D E T E C T

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

## ACT Knowledge Sharing Workshop
## Bucharest, Rumania 2017

Project Overview

Shell: **Marcella Dean,** Project Manager & WP4 Lead, Jeroen Snippe, WP3 Lead

Heriot Watt University: Andreas Bush, WP2 Lead

RWTH Aachen University: Pieter Bertier

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

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

DETECT

INTEGRATED GEOLOGICAL $CO_2$ LEAKAGE RISK ASSESSMENT

# DETECT Project

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**Overview, Objectives, Collaboration Partners, Key Targets, Project Structure**

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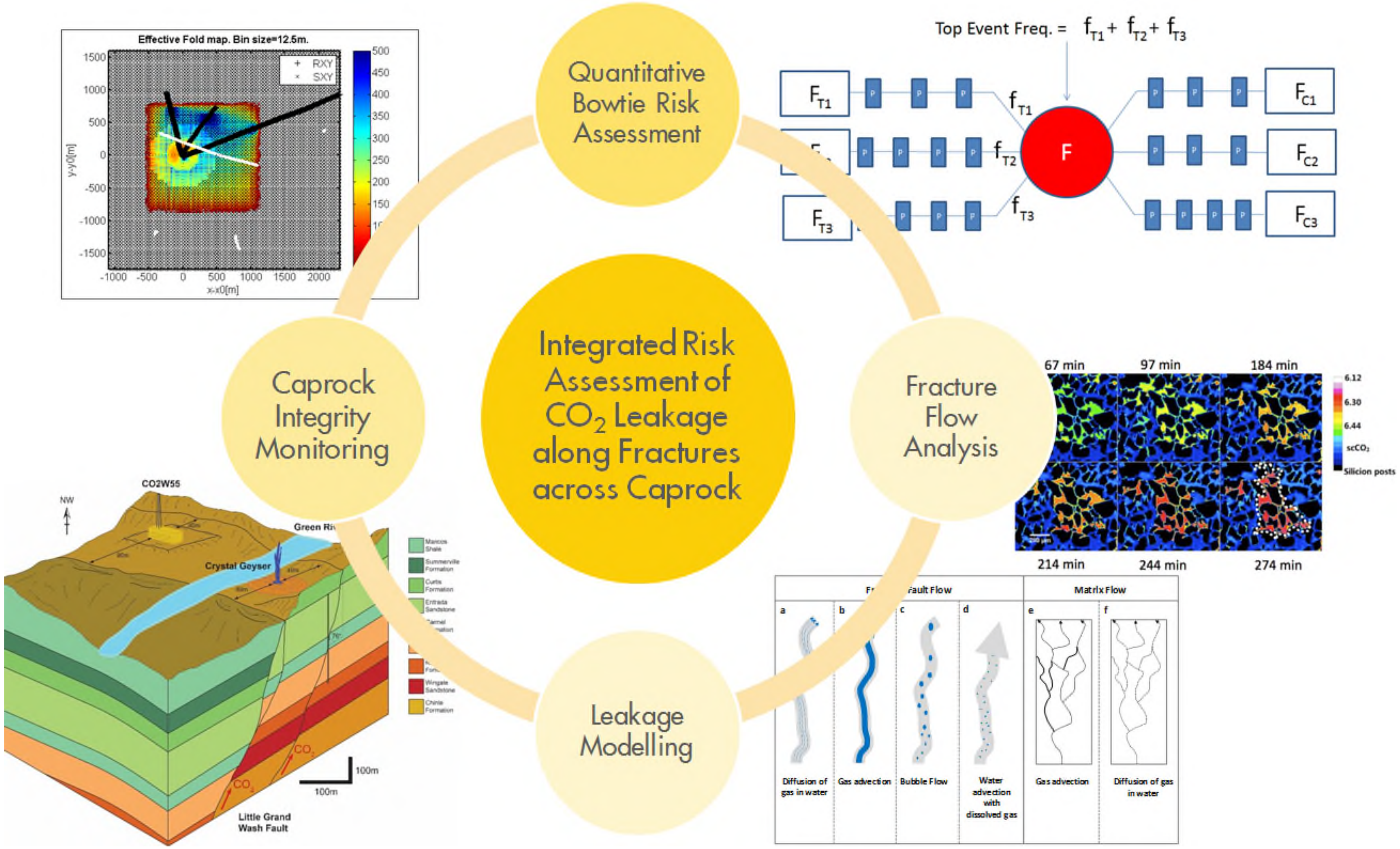
# DETECT Determining the risk of $CO_2$ leakage along fractures of the primary caprock using an integrated monitoring and hydro-mechanical-chemical approach

## Overview

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

## Objectives

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

## Collaboration

- **Focused consortium with recognized technology experts**
  - **Shell** (project lead, modelling, monitoring): Leveraging key experience from the Peterhead and Quest CCS projects
  - **Heriot-Watt** (modelling): Sebastian Geiger's group is widely recognised for modelling fractured media for hydrocarbon production and $CO_2$ storage
  - **RWTH Aachen University** (laboratory work): Has a world-class laboratory for petrophysical, geochemical and mineralogical testing of low permeability rocks
  - **Risktec Solutions** (SME subsurface risk assessment): Since early 1990s is at the forefront of using and developing the bowtie method for risk assessment

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

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INTEGRATED GEOLOGICAL $CO_2$ LEAKAGE RISK ASSESSMENT

## Key Targets

- **Laboratory experiments**
  - **Determine** the impact of reservoir stress changes, chemical reactions and swelling clays on fracture flow properties
- **Field studies**
  - **Characterise** fault and fracture network geometries
- **Hydro-mechanical-chemical modelling**
  - **Determine** flow in a single fracture and connected matrix, potential for upscaling of flow in fault damage zones
  - **Perform** fault zone leak path modelling of storage complexes
- **Monitoring feasibility studies**
  - **Identify** monitoring technologies to detect leakage across caprock
  - **Determine** expected monitoring performance based on fracture flow rates modelled
- **Integrated qualitative and quantitative risk assessment**
  - **Determine** passive safeguards (from lab and modelling) and active safeguards (from monitoring) for bowties and risk models
  - **Generate** guidance bowties for efficient risk assessment
- **Dissemination**
  - **Ensure** long-term relevance of outputs

Monitoring well at the Quest $CO_2$ Storage site.

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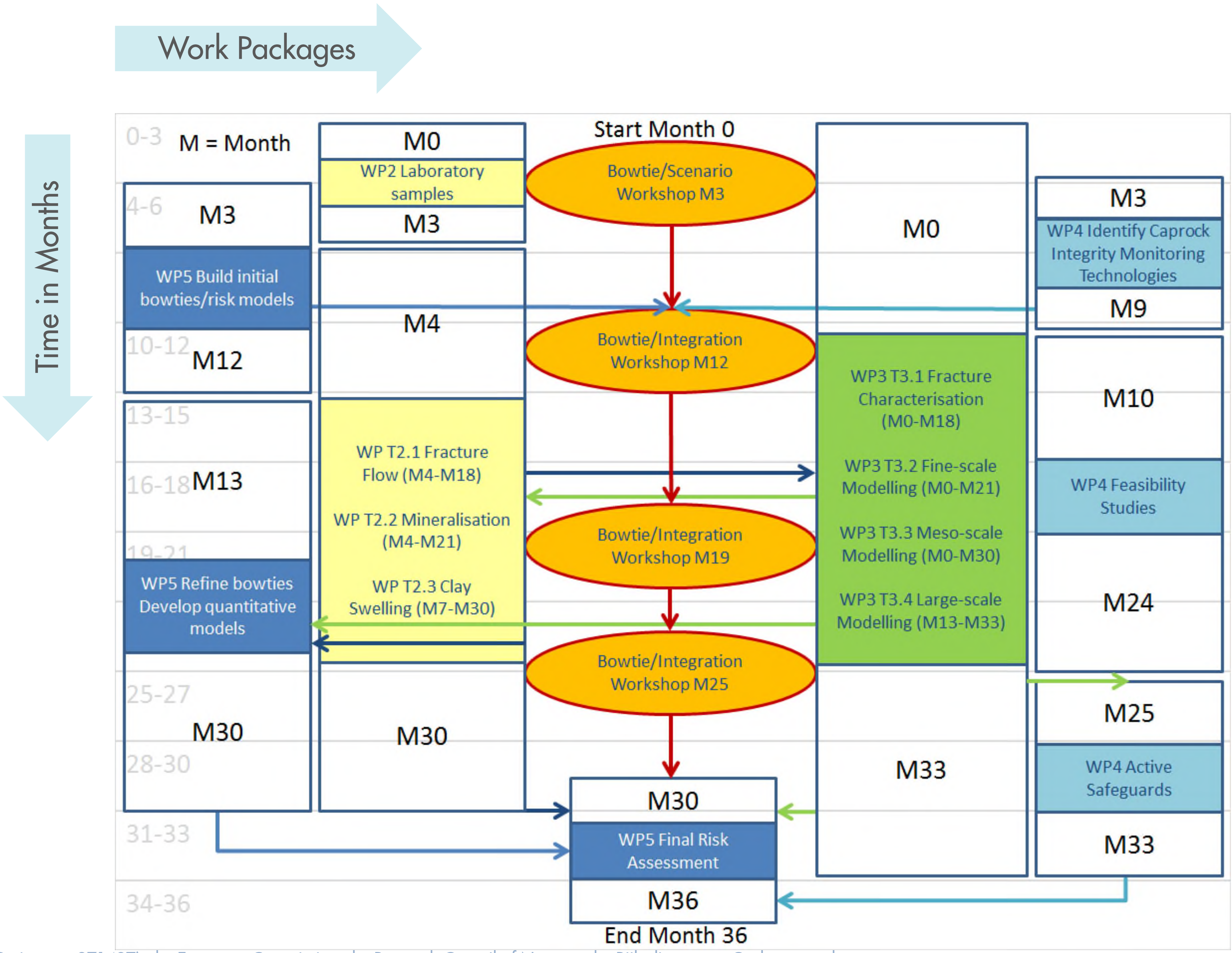
## Project Structure

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

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# Work Packages

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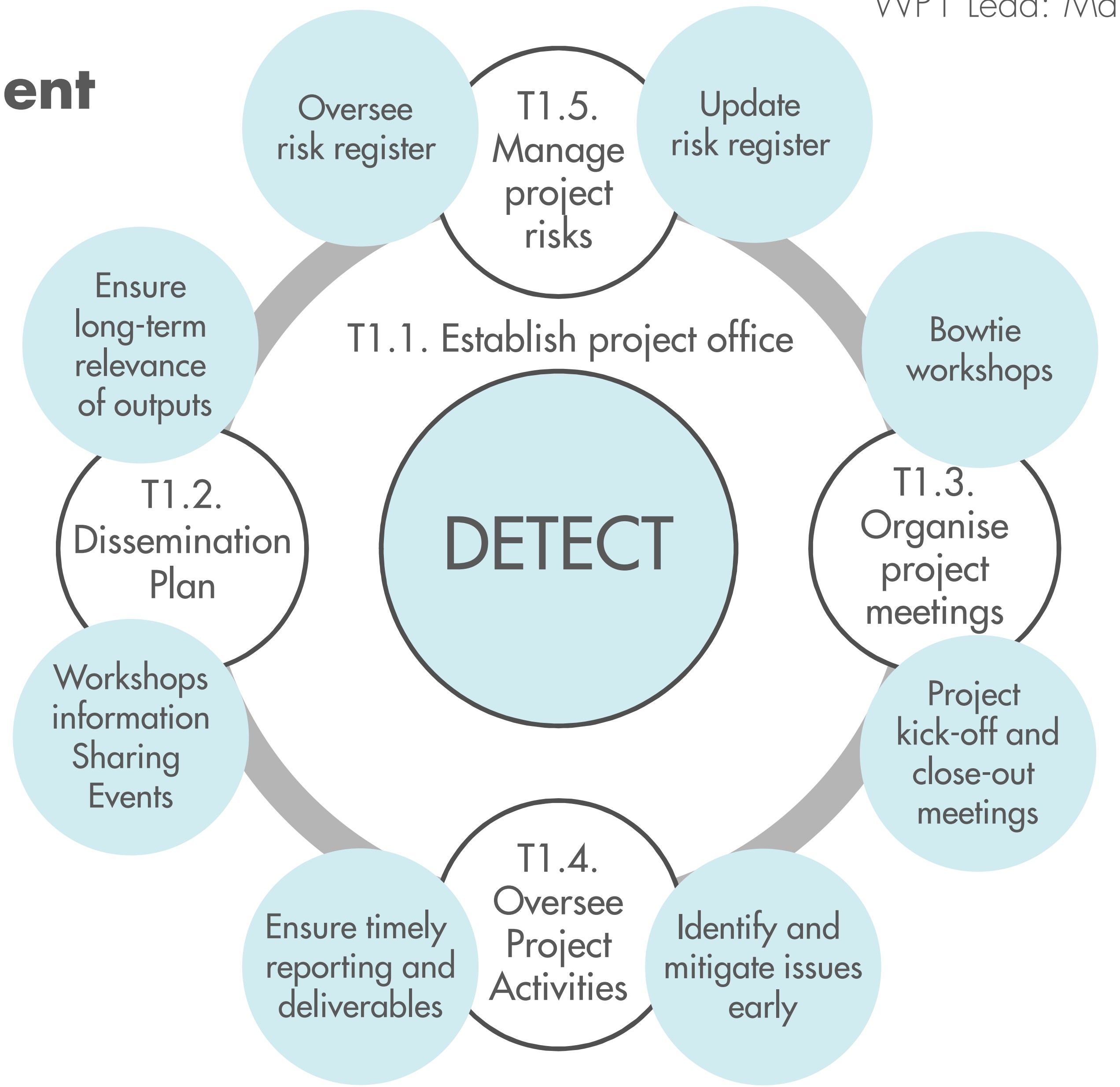
**Overview, Objectives, Collaboration Partners, Tasks**

**WP1: Project Management**
**WP2: Fracture Flow, Mineralisation, Clay Swelling**
**WP3: Fracture Characterisation and Modelling**
**WP4: Containment Monitoring for Caprock Integrity**
**WP5: Qualitative and Quantitative Risk Assessment**

WP1 Lead: Marcella Dean (Shell)

# WP1 – Project Management

- **Project Coordinator (PC):**
  - Shell, Marcella Dean
- **Supervisory Board (SB):**
  - One member from each partner
- **Project Management Support:**
  - Shell IRD Subsidy Desk, Shell External Relations and Communications team
- **Stakeholder Advisory Board (SAB):**
  - Professor Claus Otto (Curtin University), Professor Quentin Fisher (Leeds University), others TBD

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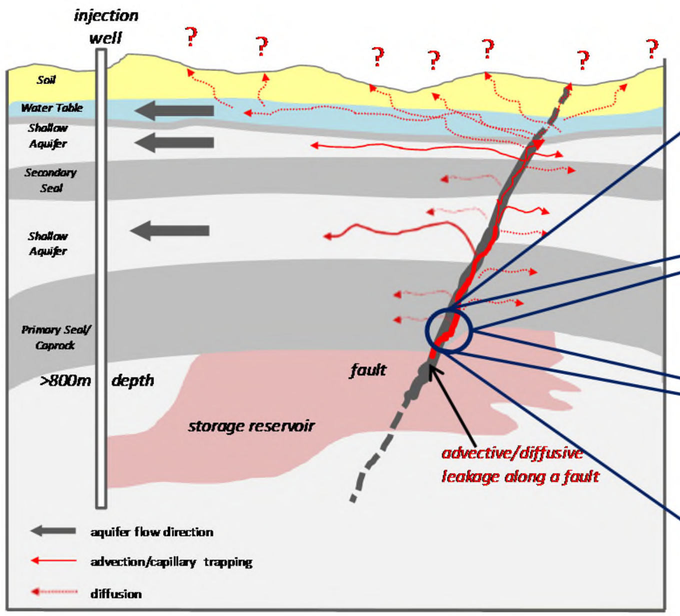
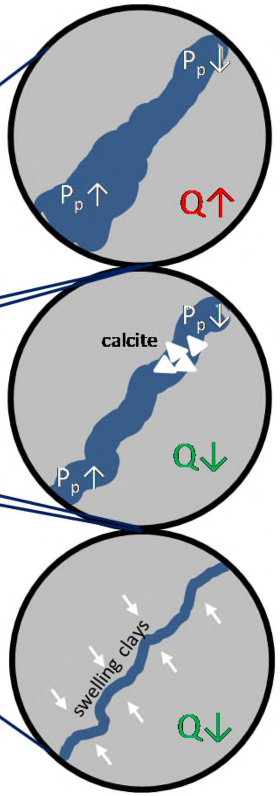
# WP2 – Fracture Flow, Mineralisation, Clay Swelling

*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 CO2 induced expansion of swelling clays in fractures
  - Determine effects of CO2-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

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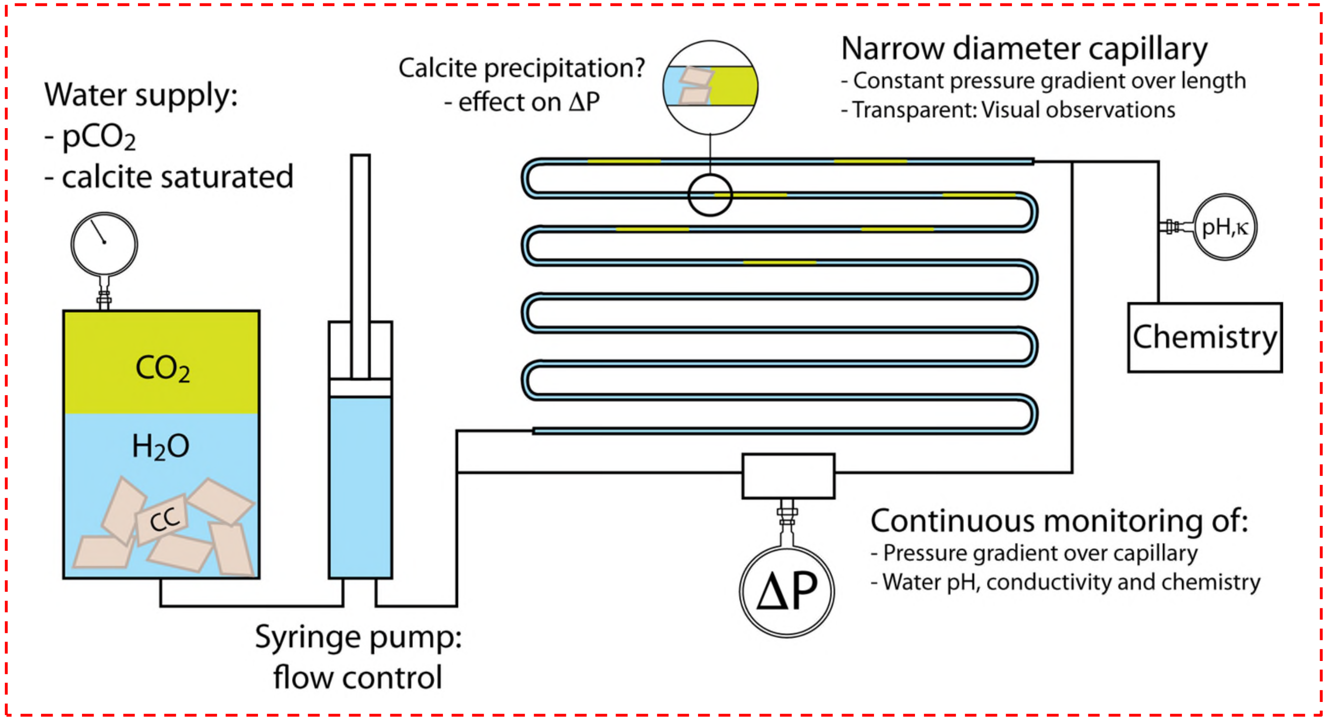
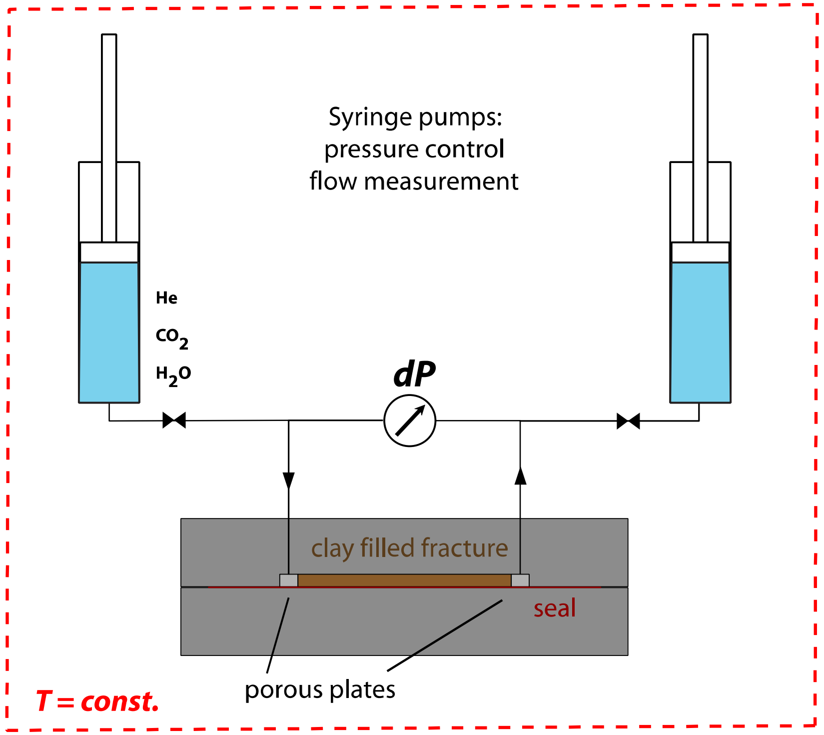
# WP2 – Fracture Flow, Mineralisation, Clay Swelling



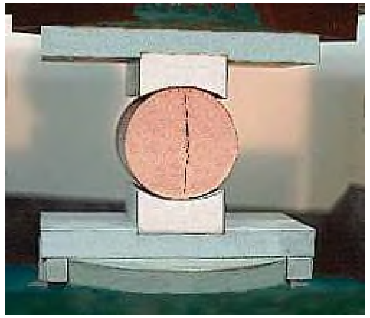




## T2.2. Mineralisation Experiments

Study reactive transport in fractures under CO2 storage conditions

## T2.1. Fracture Flow Experiments

Isotropic or triaxial cells to perform flow experiments on fractured samples



## T2.3. Clay Swelling Experiments

Permeability measurements on clay filled slits to study effect of clay swelling on fluid transport

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WP3 Lead: Jeroen Snippe, Shell

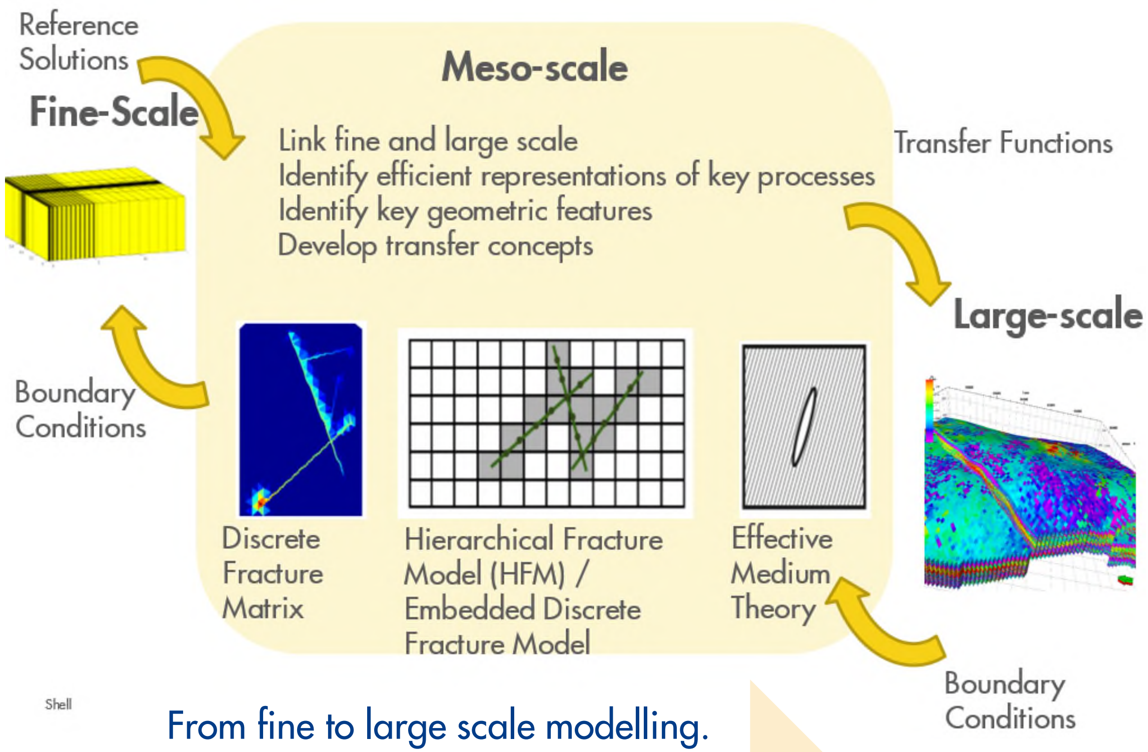
# WP3 – Fracture Characterisation and Modelling

*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**

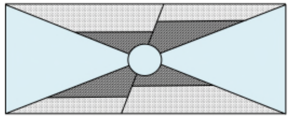
1. Develop and apply a predictive modelling workflow for realistic $CO_2$ and brine leakage rates along realistic fault/fracture damage zones through the primary caprock and continuing into shallower formations
2. Incorporating effects on fracture aperture of mineral dissolution/precipitation and clay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



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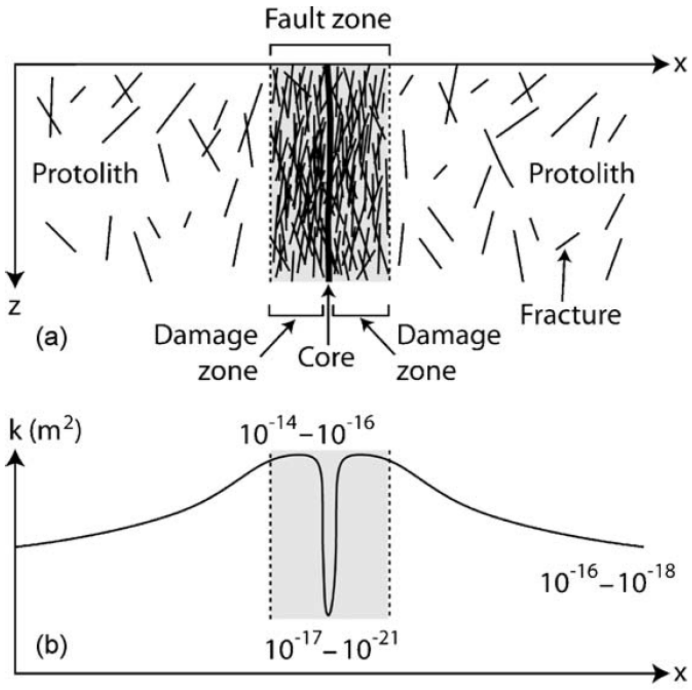
WP3 Lead: Jeroen Snippe, Shell

# WP3 – Fracture Characterisation and Modelling

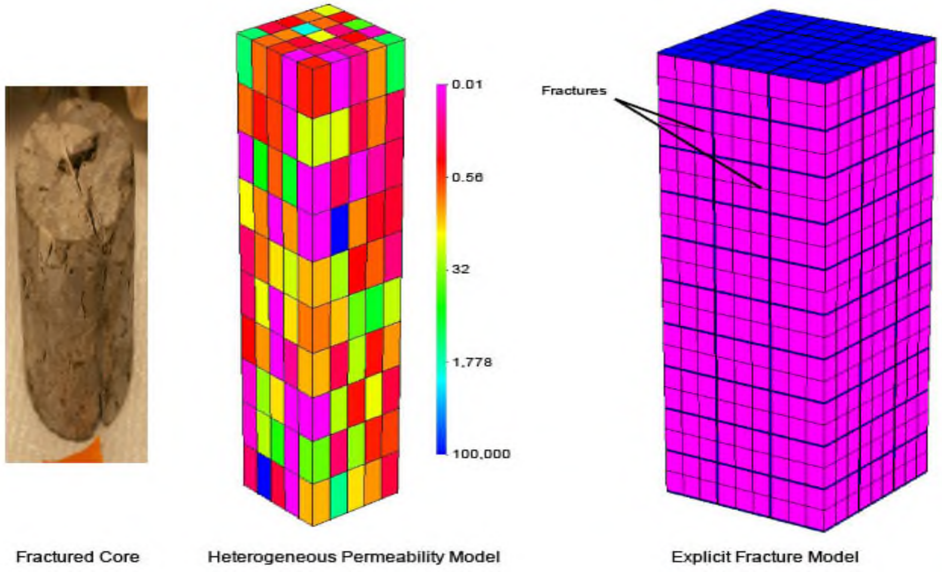
## T3.1. 2D/3D fracture network pattern characterisation (HWU)

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

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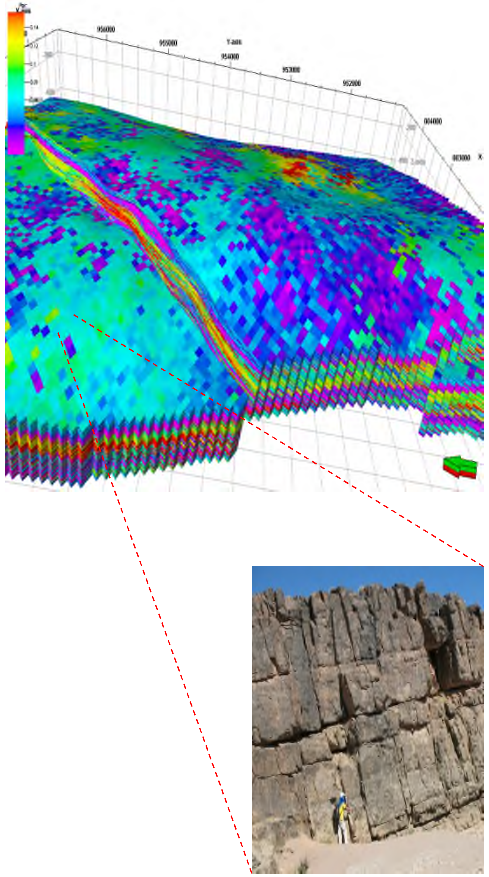
# WP3 – Fracture Characterisation and Modelling

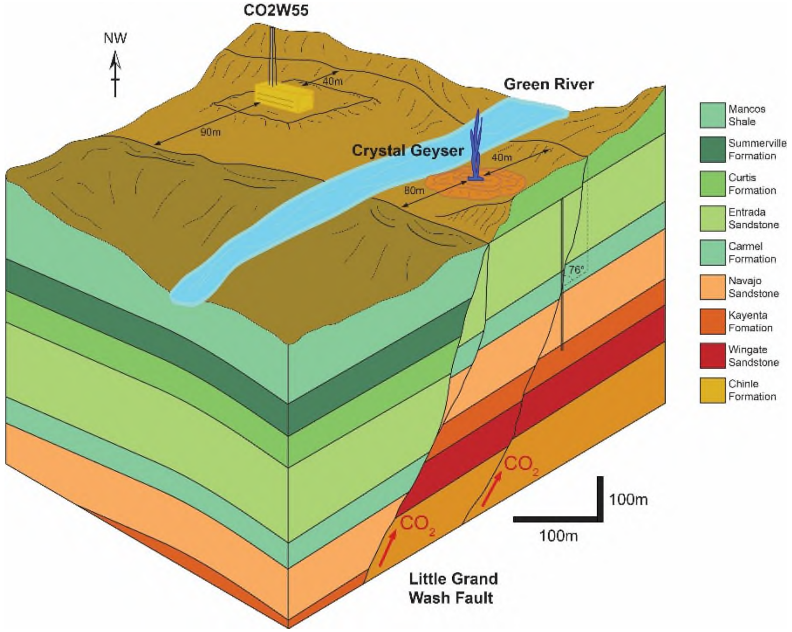
## T3.3. Meso-scale modelling and upscaling of flow in fault damage zones (HWU)

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

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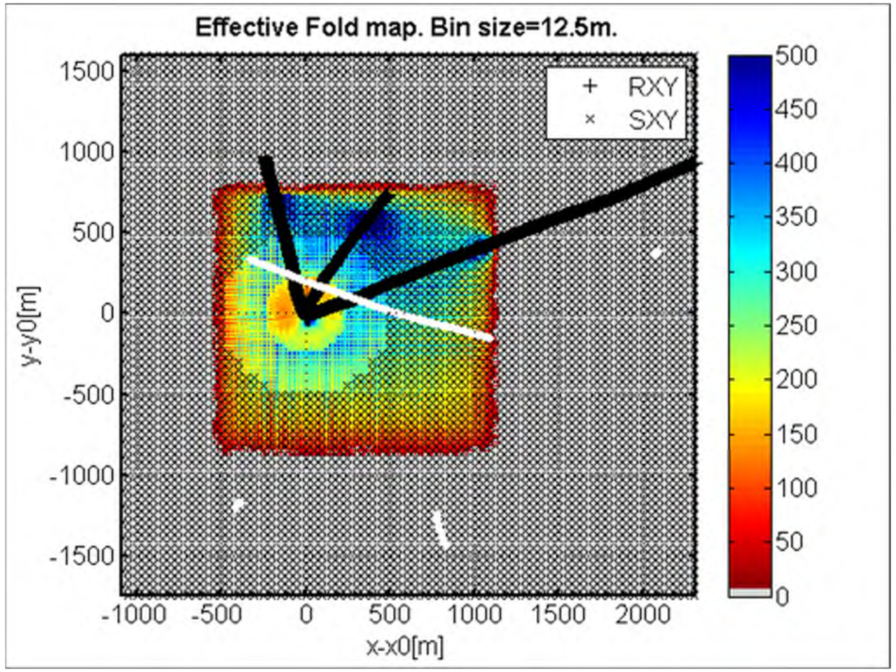
# WP4 – Containment Monitoring for Caprock Integrity

*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

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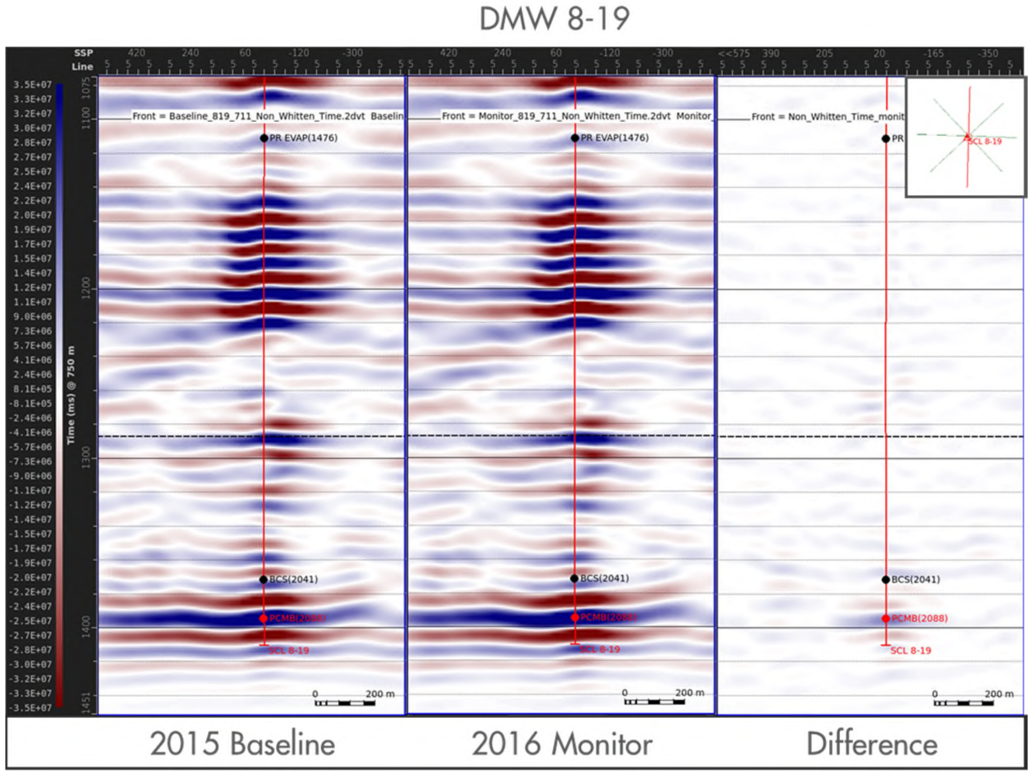
# WP4 – Containment Monitoring for Caprock Integrity




Example of a lower cost containment monitoring technology: In well Distributed Acoustic Sensing (DAS) Vertical Seismic Profiling (VSP). Baseline, Monitor and difference for well IW 8-19 at the Quest $CO_2$ Storage site.

CaMI.FRS (Containment and Monitoring Institute Field Research Station) showing injection and monitoring wells.


CaMI.FRS Program Director Don Lawton showing control panel for $CO_2$ injection.

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# 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

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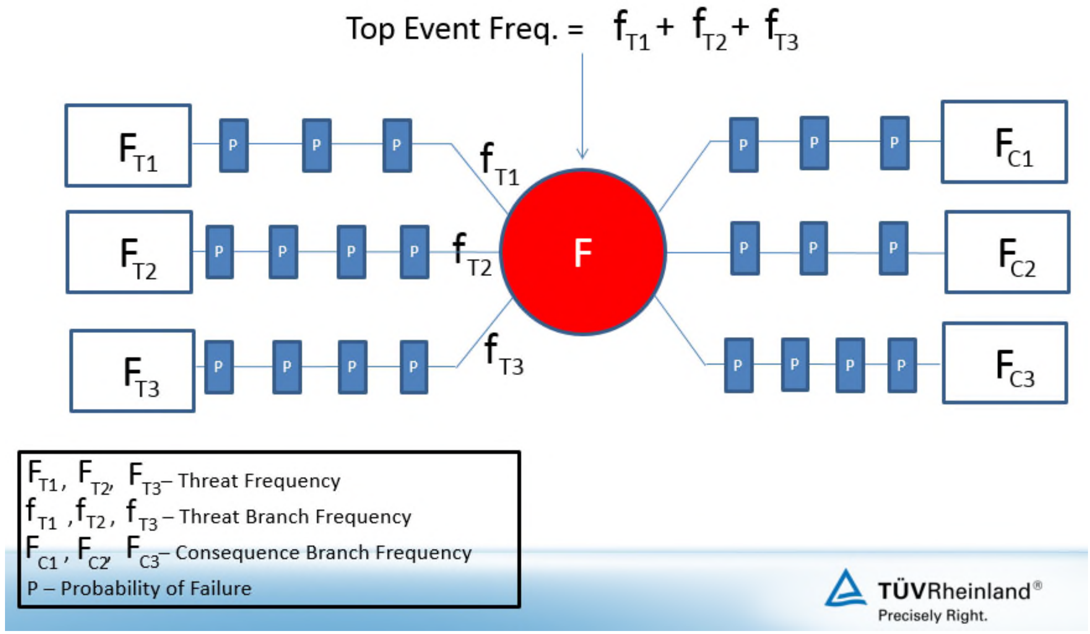
# WP5 – Qualitative and Quantitative Risk Assessment

*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)

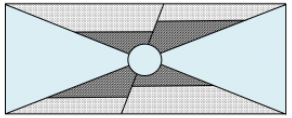



An example of a semi-quantitative risk analysis model.

WP5.T1. Identify suitable quantitative bowties risk analysis models

WP5.T2. Bowtie risk assessment for different leakage scenarios

WP2.T3. Quantitative risk analysis for different leakage scenarios



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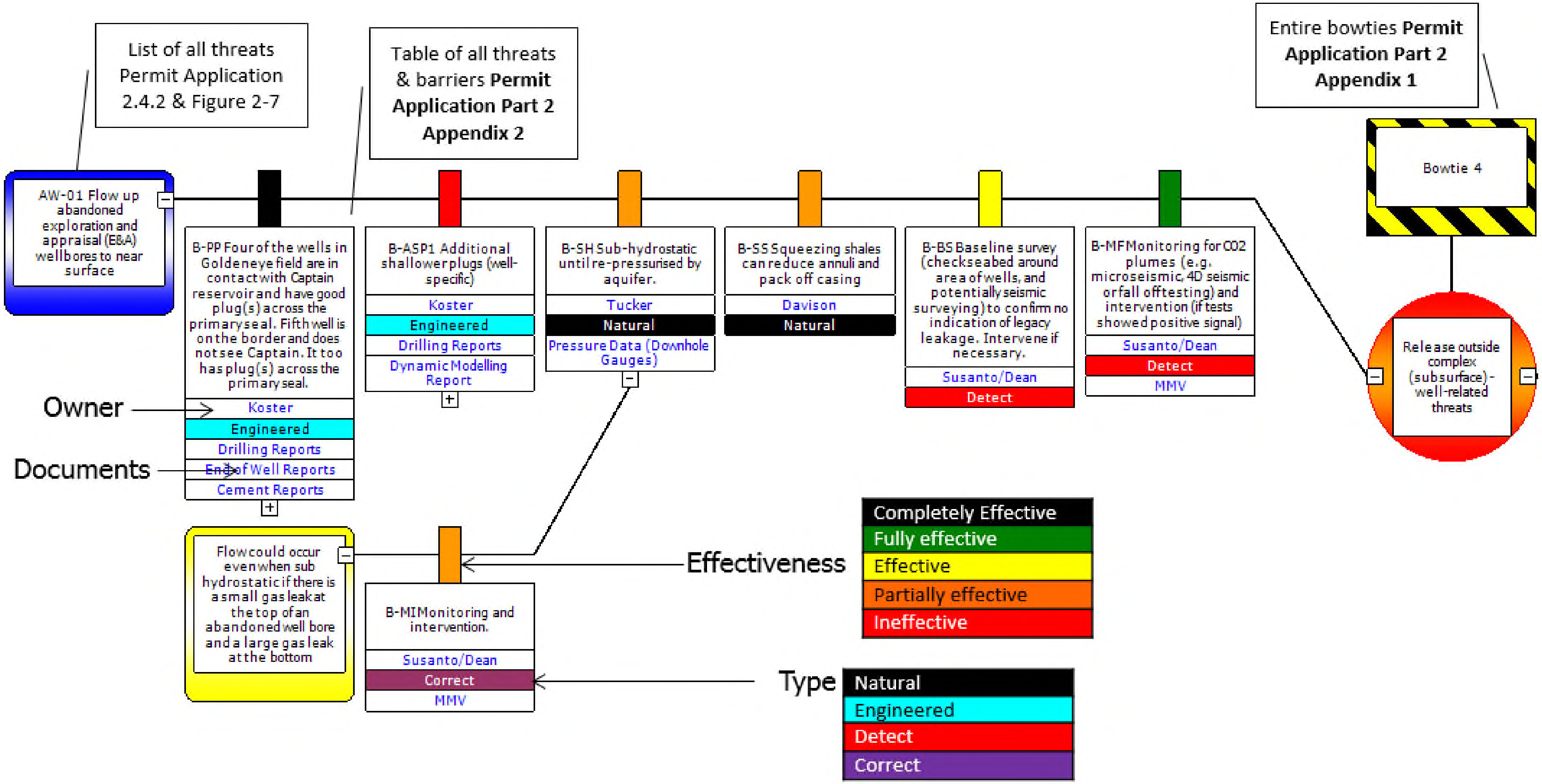
# WP5 – Qualitative and Quantitative Risk Assessment




Example subset of the bowtie done for the Peterhead CCS project. In DETECT, we will develop new quantitative methods based on the bowtie framework to assess risks related to leakage along fractures/faults in the caprock.

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