for a number of investigated leakage path scenarios

- **Collaboration**
  - Shell IRD, Risktec, CaMI.FRS, Otway Project



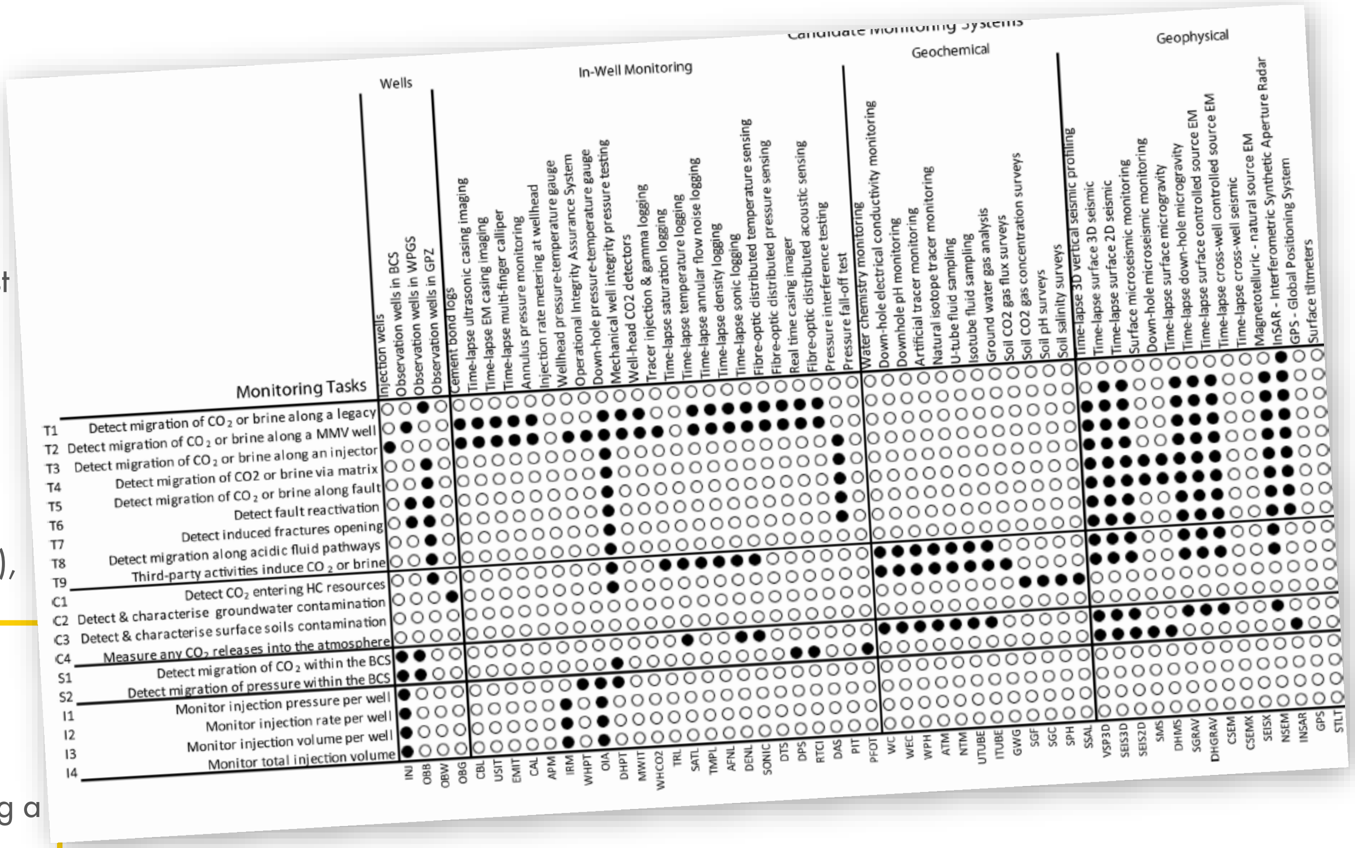
Goldeneye DAS VSP feasibility study.

- WP4.T1 Overview of relevant containment monitoring technologies
- WP4.T2 Identify monitoring technologies suitable to detect leakage across caprock
- WP4.T3 Perform feasibility studies for selected monitoring technologies
- WP4.T4 Identify detection thresholds based on results from T3 and other WPs
- WP4.T5 Incorporate results as active safeguards in bowtie with WP5

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP4 – Overview of Tasks

- **T4.1:** Overview of relevant containment monitoring technologies
  - Draw on literature and the internal experience from the MMV of the Quest and Peterhead CCS projects. Overview ready for bowtie workshop
- **T4.2:** Identify monitoring technologies suitable to detect leakage across caprock
  - Reduce the list of potential technologies based on leakage scenarios, the potential to perform the required monitoring tasks (resolution, space, time), technology readiness, innovation, cost
- **T4.3.** Perform feasibility studies for selected monitoring technologies
  - Shortlisted CMTs will then undergo individual feasibility studies considering a number of different leakage scenarios across the caprock
- **T4.4.** Compare Modelled Fracture Flow Rates and Expected Monitoring Performance
  - Compare realistic leakage rates from WP2&3 with monitoring sensitivities to determine detection threshold ranges



- **T4.5.** Incorporate results as active safeguards in bowtie with WP5
  - Incorporate safeguards in project risk assessment

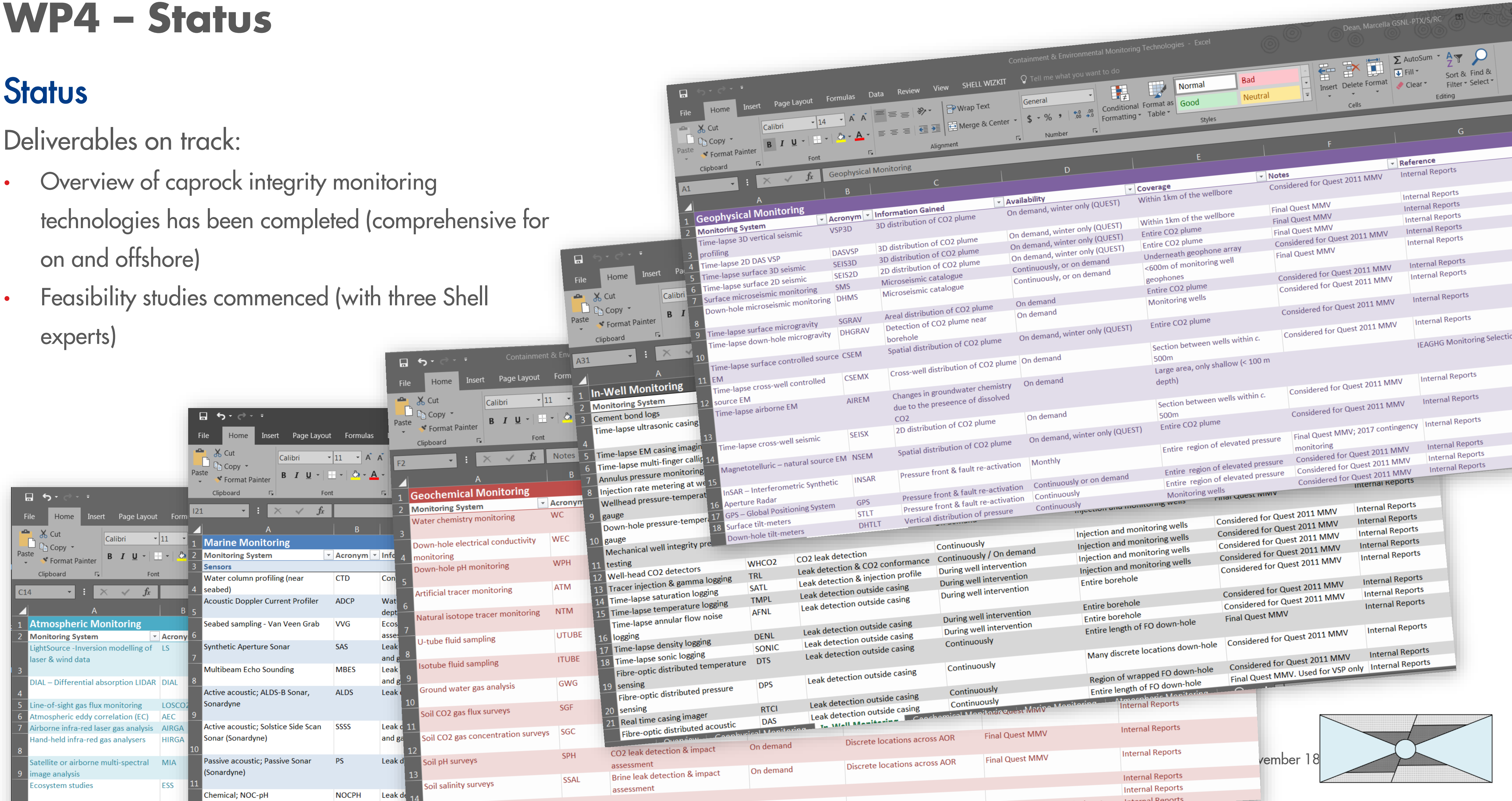
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP4 – Status

Status

Deliverables on track:

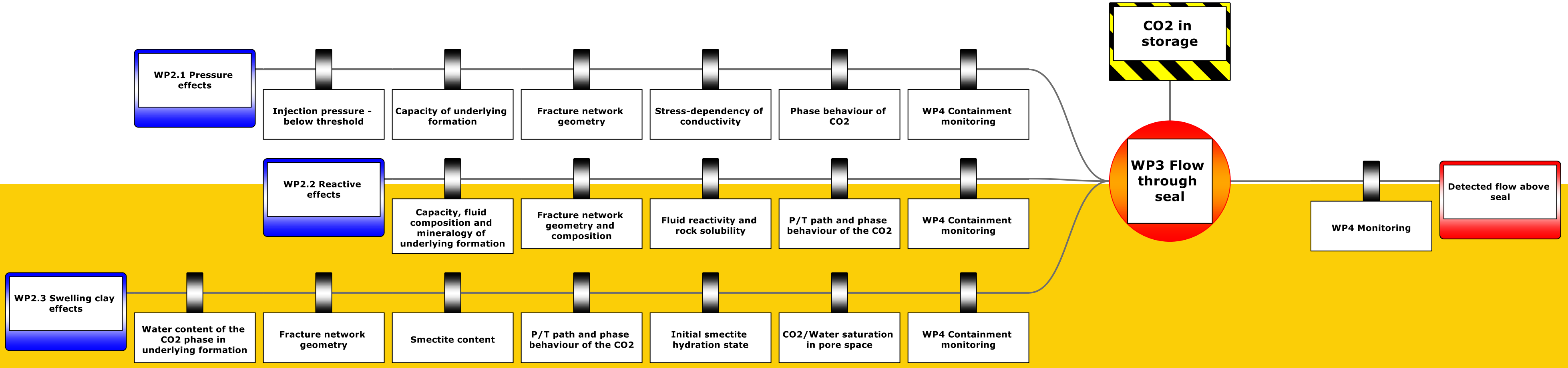
- Overview of caprock integrity monitoring technologies has been completed (comprehensive for on and offshore)
- Feasibility studies commenced (with three Shell experts)



D E T E C T

INTEGRATED GEOLOGICAL CO_2
LEAKAGE RISK ASSESSMENT

WP5 – Qualitative and Quantitative Risk Assessment



6

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

Accelerating CCS Technologies

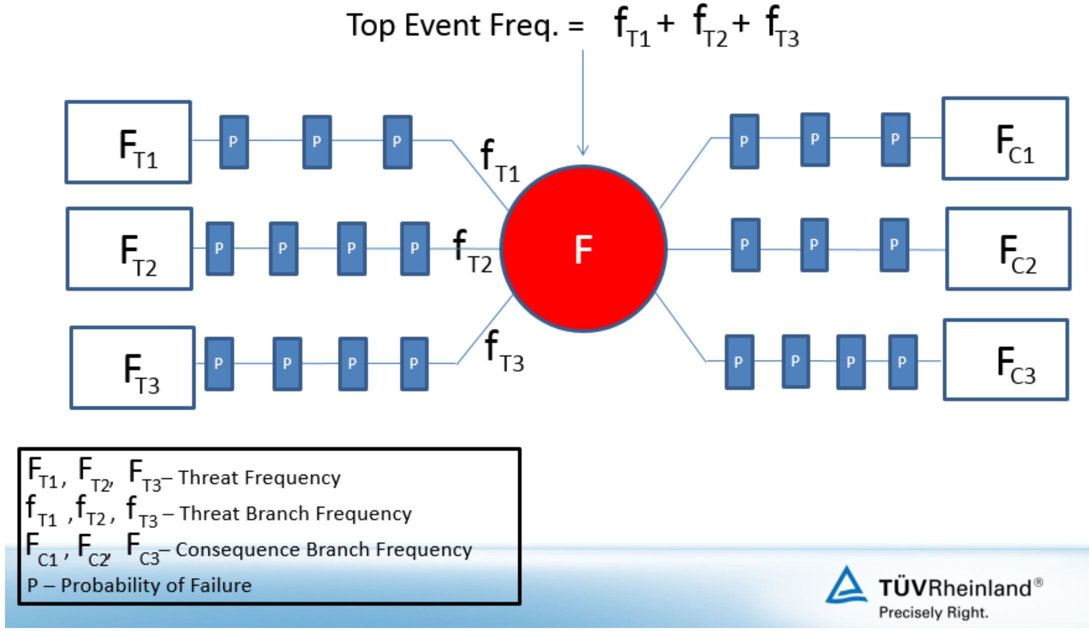
WP5 – Qualitative and Quantitative Risk Assessment

WP5 will integrate learnings from DETECT into qualitative and quantitative bowties to serve as an industry guideline for risk assessment of CO_2 leakage across fractures in the caprock.

- **Objectives**

1. To develop bowtie diagrams depicting the natural pathways for CO_2 release from subsurface storage and the measures in place to prevent/mitigate the risk
2. To develop a quantitative risk assessment model aligned to the bowtie, using output from the other WPs to determine prevention/mitigation measure effectiveness
3. To calculate relative risks of CO_2 leaking through caprock, enabling the model to be used for future site comparison/screening purposes

- **Collaboration**
  - Risktec (TÜV Rheinland Group), Shell IRD (build on learnings from Peterhead and Quest CCS projects)



An example of a semi-quantitative risk analysis model.

WP5.T1. Identify suitable quantitative bowties risk analysis models

WP5.T2. Bowtie risk assessment for different leakage scenarios

WP5.T3. Quantitative risk analysis for different leakage scenarios

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP5 – Overview of Tasks

- **T5.1: Identify suitable bowties and risk analysis models**
    - Draw on literature and experience from the Quest and Peterhead CCS projects.
- **T5.2: Bowtie risk assessment for different leakage scenarios**
    - Collaborate with other WPs to build qualitative bowtie diagrams, to describe the various leak paths and the prevention and mitigation measures expected to be in place
- **T5.3: Quantitative risk analysis for different leakage scenarios**
    - Create a quantitative model, aligned with the bowtie analysis, to predict relative risk associated with leak paths

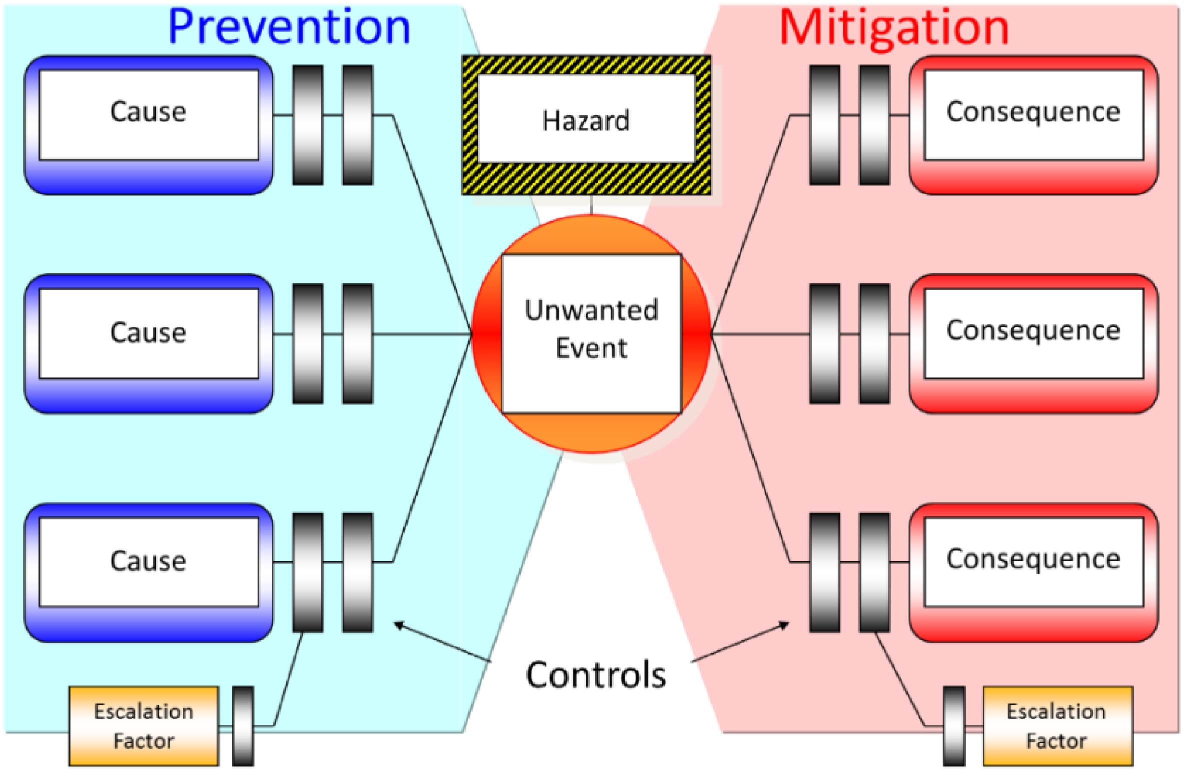


Illustration of bowtie risk assessment.

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

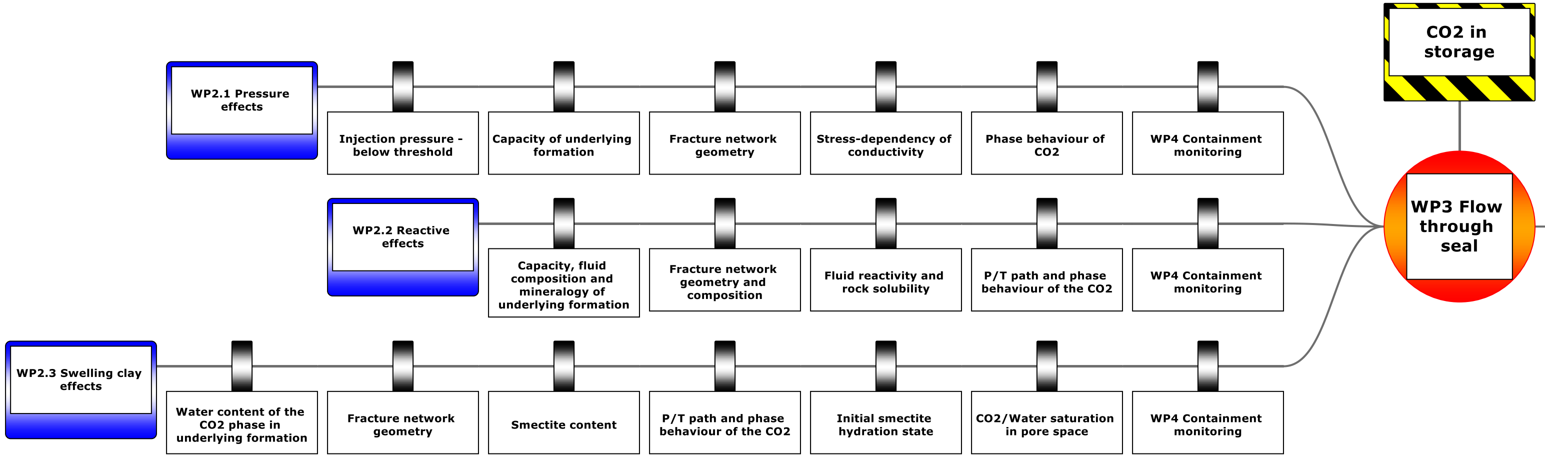
WP5 status 1st November 2018

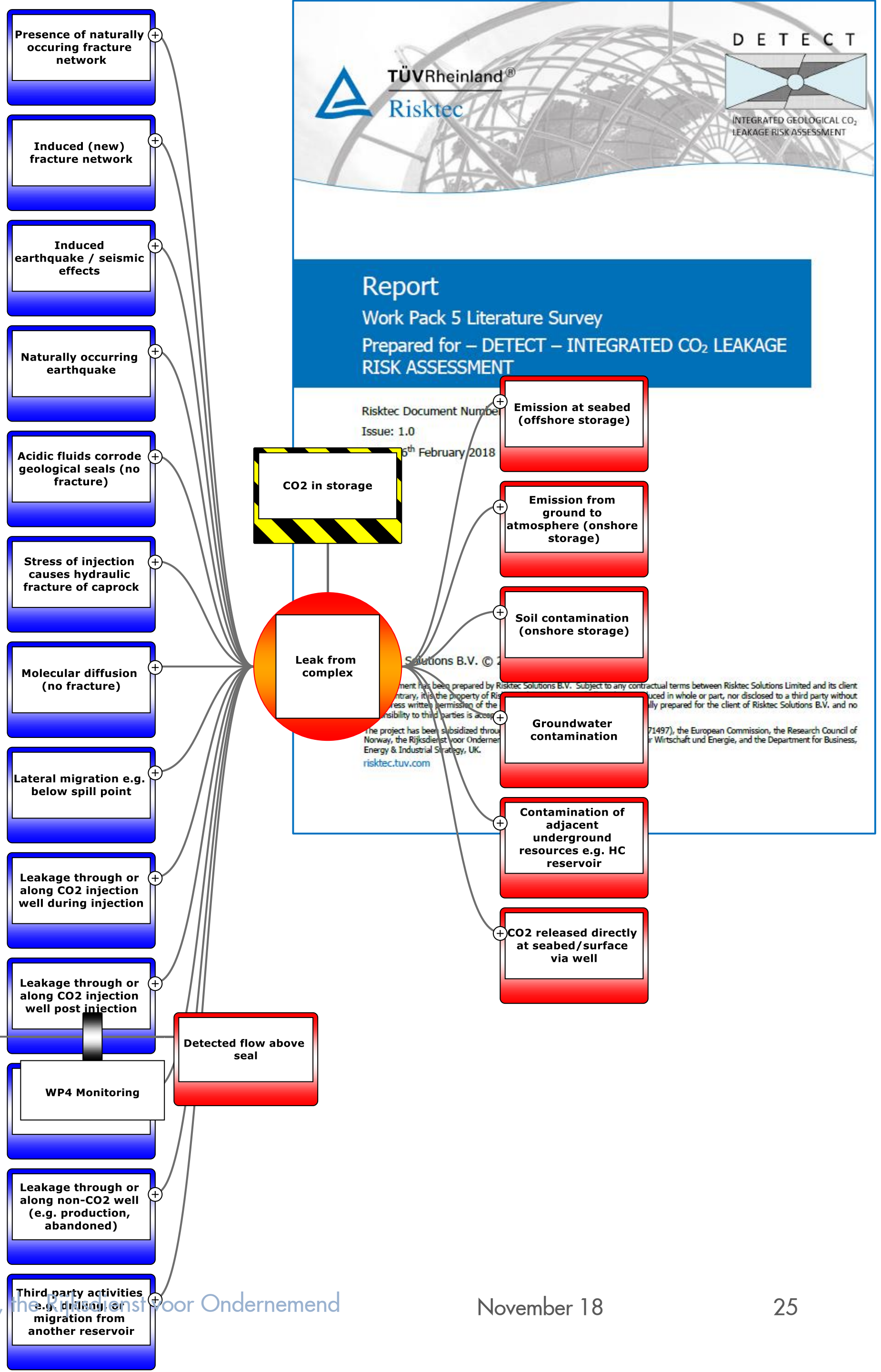
Status

T5.1: Literature review report issued

T5.2: Outline overarching (motherhood) bowtie developed at first bowtie workshop (November 2017)

- Detailed (daughter) bowtie reflecting mechanisms influencing leakage via faults/fractures developed at second bowtie workshop (April 2018)
- Currently working on completing prevention and mitigation measures on draft motherhood bowtie for early 2019





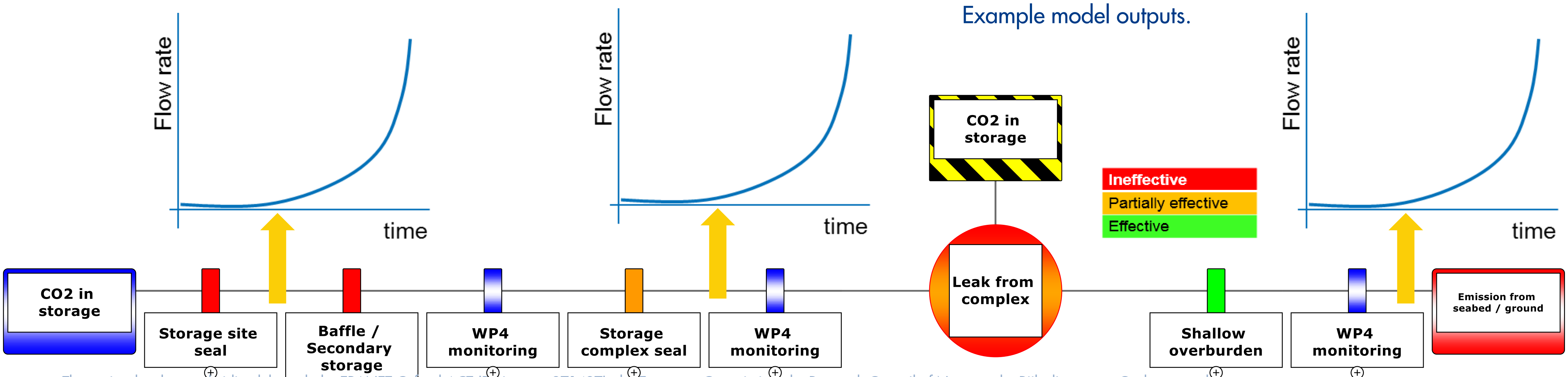
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

WP5 status 1st November 2018

Status

T5.3: Following on from literature review, investigation of existing quantitative models conducted e.g. MoReS, NRAP

- Key input and output parameters confirmed during bowtie workshops
- Draft specification developed for quantitative model
- Intent is that model will give risk values for candidate CO_2 storage sites based on key input parameters



The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.