CO_2QUEST

Techno-economic Assessment of CO_2 Quality Effect on its Storage and Transport

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Introduction

Challenge

The ultimate composition of the CO2 stream captured from fossil fuel power plants or other CO2 intensive industries and transported to a storage site using high pressure pipelines will be governed by safety, environmental and economic considerations.

'*What is good for the pipeline is not necessarily good for storage'.*

It is clear that the optimum composition and concentration of the impurities in the captured CO2 stream involves a delicate balance between the different requirements within the CCS chain, spanning capture, transportation and storage, with cost and safety implications being the over-arching factor. Pivotal to these considerations is an understanding of the impact of the impurities on the physico-chemical properties of CO2 and its hazard profile.

Introduction

Approach

The work programme focuses on the development of state-of-the-art mathematical models, backed by laboratory and industrial-scale experimentation using unique EC-funded test facilities, to perform a comprehensive techno-economic, risk-based assessment of the impact of the CO2 stream impurities on the phase behaviour and the physico-chemical reactions governing the pipeline and storage site integrities.

The above involves the determination of the important CO2 mixtures that have the most profound impact upon the pipeline pressure drop, compressor power requirements, pipeline propensity to ductile and brittle facture propagation, corrosion of the pipeline and wellbore materials, geochemical interactions within the wellbore and storage site, and the ensuing health and environmental hazards.

Introduction

Value

Based on a cost/benefit analysis and whole system approach, the results will in turn be used to provide recommendations for tolerance levels, mixing protocols and control measures for pipeline networks and storage infrastructure thus contributing to the development of relevant standards for the safe design and operation of CCS.

Objectives

i) Establish the typical range and concentration of the CO_2 stream impurities based upon the three main capture technologies *including pre-combustion, post-combustion and oxyfuel technologies by reference to published literature and recent analysis of flue-gas samples*.

ii) Use experimentation and theoretical modelling to develop accurate, robust and efficient physical property models based on SAFT Equation of State (EoS) *for gas and dense phase CO_2 mixtures containing the typical impurities at the operating temperatures and pressures encompassing the entire CCS chain*.

iii) Model non-isothermal steady state flows in pressurised pipelines transporting CO_2 containing the typical impurities using the EoS developed in (ii), followed by its application to realistic pipeline network systems *in order to identify the type of impurities that have the most adverse impact on CO_2 pipeline pressure drop, capacity, fluid phase and compressor power requirements*.

iv) Model the impact of impurities, using the EoS from (ii), *on the near-field structure of accidental releases, and the impact this has on their dispersion characteristics, with validation against data gathered as part of the project. Additionally, provide detailed pipe-wall and crack-flow interaction predictions for input into (v).*

v) Develop and validate fluid/structure fracture models for ductile and brittle fracture propagation in CO_2 pipelines. Apply these models, based on various candidate pipeline steels, *to identify the type of impurities and operating conditions that have the most adverse impact on a pipeline's resistance to withstanding long running fractures*.

vi) Using results of recently published experimental data and knowledge transfer through on-going national research programmes, identify CO_2 mixtures that have the most pronounced impact on the corrosion behaviour of pipe and wellbore candidate steels *and develop appropriate corrosion prevention measures.*

vii) Quantify the effect of impurities on the performance of CO_2 geological storage, both in terms of *fluid/rock interactions and leakage of trace elements through a combination of modelling studies, laboratory experiments and large-scale field injection experiments using CO_2 and CO_2 mixtures*.

viii) Design a *decision making risk assessment tool for determining the additional safety and environmental impacts associated with the presence of impurities during CO_2 transportation and storage followed by its application for recommending appropriate prevention and mitigation measures.*

ix) Develop a model-based approach for assessment of the *impact of impurities in the CO_2 stream on the CCS system performance, and use this approach to explore feasible operational envelopes*.

x) Undertake a cost-benefit analysis of the whole system, based on the above findings, *exploring appropriate levels of purity from a whole system perspective and recommend mixing protocols*.

CO2QUEST project overview

- Start date: 1st March 2013
- Duration: 36 months
- Type of Project: Collaborative project
- Funding: FP7-ENERGY-2012-1-2STAGE
- Total EC Funding: 3M €
- 10 partners
- 8 countries

Project partners

University College London (UK)

Imperial College of Science, Technology and Medicine (UK)

University of Leeds (UK)

Institut National De L'Environment et des Risques, INERIS (France)

National Research Centre for Physical Sciences "Demokritos" (Greece)

Uppsala Universitet (Sweden)

Dalian University of Technology (China)

Environmental & Water Resources Engineering Ltd. (Israel)

Onderzoekscentrum voor Aanwending van Staal N.V. (Belgium)

Undesanstalt fuer Geowisseschaften und Rohstoffe, BGR (Germany)

Work packages

WP1: Fluid Properties and Phase Behaviour (**NCSR)**

WP2: CO2 Transport **(UCL)**

WP3: CO2 Storage Reservoir Performance (**UU**)

WP4: Techno-Economic Assessment (**ICL**)

WP5: Impacts and Risk Assessment (**INERIS**)

WP6: Dissemination (**UoL**)

WP 7: Project Management (**UCL**)

Project block diagram

WP2: CO_2 Transport (LEAD: UCL)

WP2.1: Pressure Drop/Compressor Requirement (UCL)
WP2.2: Near-field Dispersion (UoL, DUT, NCSR, INERIS)

WP2.3: Materials Selection
WP2.3.1: Ductile Fractures (UCL, OCAS, DUT)
WP2.3.2: Brittle Fractures (OCAS, UCL, UOL, DUT)

WP1: Fluid Properties & Phase Behaviour (LEAD: NCSR)

WP1.1: Typical Impurities (UoL, DUT, CANMET, BGR)
WP1.2: Equation of State Development and Validation (NCSR, CANMET)
WP1.3: Experimental Evaluation (INERIS, NCSR, CANMET)

WP3: CO_2 Storage Reservoir Integrity Performance (LEAD: UU)

WP3.1: Experimental Evaluation Impurities Effects on Storage (UU, EWRE, INERIS, BGR, CANMET)
WP3.2: Modelling Impurities Effects on Geological Storage (UU, EWRE, BGR, CANMET)

WP4: Techno-economic Assessment (LEAD: ICL)

WP4.1: Cost/Benefit Analysis (ICL, OCAS, UCL, NCSR, DUT, UU, INERIS)

WP4.2: Integrated Whole System Approach (ICL, NCSR, UCL)

WP5: Impacts and Risk Assessment (INERIS)
WP5.1: Risk Profiles of Impurities (ICL, INERIS)
WP5.2: Safety and Impacts Decision Making Method (INERIS)
WP5.3: Risk Mitigation and Prevention of Long-Term Impacts (INERIS, ICL, EWRE, UOL)

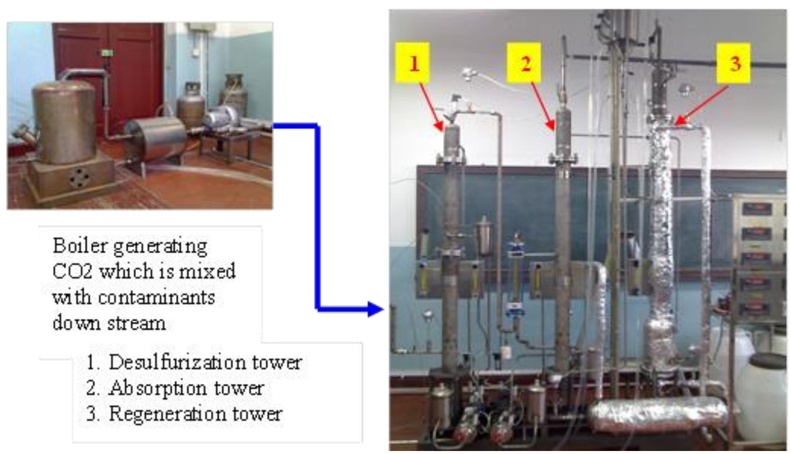
WP1: Fluid Properties and Phase Behaviour

Identify the range and level of impurities expected in CO_2 product gas streams from different capture technologies and other CO_2 intensive industries

Verification (DUT, COORAL, PACT, MATTRAN, CANMET):

250 kW oxy-fuel test facility (PACT)

Amine plant

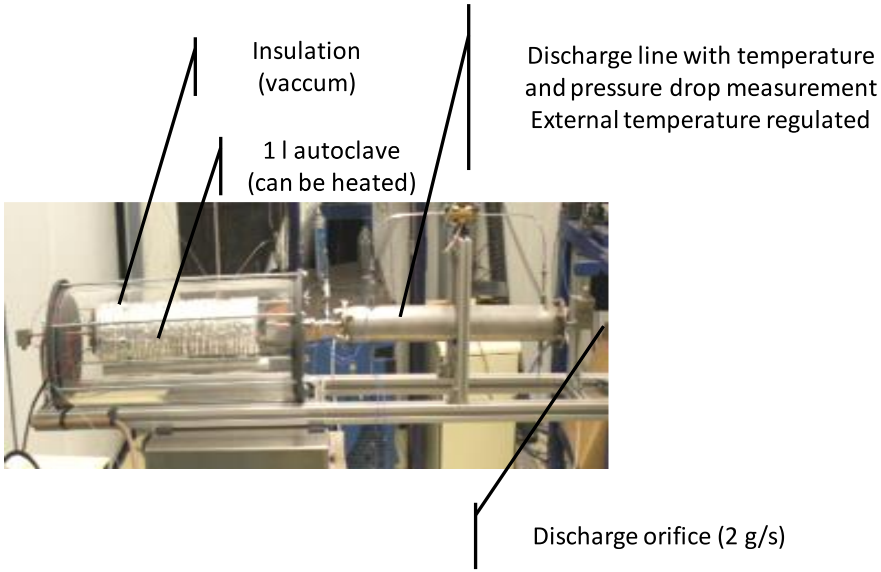


CO2 purification pilot unit (DUT)

WP1: Fluid Properties and Phase Behaviour

Experimental Evaluation

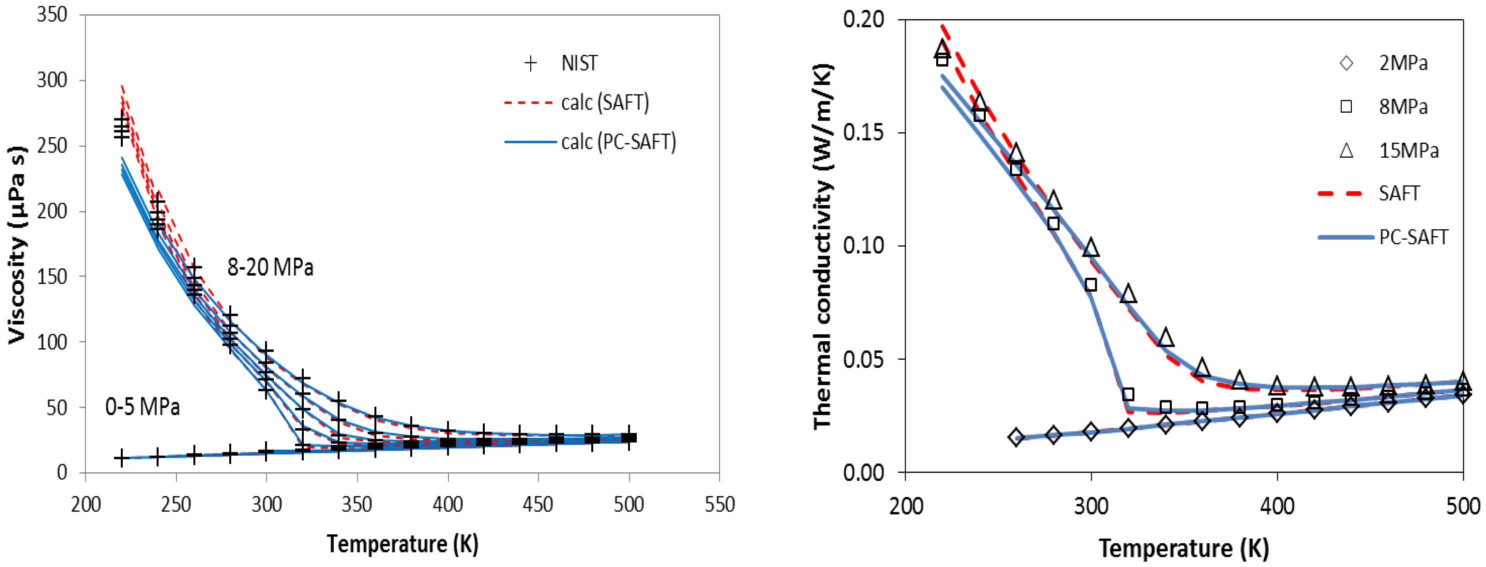
- VLE data for the binary, ternary and multi-component mixtures of CO_2 with impurities.
- Transport properties of CO_2 with impurities



A small-scale adiabatic calorimeter for studies of the thermodynamic and transport properties of vapour-liquid CO_2 mixtures at INERIS

CanmetENERGY's high pressure CO_2 test facility

WP1: Fluid Properties and Phase Behaviour

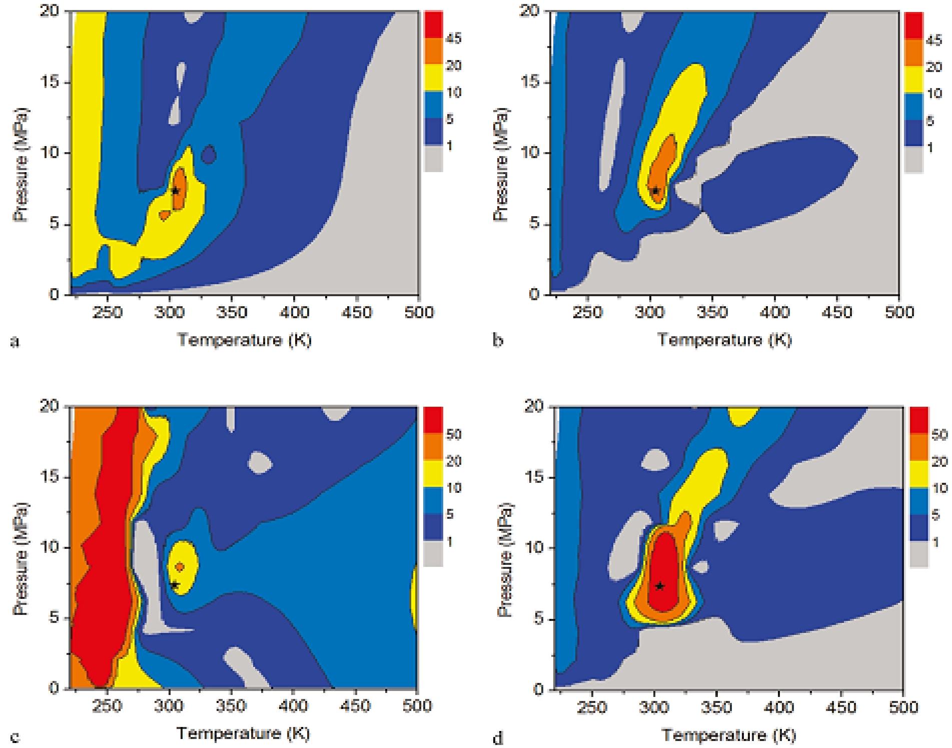


Viscosity and thermal conductivity of pure CO_2 as calculated using the SAFT and PC-SAFT EoS coupled with the model of Vesovic et al.

WP1: Fluid Properties and Phase Behaviour

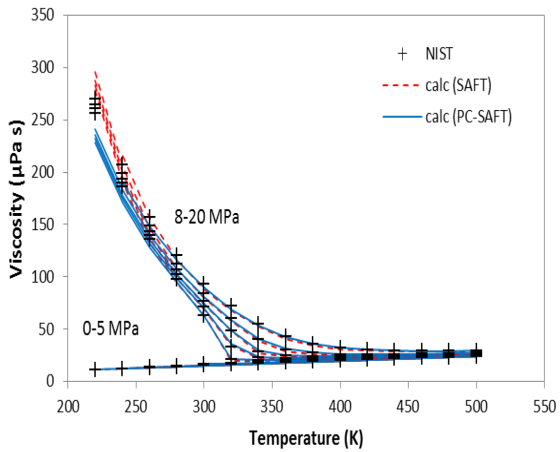
Equation of State Development and Validation

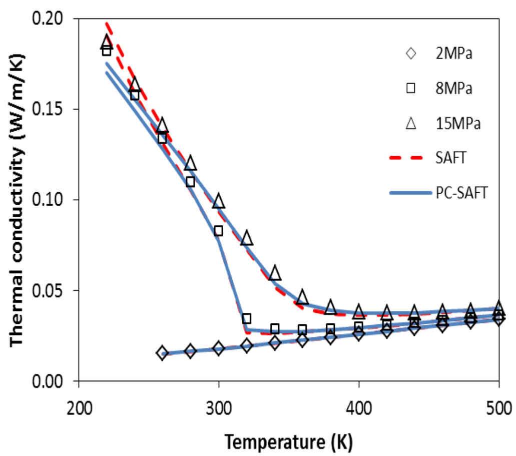
Develop new SAFT based models for CO_2 mixtures with typical impurities applicable to solid-phase CO_2 (dry ice) and electrolytic solutions (water + brine)

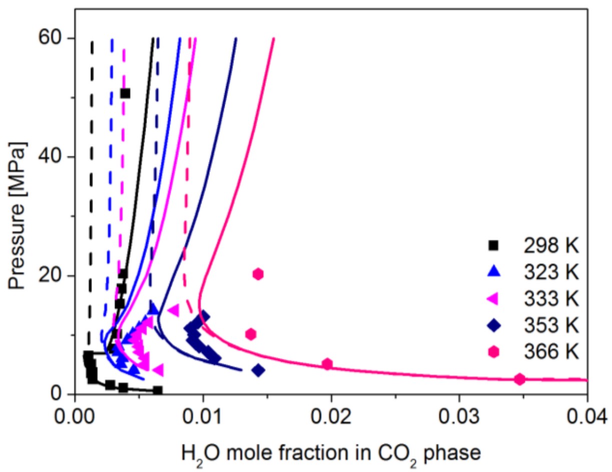


% absolute deviation between experimental data and PC-SAFT predictions for cp (upper left), speed of sound (upper right), Joule-Thomson coefficient (bottom left) and isothermal compressibility coefficient (bottom right) of CO2 at different temperatures

WP1: Fluid Properties and Phase Behaviour





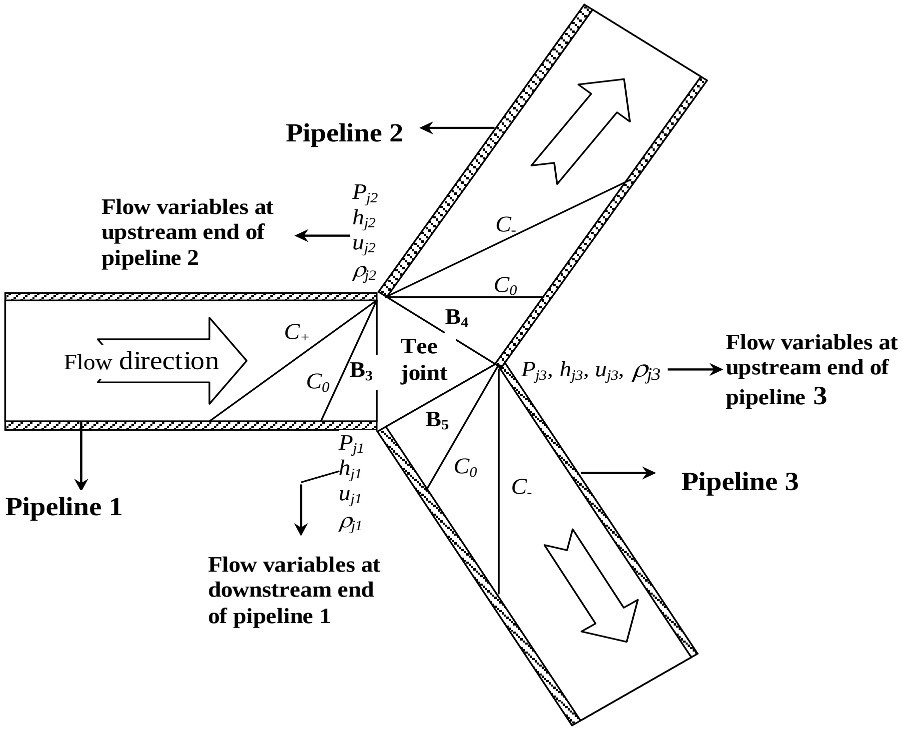


Solubility of water in CO2:
Points - experimental data,
Solid lines - PC-SAFT
Dashed lines - tPC-PSAFT

Viscosity and thermal conductivity of pure CO_2 as calculated using the SAFT and PC-SAFT EoS coupled with the model of Vesovic *et al*

Pressure Drop/Compressor Requirement

- Pressure drop requirements and compression strategies for pipeline networks transporting CO_2 with impurities.
- *The impact of impurities on the CO_2 pipeline capacity, pressure drop, fluid phase and compressor power requirements.*



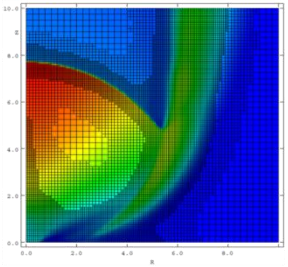
Schematic representation of flow variables at the junction between three pipelines

Near-Field Dispersion

1. Small and medium-scale experimental studies of high pressure releases of CO_2 with impurities.
2. Large-scale experiments involving high pressure releases of CO_2 with impurities.
3. Development and validation of CFD model describing release of supercritical, dense phase and gaseous CO_2 containing impurities.
4. Case studies for qualitative risk assessment.

Photograph of the 40 m long, 40mm internal diameter pipeline for conducting the CO_2 blowdown experiments at INERIS

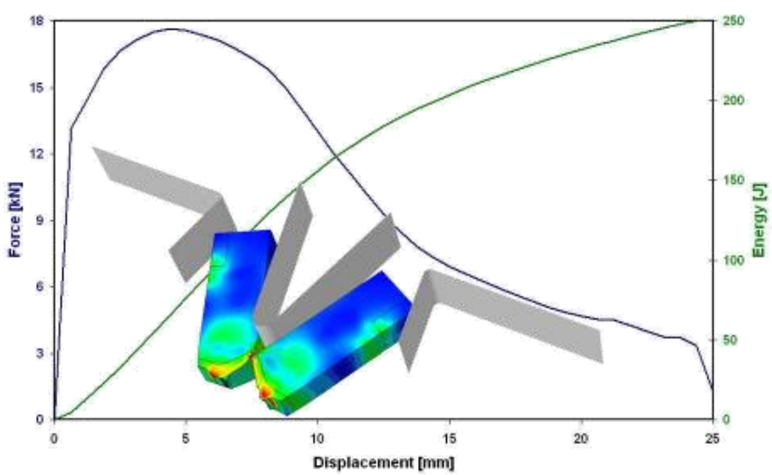
The fully instrumented 256 m long, 0.233 m i.d. pipeline for CO_2 release experiments, constructed by DUT in the Lioahe Oilfield in China



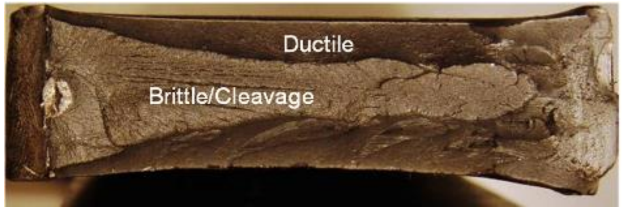
CFD predictions of the near-field shock structure of a CO_2 release

Fracture Propagation

1. Fluid/structure interaction models for the ductile/brittle fracture propagation.
2. Experimental determination of fracture toughness parameters
3. Shock tube experiments for the outflow and fracture models validation.
4. Sensitivity studies of the impact of impurities on:
   - ductile facture propagation behaviour in CO_2 pipelines.
   - pipeline’s resistance to withstanding long-running fractures for various pipeline steel types



Simulation of energy absorption during Charpy impact test



BDWTT fracture surface appearance

WP3: CO_2 Storage Reservoir Integrity

Study of the effects of impurities on the performance of the geological storage operation, in terms of fluid/rock interactions and leakage of trace elements:

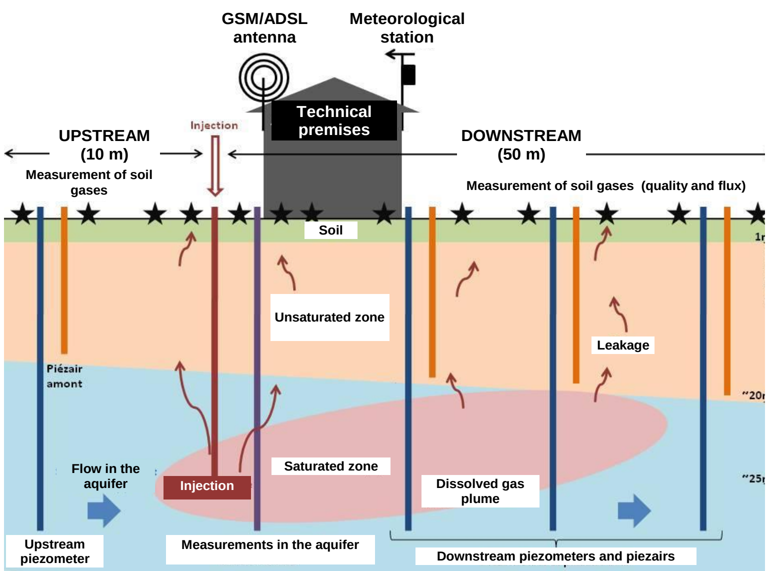
1. A unique field injection test of water and of super-critical CO_2 at the experimental site of Heletz (Israel);
2. Conducting laboratory experiments aimed at determining the impact of the impurities on the mechanical properties of the reservoir and the caprock;
3. Integrate the results of the laboratory experiments conducted in the frame of the COORAL project, coordinated by partner BGR and funded by the German Federal Ministry of Economics and Technology (BMWi).

WP3: CO_2 Storage Reservoir Integrity

Experimental Evaluation of Impurities Effects on Storage Properties

1. Laboratory experiments - impurities' effects on caprocks, wellbore cement and steel
2. Singe-well push-pull experiments of CO_2 and water at the Heletz test site
3. Injection of industrial grade CO_2 in a shallow freshwater aquifer for the monitoring of the trace elements impurities

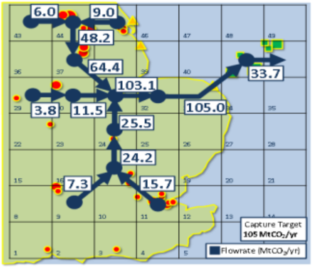
Modelling of the Impurities Impacts on Geological Storage



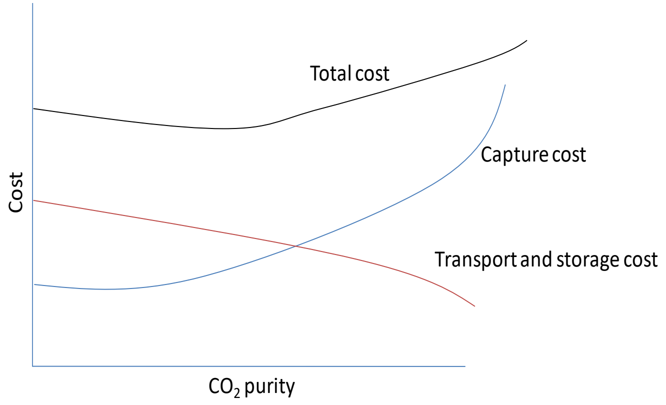
Schematic illustration of injection of CO_2 mixture into a shallow aquifer and associated monitoring equipment

WP4: Techno-Economic Assessment

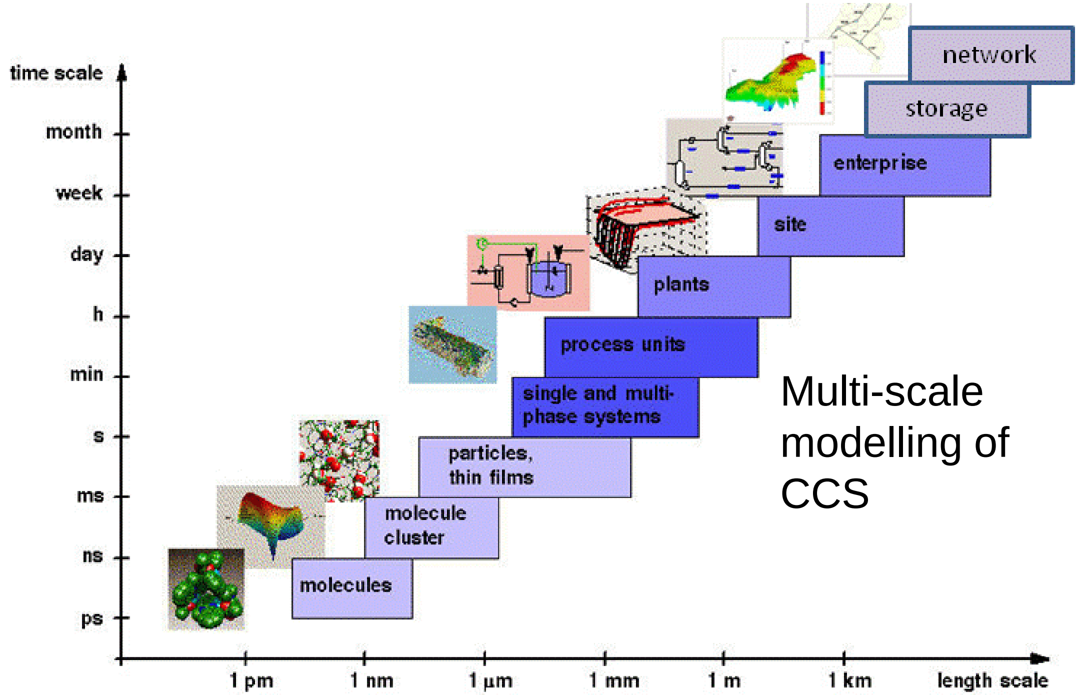
1. To develop a multi-scale whole-systems approach for CCS capture and transport networks
2. To understand the costs and benefits of higher or lower CO_2 purity and generate feasible operational envelopes for CCS systems



Example of network design



Cost trade-offs associated with CO2 purity



Multi-scale modelling of CCS

WP5: Impacts and Risk Assessment

1. Analysis of incremental risks across the chain implied by the presence of impurities in the CCS chain
2. Decision making risk assessment (safety and environmental impact) accounting for the role of impurities
3. Planning prevention and mitigation measures for selected risks

Project block diagram

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Thank you

Questions

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