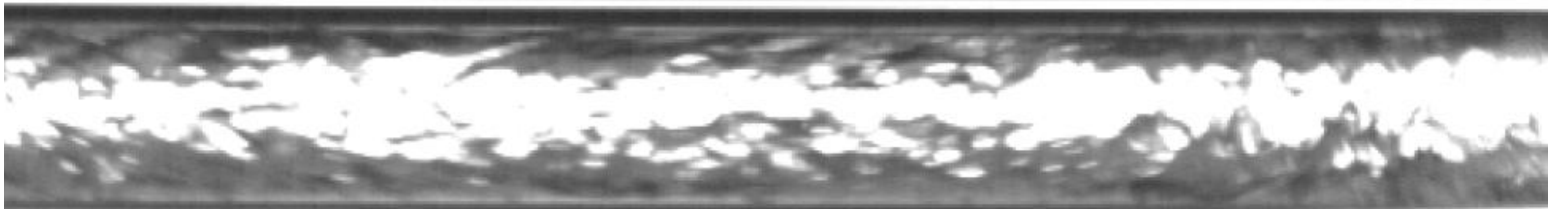

Photo: Jostein Pettersen

CLIMIT Summit, Oslo, 2015-02-24

Knowledge for safe and efficient CO_2 transport

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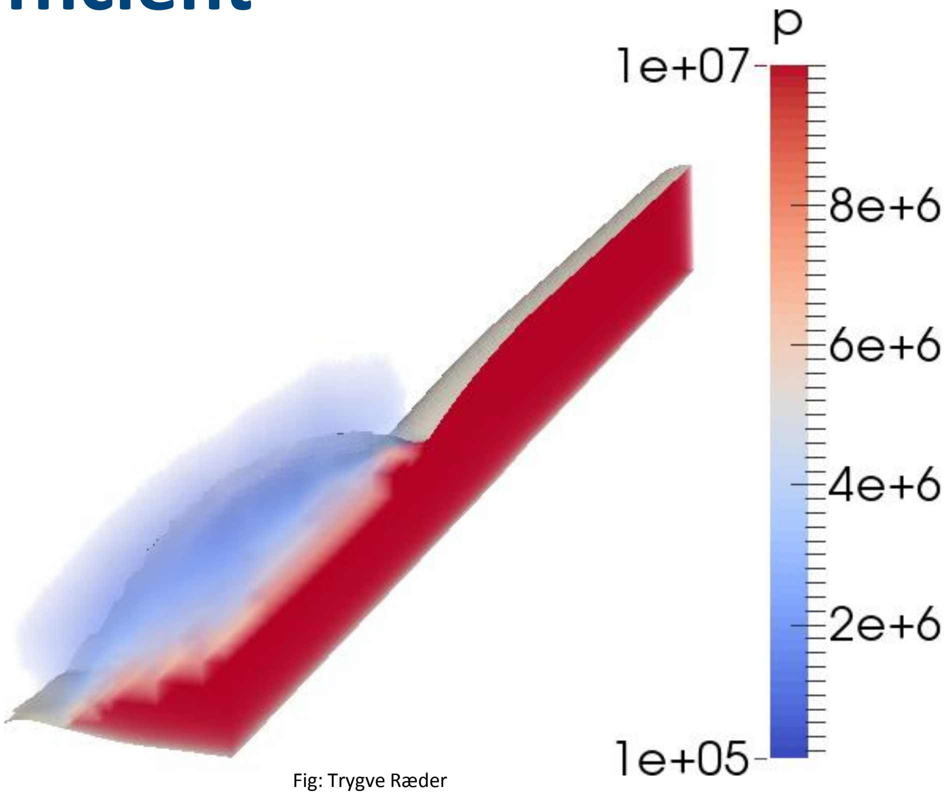

Fig: Trygve Ræder

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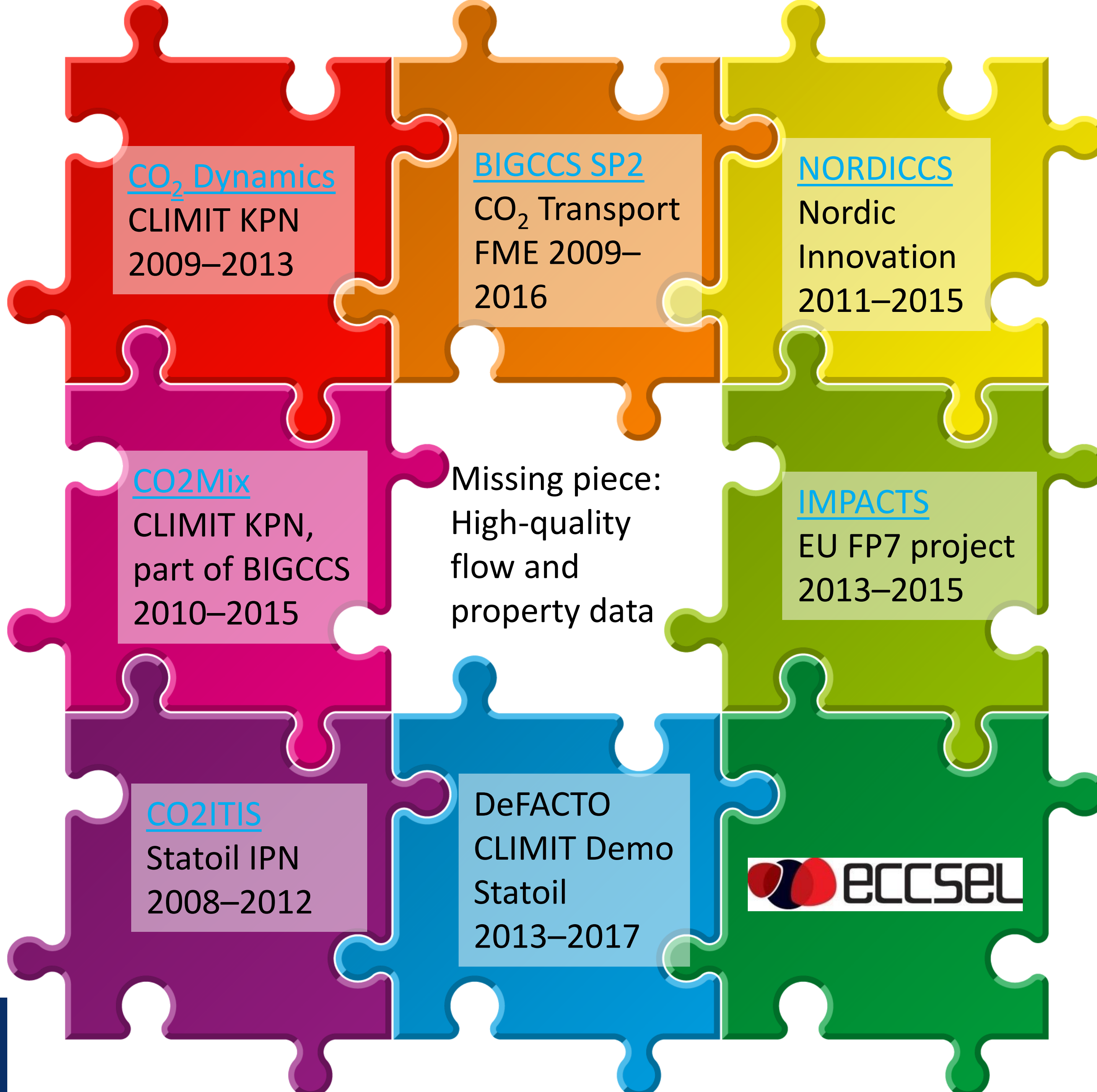

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CO_2 transport exists, but more knowledge is needed

SINTEF MC

- In the USA, CO_2 has been transported in pipelines since the 1970's for enhanced oil recovery (EOR)
- However, for CCS, there are several factors requiring more knowledge:
  - Onshore pipelines near populated areas – safety essential
  - Larger scale (cf. 2DS; 6 Gt/year in 2050)
  - Offshore pipelines
  - More and different impurities
  - More sources, some of which operate intermittently
  - Injection into aquifers
- Significant cost, 10–20 EUR/t [7]
- We need more knowledge, and we know how to obtain it

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Review

Pipeline transport of CO_2 mixtures: Models for transient simulation

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ABSTRACT

This paper reviews current research challenges related to the modelling of transient flow of multiphase CO_2-rich mixtures in pipes. This is relevant not only for events like start-up, shutdown or planned or uncontrolled depressurization of pipelines, but also for normal operation, and therefore needs to be taken into account by simulation tools employed for design and operation of CO_2 pipelines. During transportation, CO_2 will often be in a dense liquid phase, whereas e.g. natural gas is in a dense gaseous phase. This requires special attention to depressurization and the possible propagation of cracks. In addition, we highlight and illustrate research challenges related to thermodynamics, and the modelling of the wave-propagation velocity (speed of sound) for two-phase flows. Further, some relevant currently available simulation tools, and their applicability to CO_2 transport, are briefly discussed.

CO_2 value chain?

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1911 State of the art

Source: Wikipedia

Contents

- Background
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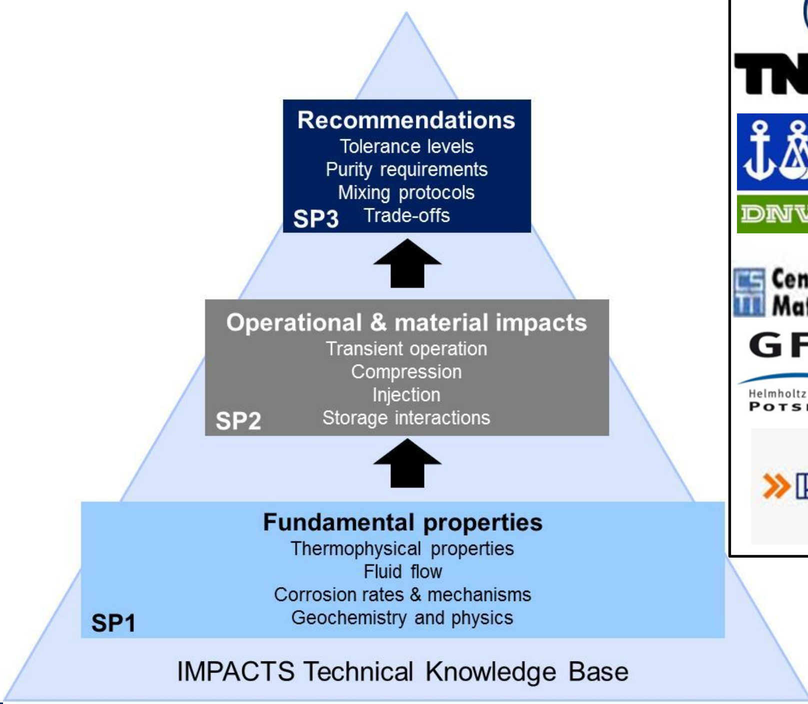
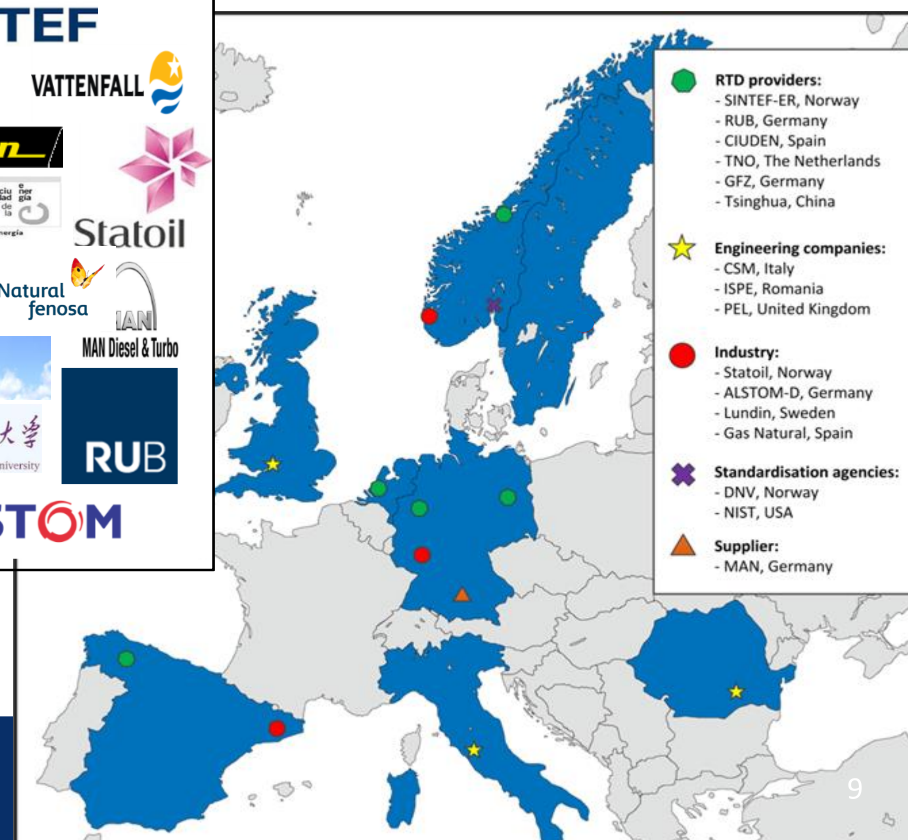
Objective: Enable realization of safer and more cost-efficient solutions for CCS by closing critical knowledge gaps related to transport and storage

Duration 2013—2015; Budget 5.6 MEUR; Coordinator SINTEF ER





Safety and efficiency requires quantification

- **Thermodynamic properties** density, phase fraction, speed of sound,…
- **Reference EOS** GERG for natural gas, none yet for CCS
- **Metering/taxation**

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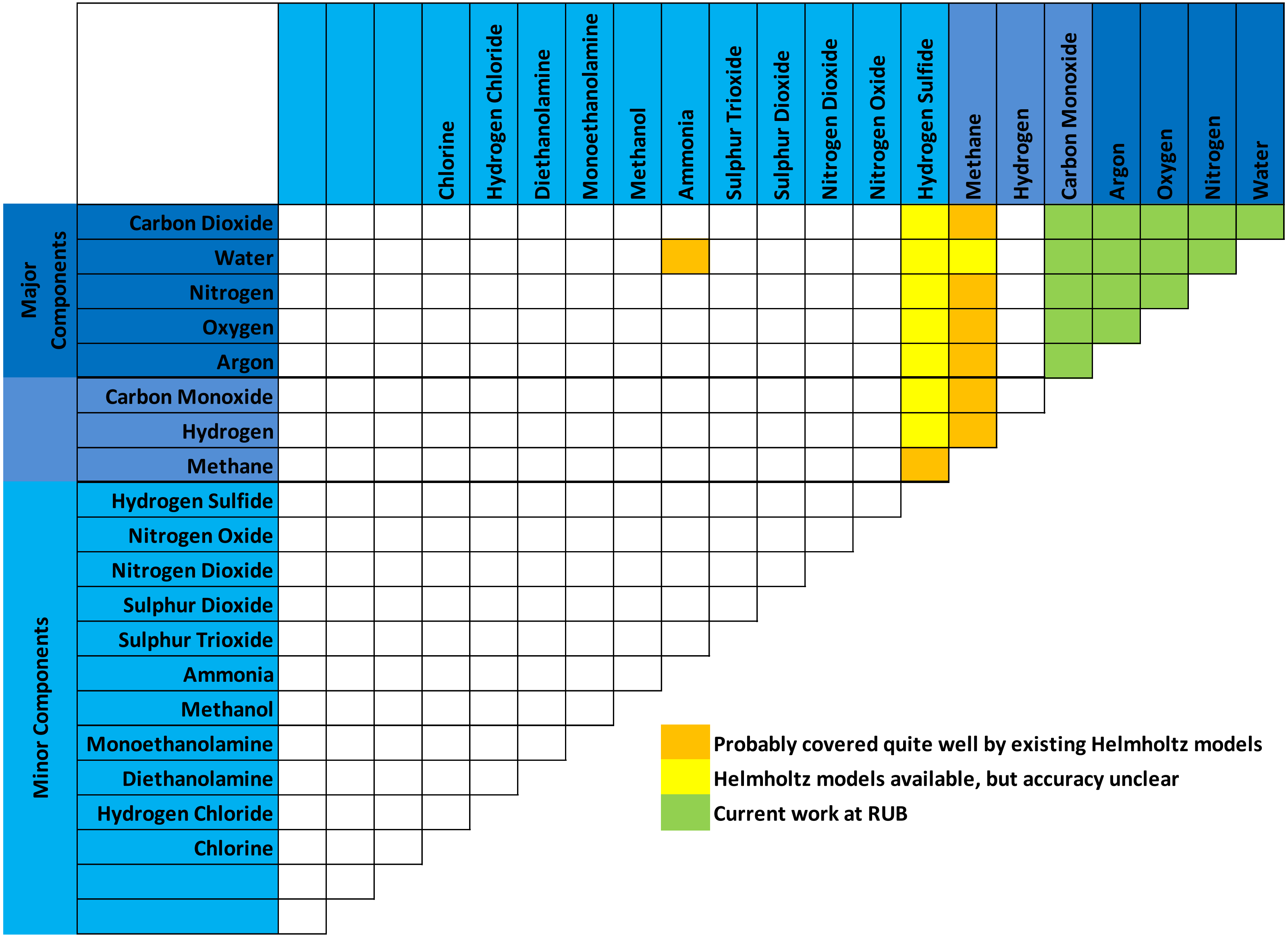
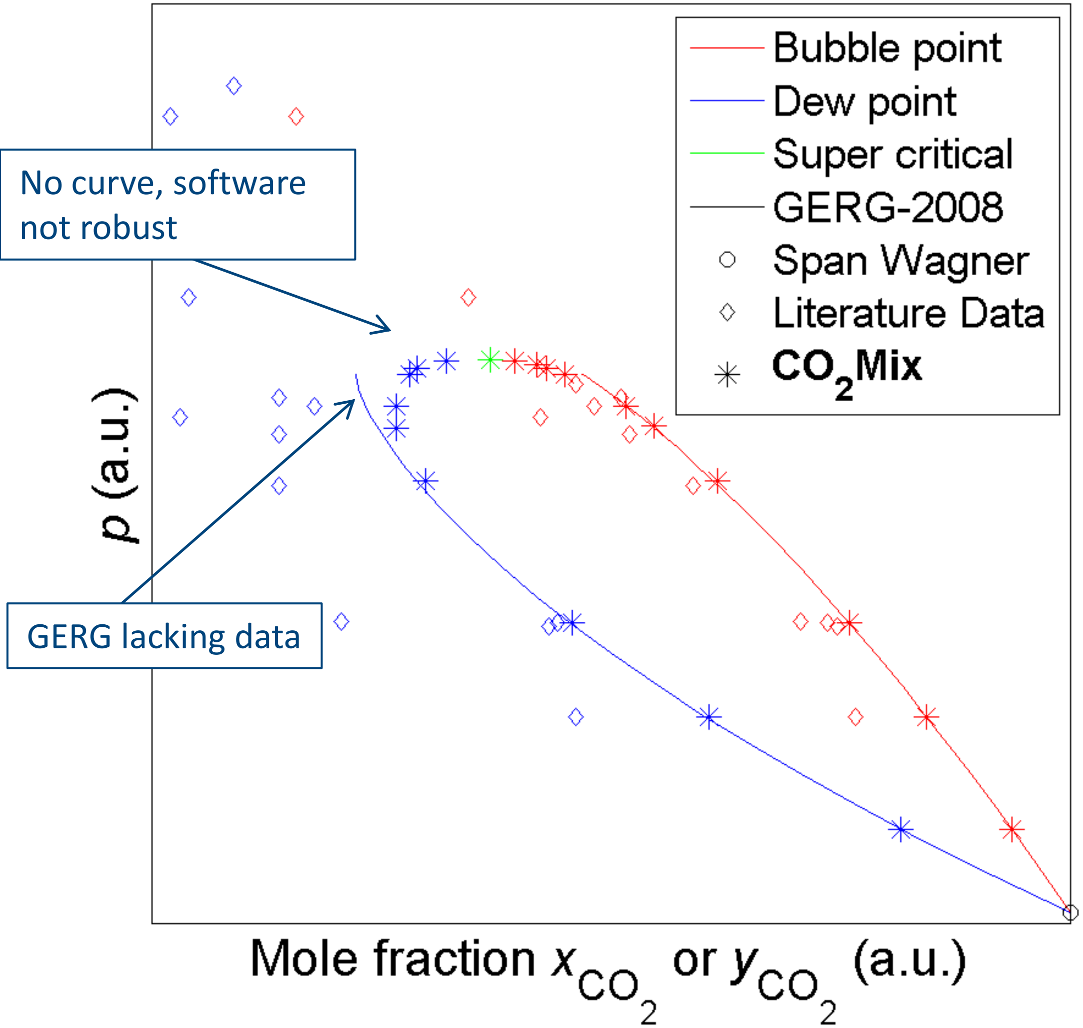
- **Transport properties** viscosity, thermal conductivity,…
- **Pipe-material properties**
- **Flow models** flow regimes, discontinuities, small amounts of impurities, …

- **Data are required far outside the "transport spec"**
  – To obtain a predictive model, not only a point value
  – To calculate capture, conditioning, storage
  – To perform optimization
  – Since gas and liquid composition can be significantly different from the total composition

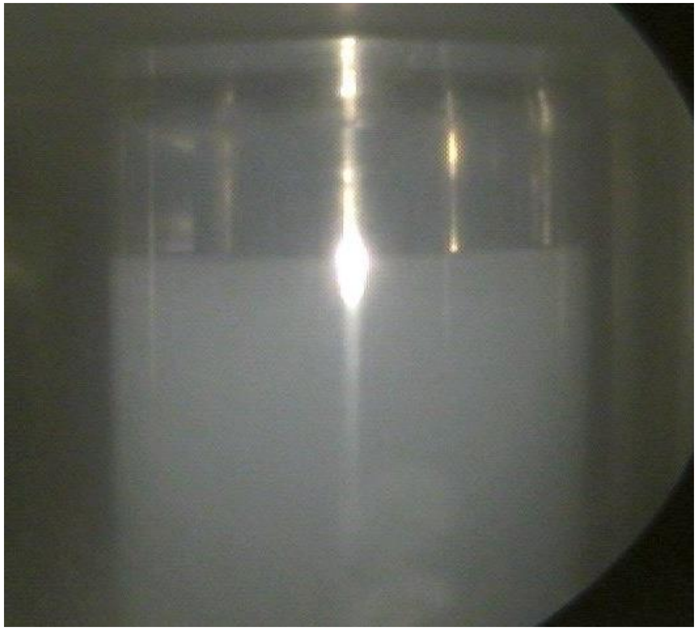
Relevant components / coverage by Helmholtz models



Phase equilibrium measurement for CO_2–N_2



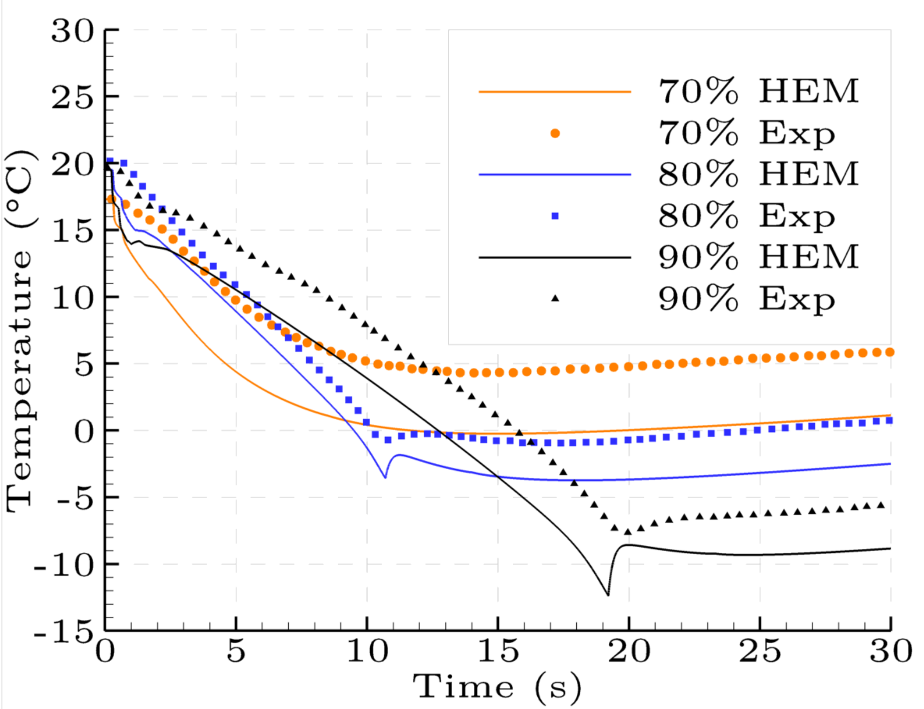
An isotherm of the CO_2 – N_2 system.
Insert: Critical region, fits using cubic spline and 4th-order polynomial

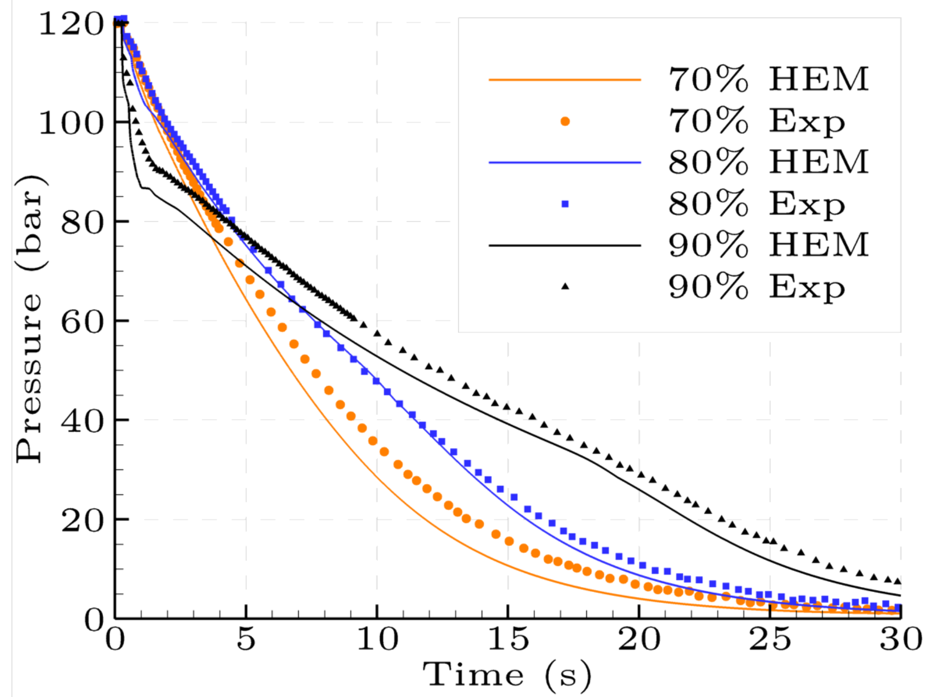


Approaching critical point in a CO_2-N_2 mixture

High-quality data from CO_2Mix to be employed in the development of reference EOSs at RUB

Multiphase flow of CO_2-rich mixtures in pipes



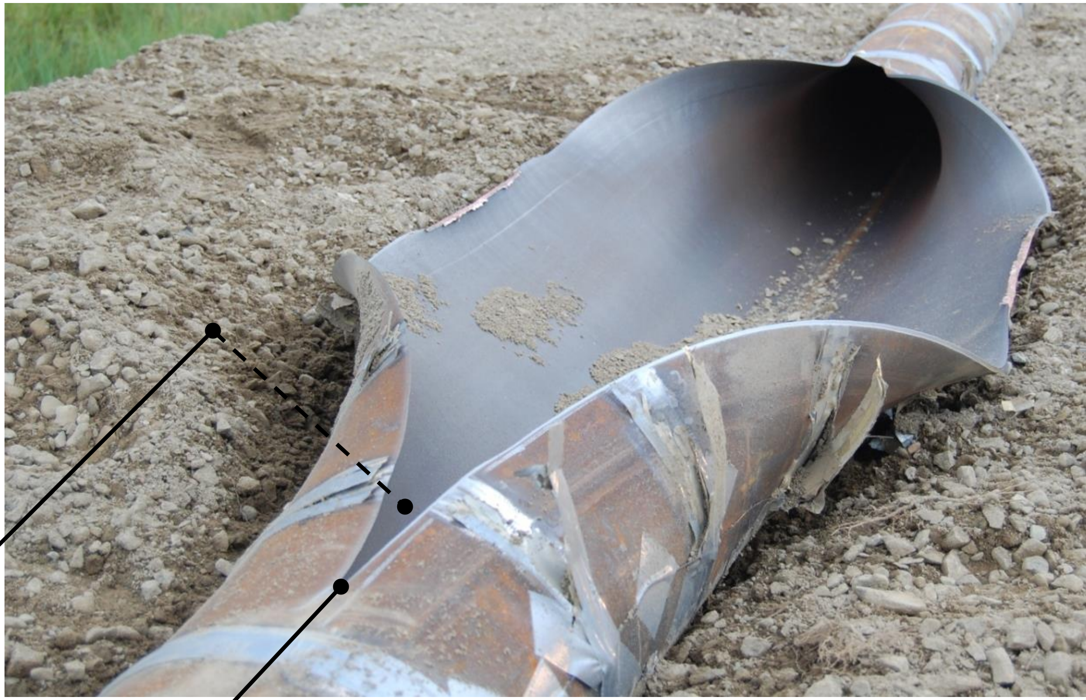


- Depressurization of a 140 m long tube filled with CO_2-N_2 [3]
- Experiments and calculations using the homogeneous equilibrium model (HEM)

- Good agreement for pressure
- Improvement requires more detailed modelling and experiments

The fracture race

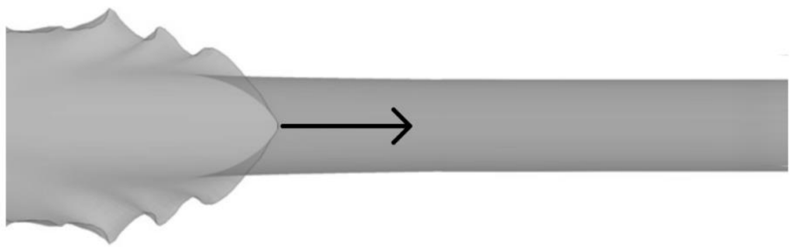
Pipe with methane
D=267mm


SINTEF MC

- Pressure-propagation speed (sound speed)
  - Gas, liquid or mixture
  - Fluid composition
  - Pressure
  - Temperature
  - Fluid flow

- Fracture-propagation speed
  - Pipe material
  - Pipe geometry
  - Pressure
  - Temperature

BIGCCS Coupled fluid-structure model predicting running-ductile fracture in CO_2-transport pipes



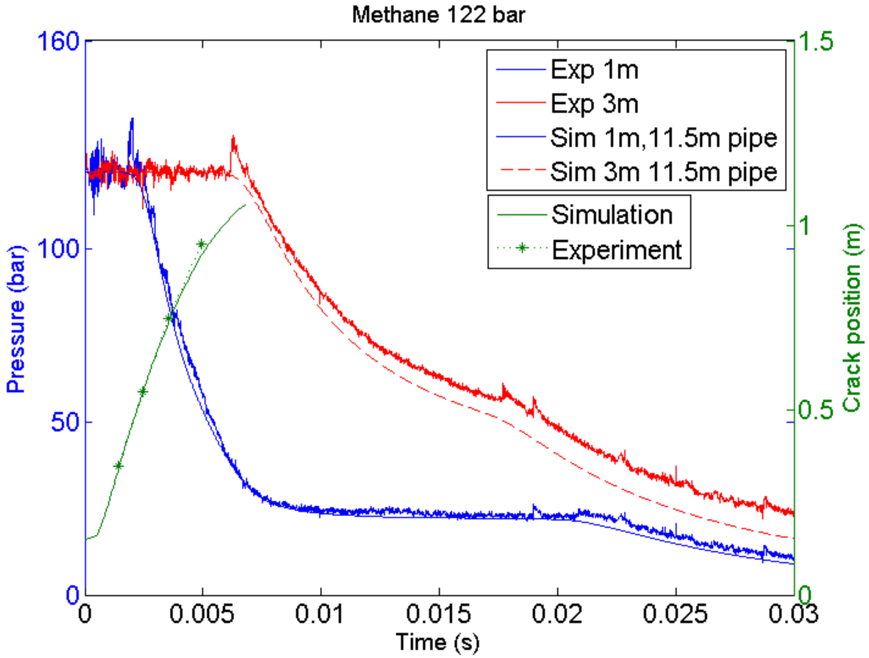
First simulation of CO2Pipetrans experiment using BIGCCS coupled code

Motivation:

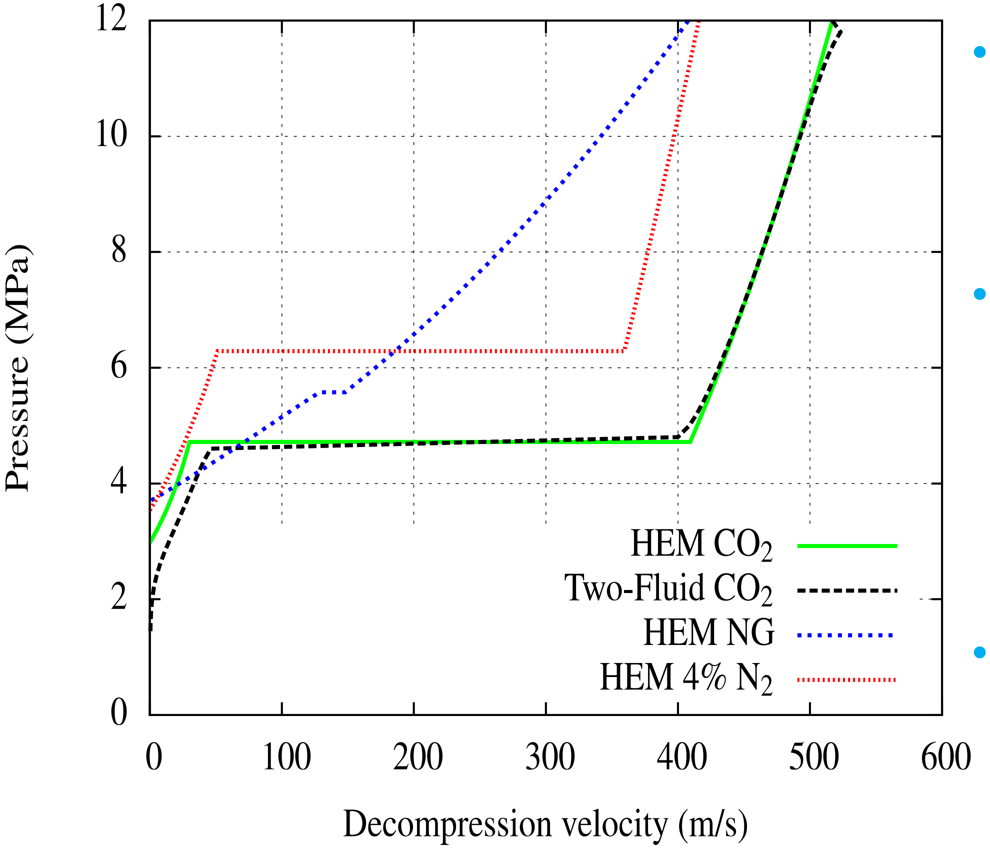
- *"The Battelle two-curve method cannot be directly applied to dense phase CO_2 pipelines"* (COOLTRANS project, UK)

BIGCCS coupled code:

- **Unique** due to its inclusion of advanced models both regarding thermo-fluid dynamics and structural mechanics (SINTEF ER and MC)
- Left: Verification for methane [6].



Fluid pressure versus decompression velocity



- Similar plots are employed in semi-empirical methods to evaluate running-ductile fracture (Battelle, etc.). (Material curve not shown here).
- In the left region of the plot, CO_2 has a lower decompression speed than natural gas
  - The CO_2 pipe may be more vulnerable to running-ductile fracture
  - N_2 aggravates the situation
- The HEM would give a more conservative design than the two-fluid model.

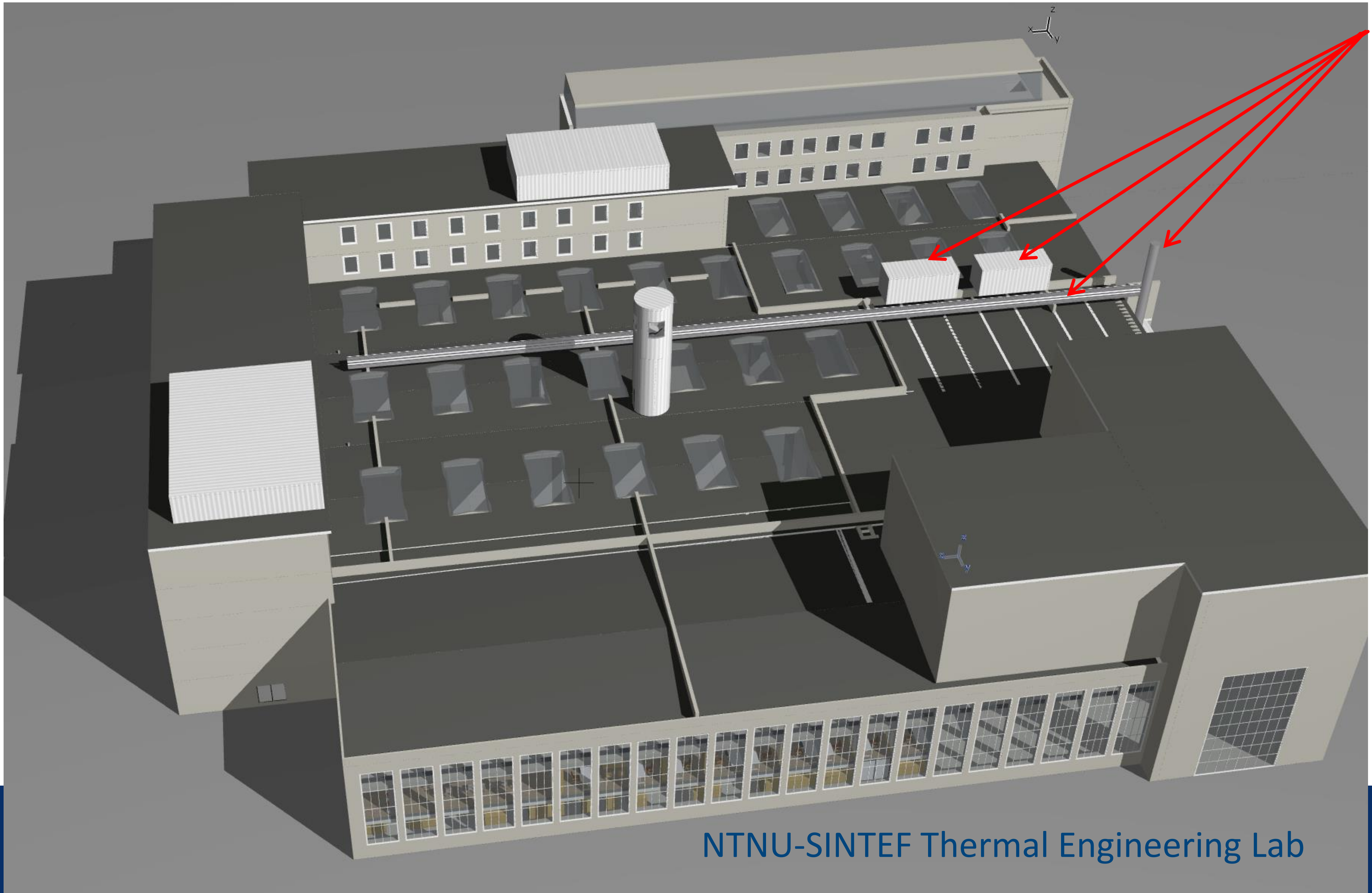
- Initial state 12 MPa, 293 K, see [2]

Ship transport of CO_2

- An enabling technology e.g. due to its flexibility
- Our research is relevant both for ship and pipeline transport
  - Thermophysical properties
  - Pipeline integrity and tank integrity
- Subjects for further study
  - Thermophysical properties
  - Loading and unloading
  - Non-equilibrium
  - Tank integrity
  - Boiling liquid expanding vapour explosion (BLEVE)

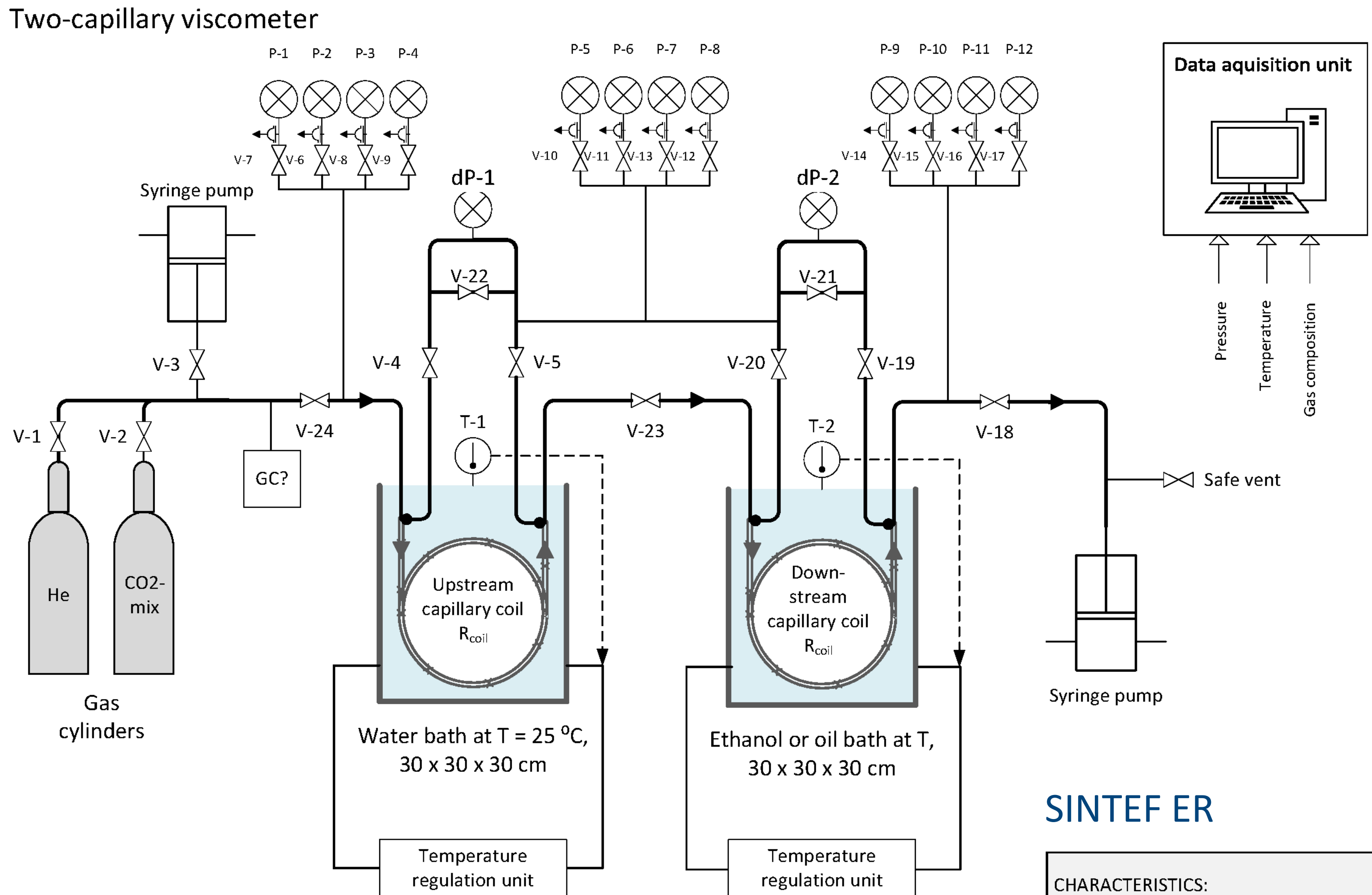
Depressurization facility

- Design is underway
- Will support development of depressurization flow models



Viscometer including liquid

- Design is underway
- Data needed e.g. for friction and for flow models in reservoirs



SINTEF ER

CHARACTERISTICS:
Temperature: from -60 °C to +200 °C
Working pressure: 1-200 bar

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Conclusions

- CO_2 can be (and is) transported.
  - CCS brings new challenges regarding scale, impurities, etc.
  - There is a need to ensure safety and efficiency.
- There is still no reference EOS for CCS. Accurate property models
  - Need high-quality data. There are still many white spots on the research map.
  - Are needed for safety, efficiency and metering.
- Transient multiphase flow calculations for CO_2-rich mixtures are needed.
  - For transient events in pipes and wells.
  - Loading and unloading of ships.
- Prediction of running-ductile fracture in CO_2 pipelines is a challenge.
  - The BIGCCS coupled fluid-structure model is one step towards the goal.
- Good initial results have been obtained:
  - Phase-equilibrium data, depressurization, fracture-propagation control.
- Now the fun begins.

Thank you for your attention

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References for the interested reader

1. Aursand E, Dørum C, Hammer M, Morin A, Munkejord ST, Nordhagen HO, 2014. CO_2 pipeline integrity: Comparison of a coupled fluid-structure model and uncoupled two-curve methods. *Energy Procedia* **51**, 382–391.
2. Aursand P, Hammer M, Munkejord ST, Wilhelmsen Ø, 2013. Pipeline transport of CO_2 mixtures: Models for transient simulation. *Int. J. Greenh. Gas Con*. **15**, 174–185.
3. Drescher M, Varholm K, Munkejord ST, Hammer M, Held R, de Koeijer G, 2014. Experiments and modelling of two-phase transient flow during pipeline depressurization of CO_2 with various N_2 compositions. *Energy Procedia* **63**, 2448–2457.
4. Hammer M, Ervik Å, Munkejord ST, 2013. Method using a density-energy state function with a reference equation of state for fluid-dynamics simulation of vapor-liquid-solid carbon dioxide. *Ind. Eng. Chem. Res*. **52**, 9965–9978.
5. Munkejord ST, Jakobsen JP, Austegard A, Mølnvik M J, 2010. Thermo- and fluid-dynamical modelling of two-phase multi-component carbon dioxide mixtures. *Int. J. Greenh. Gas Con*. **4** 589–596.
6. Nordhagen HO, Kragset S, Berstad T, Morin A, Dørum C, Munkejord ST, 2012. A new coupled fluid-structure modelling methodology for running ductile fracture. *Comput. Struct* **94–95**, 13–21.
7. Roussanaly S, Brunsvold AL, Hognes, ES, 2014. Benchmarking of CO_2 transport technologies: Part II – Offshore pipeline and shipping to an offshore site. *Int. J. Greenh. Gas Con*. **28,** 283–299.