IMPACTS

The impact of the quality of CO_2 on transport and storage behaviour

4th Newsletter, December 2014

Dear reader,

Before you is the fourth edition of the IMPACTS newsletter, covering the period August – December 2014. The newsletters inform partners and stakeholders on the developments in the EU FP7 IMPACTS project[1]. You can navigate through this document by clicking on the elements of the content list (below).

Previous newsletters:

- **Newsletter 1, January – July 2013**
- **Newsletter 2, August – December 2013**
- **Newsletter 3, January – July 2014**

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About IMPACTS

IMPACTS is a collaborative project co-funded by the European Commission under the 7th Framework Programme. The goal of the IMPACTS project is to close knowledge gaps related to transport and storage of CO_2-rich mixtures from various CO_2 sources to enable realisation of safer and more cost-efficient solutions for CCS. The results of IMPACTS will help to ensure safe and reliable design, construction and operation of CO_2 pipelines and injection equipment, and safe long-term geological storage of CO_2. The project started on 1 January 2013 and has a duration of three years. It has 12 research performing partners and 5 funding partners. You can find more information on the project website.

[1] If you wish to receive this newsletter, but are not on the mailing list, please send an e-mail to an.hilmo@sintef.no.

Events & meetings

Papers presented at the Greenhouse Gas Technologies conference 12 (GHGT12), October 6-9, 2014, Austin, Texas.

Two papers from the IMPACTS project were presented at the GHGT12 conference in Austin, Texas.

Stakeholder meeting, October 7, 2014, at the GHGT12 conference, Austin, Texas

An IMPACTS informational workshop was held during the GHGT 12 meeting in Austin on October 7th, 2014. Marit Mazzetti gave an overview presentation of IMPACTS. Marie Bysveen also from SINTEF gave an overview of the EERA CCS project. Then all the work packages gave a presentation Jacob Stang from SINTEF represented WP1 talking about impact of impurities in CO_2 transport. And Sebastian Fischer from GFZ showed results from the important CO_2/N2 injection experiments at Ketzin.

IMPACTS GOAL: ***To develop the CO_2 quality knowledge base required for defining norms and regulations to ensure safe and reliable design, construction and operation of CO_2 pipelines and injection equipment, and safe long-term geological storage of CO_2***

Filip Neele presented the work to be performed in WP3 as that has just now started. There was great interest in the techno economic assessment and the tools that are under development in WP3. The techno-economic tool aims to study the relation between CO_2 quality and the cost of constructing and operating a CCS system (including capture, transport and storage).

There was also a interesting guest lecture by Rebecca Hollins from CO_2 Global, USA. As Texas has the longest experience with operating CO_2 pipelines in the world, it was interesting to learn from the US Experience of impact of impurities in CO_2 pipelines.

IMPACTS Information workshop, GHGT12

The US has an extensive network of CO_2 pipelines as can be seen from the picture from Dr. Hollis's presentation shown below. The US pipelines are regulated by the US Department of Transportation.

The CO_2 pipelines are not hazardous. A 90% molar purity is required for supercritical. Pressure rating is 2-3000 psig, about 3 times that of natural gas pipelines.

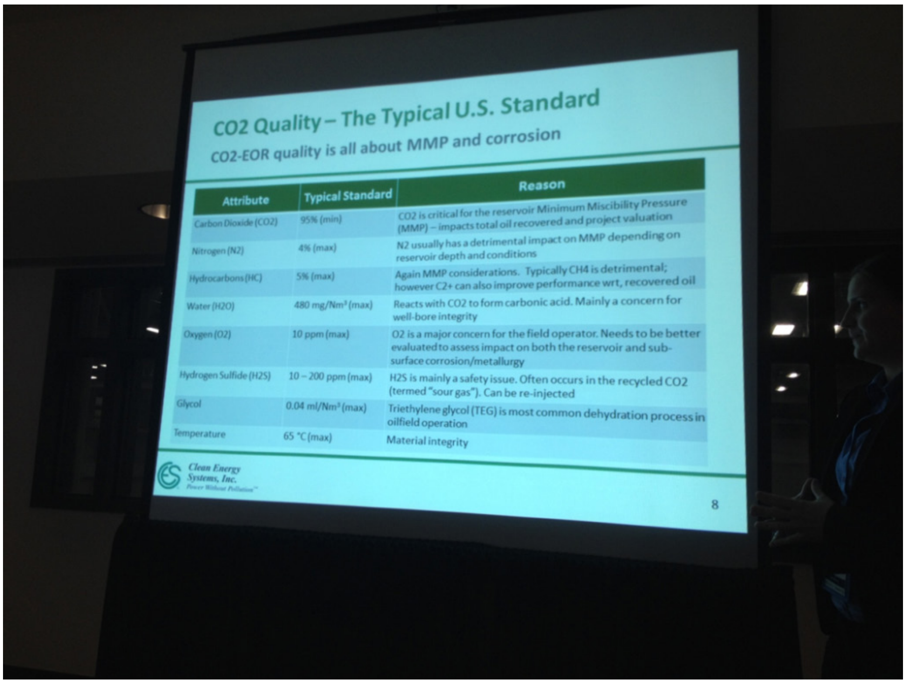
The standard in the US has been CO_2 for use in EOR. The CO_2 quality is therefore all about corrosion and MMP (Minimum Miscibility Pressure) which impacts total oil recovered and project valuation. The CO_2 is set to 95% purity. The nitrogen is limited to 4 % as it usually has a detrimental impact on MMP depending on reservoir depth and conditions.

Oxygen is set at 10 ppm max. It is a major concern for the field operator. It needs to be better evaluated to assess impact on both the reservoir and sub-surface corrosion/metallurgy. There is a H_2S requirement set at 10-200ppm (max.). It is a safety issue. It can be re-injected however.

Points brought up for further consideration were:

- There is extensive experience with CO_2 for EOR, however there is little compatibility with this and the requirements for storage in Deep Saline Formations (DSF).
    - DSF is more related to criteria for environment and safe drinking water
- There also remain challenges for defining CO_2 quality criteria with various capture technologies that require different downstream CO_2 processing and clean-up.

Overall it was an interesting workshop with great interaction and discussions among the participants.



Summary of the US Standard for CO2 Quality by Rebecca Hollins, Clean Energy Systems, USA

Impacts Informational Workshop Programme
14:15-14:30: Welcome and Introduction to the IMPACTS project
Marit Mazzetti, SINTEF
14:30-14:40: The EERA CCS project
Marie Bysveen, SINTEF
14:40-15:00: EOR requirements for CO_2 quality and composition- Experience from US Projects
Rebecca Hollis, Clean Energy Systems
15:00-15:15: Impact of impurities on CO_2 transport
Jacob Stang, SINTEF
15:15-15:30: Results from CO_2/N_2 injection experiment
Sebastian Fischer, GFZ
15:30-15:45 Techno-economic evaluation in Impacts
Filip Neele, TNO
15:45-15:55: Discussion and Wrap-Up

Workshop on September 23-24, at TNO, Utrecht, The Netherlands

Following the workshop in June, 2014, also held at TNO in The Netherlands, a second workshop was organised to further discuss the translation of results from the work done in the 'technical work packages' to input for the techno-economic model of CCS chains. The technical work packages focus on the study of CO_2 mixtures in such areas as fluid properties and behaviour, corrosion and transport and injection. In IMPACTS, the results from these studies are to be used to reach conclusions about the relation between the quality of the CO_2 stream and the design and operation of CCS chains –in terms of safety, technology and economics. The project's goal is a series of studies of the trade-offs between mixture quality and the costs of building and operating a CCS chain in various different circumstances.

The workshop concluded with identifying how each of the main categories of expected impurity influences were going to be "translated", what kind of result could be anticipated in each case and (importantly) who was going to provide what. This information is held in a document commonly known as the SP2 Shopping List.

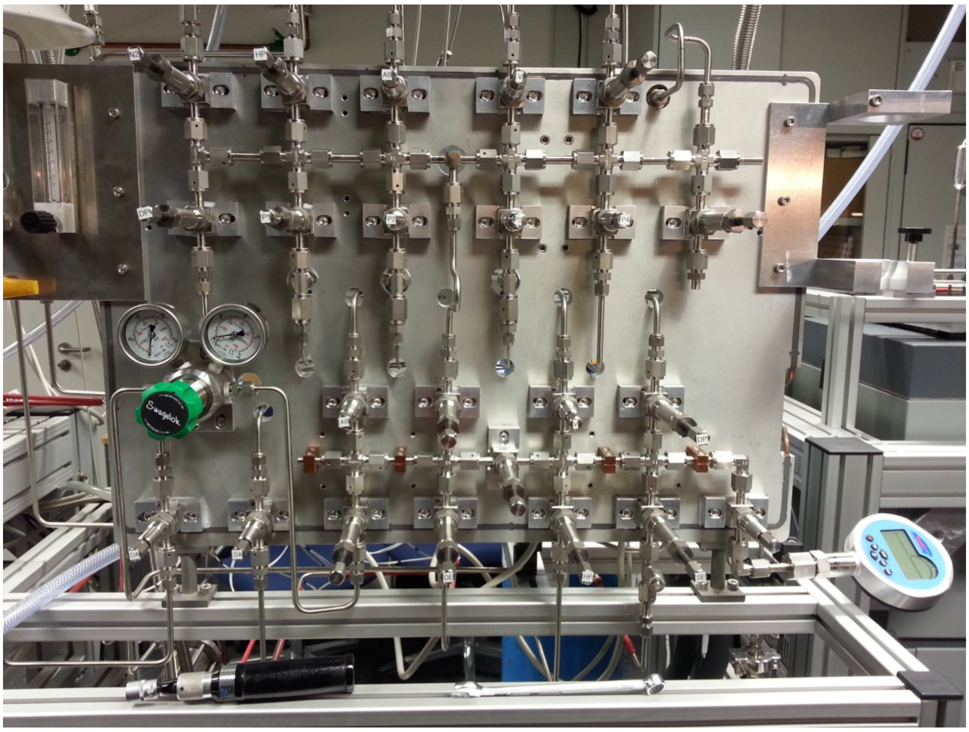
Executive Board meeting, October 20, 2014, Ruhr Universitat Bochum, Germany

The third EB meeting was held in October, in Bochum, hosted by the Ruhr Universität in Bochum.

Consortium technical meeting, October 21, 2014, Ruhr Universitat Bochum, Germany

A technical meeting was held on the day following the Executive Board meeting. The meeting was attended by most IMPACTS participants and used to update the group on the progress of work in the various work packages, as well as to look ahead at 2015, the final year of the project, and to prepare for dissemination activities like conference attendance and workshops.

After the meeting the lab facilities of the research group of Prof. Span were visited, to view the installations used to measure gas mixture properties.



A gas mixing installation in the labs of Ruhr University

Current activities

WP1.2 Thermophysical behaviour of CO_2 mixtures

In September 2014 Ruhr-University Bochum in Denmark organized an international workshop addressing algorithms for the evaluation of multiparameter mixture models. 22 scientists from six countries (including the USA and Japan) joined the workshop, which was closely related to the goals addressed in WP1.2 in Impacts. The whole team working on thermodynamic property models in IMPACTS attended the workshop.

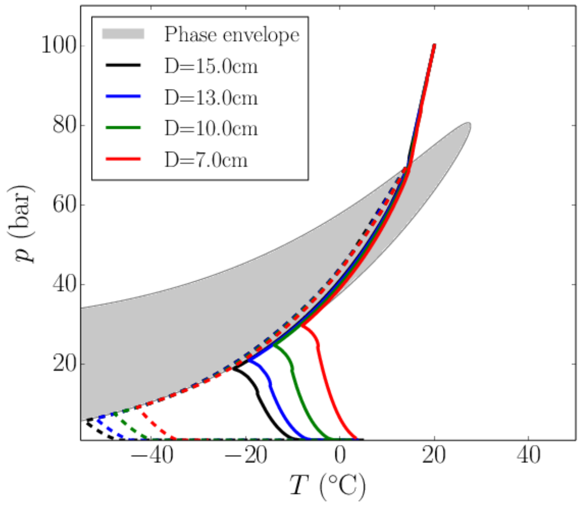
Participants of the modelling workshop in Denmark

Results of the work in Impacts were presented on the workshop "CO_2 Properties and EoS for Pipeline Engineering" organized by the UKCCS Research Centre in York in November.

The experimental work at Tsinghua and Ruhr-Universität continues. The data generated at both laboratories are directly utilized in the development of improved property models. Mutual visits have strengthened the cooperation between both groups. From October 2014 to March 2015 Xiaoxian Yang, a young researcher working on the Impacts project at Tsinghua University, stays at Ruhr-University as guest researcher to further intensify the cooperation.

WP1.3 Transient fluid dynamics of CO_2 mixtures

WP1.3 produced two deliverables in the past six months. The first concerned the effect of impurities on the lowest temperature reached during a depressurization. When emptying a pipeline filled with CO_2 there will be a large cooling due to the evaporation of the initially liquid CO_2. The report shows that the studied impurities (N_2, O_2, H_2, CH_4, C_2H_6) have a positive effect on the lowest temperature, that is there is less cooling than with pure CO_2. It also points out that the area of the valve through which the pipe is emptied has a much larger effect than impurities, as shown in the figure below.



Results from the de-pressurisation of a pipeline containing CO_2 with 5 mol% N_2, with varying valve opening diameter. The plot shows the state close to the valve (solid line) and at the escape-point inside the valve (dashed line), on top of the phase envelope for the initial mixture.

The second report contains a benchmark of three different simulation tools for CO_2 pipeline: The commercial simulator OLGA, ANSYS Fluent with CSM's thermodynamic library CO_2 GASMISC, and SINTEF Energy Research' in-house code. Both steady-state flow and depressurization and filling of a pipeline were considered, with impurities typical for various capture processes. Especially for depressurization and filling some discrepancies were found between the various tools. The report shows that simulation of two-phase flow of CO_2 with impurities still requires more research.

WP1.4 Corrosion potentials in CO_2 infrastructure

Corrosion and test corrosion tests are ongoing. Three different pipeline materials have been selected for the testing activity:

- Grade X60
- Grade X65
- Grade X70

The test corrosion testing activity will include measurements on samples cut out form a girth weld. All the samples have been machined. All the testing activity will finish in the first months of 2015.

WP1.5 Chemical and physical effects of impurities on CO2 storage

Within the last months the work performed in WP1.5 made a great step forward towards understanding the physicochemical effects of an impure CO_2 stream in the deep subsurface during injection and subsequent storage. Reservoir engineering simulations were conducted, considering mixture of gases, like CO_2 and SO_2, and assessed the influence of the various impurity concentrations in the CO_2 stream on e.g. the pressure development and storage capacity. In addition, the presence of CO_2 and additional substances has varying influences on chemical fluid-rock interactions and results most notably in dissolution of primary minerals and the precipitation of newly formed phases, causing changes in porosity and permeability. By using geochemical modelling tools we showed that the presence of SO_2 may have a significant influence on the porosity evolution of the reservoir sandstones over time. The fluid-rock interactions also caused minor pressure changes due to the transition of the gas-fluid-solid phases. In a second step, the porosity and pressure changes were integrated in an updated reservoir model to assess the influence of chemical mineral reactions on e.g. storage capacity. Although the chemical reactivity plays a role in geochemical models, the corresponding influence on the storage capacity was found to be insignificant. Similar geochemical modelling approaches and corresponding sensitivity analyses were performed on caprock material.

WP2.1 Operational and material effects of impurities in CO_2 streams

During the last quarter of 2014 CIUDEN has conducted internal tests to prepare in advance the CO_2 transport installation for measurements to be done early 2015. In parallel, a draft test matrix has been presented to the partners in Bochum for discussion; inputs and support were received from the group. CIUDEN is working jointly with PEL in the preparation of a special sample to be installed during the test session.

CO_2 back-production at the Ketzin pilot site successfully performed

To study the geochemical and operational effects of impure CO_2 and its subsurface behaviour, a four week N_2-CO_2 co-injection field test was conducted at the Ketzin pilot site in summer 2013 (see IMPACTS Newsletter No. 2). Major objectives included demonstrate the technical feasibility of a continuous N_2-CO_2 co-injection scenario, monitor spreading and behaviour of the CO_2-N_2 gas mixture in the reservoir, and determine potential chromatographic effects within the reservoir. During the field test, a total of 32 t of N_2 and 613 t of CO_2 were co-injected to ensure a CO_2:N_2 ratio of approximately 95:5. The CO_2-N_2 co-injection was followed by a final injection of 66 t pure CO_2. To allow study isotopic mixing effects, CO_2 from a natural CO_2 source was used for the field test instead of the normally used industrial CO_2 from a refinery process. The natural CO_2 had a much heavier carbon isotope composition ($\delta^{13}C$ = -3.4±0.2‰) than the industrial CO_2 ($\delta^{13}C$ = -30.6±0.4‰). To chemically mark the start of N_2-CO_2 co-injection field test, Krypton and SF_6 as additional inert tracers were injected. A capillary riser tube installed in a nearby observation well at 25 m distance to the injection well was used to collect reservoir fluid and gas samples. Based on Kr and $\delta^{13}C$ data, the CO_2-N_2 gas mixture arrived after about 17 days at the observation well. Increasing Kr concentrations positively correlate with both increasing N_2 concentrations and $\delta^{13}C$ values. Additionally, the $\delta^{13}C$ data also indicate mixing between natural and industrial CO_2 within the reservoir. The N_2-CO_2 co-injection field test terminated the injection period at the Ketzin site.

Picture courtesy T. Kollersberger, GFZ German Research Centre for Geosciences

The field test on N_2-CO_2 co-injection was complemented in October 2014 - 14 months after end of injection - by a field experiment on the back production of the formerly injected CO_2-N_2 stream from the reservoir. The field experiment aimed at three main questions: What is the chemical composition of the back produced CO_2 and the co-produced formation fluid? What is the behaviour of the reservoir and the wellbore during back production of CO_2? What is the surface spreading of the back produced CO_2? Over 13 days 240 t of CO_2 and 57 m^3 formation fluid have been safely and smoothly back produced from the reservoir and continuously sampled and analysed. The measured compositions of back produced CO_2 and formation fluid will allow study the geochemical interactions between impure CO_2, formation fluid and rocks under real in-situ conditions. First results indicate that the back produced CO_2 has a purity > 97%. Most important impurity in the back-produced CO_2 stream is N_2 which most probably stems from the N_2-CO_2 co-injection experiment. The N_2 concentration in the CO_2 stream decreased from about 3% to 1% during the two weeks duration of the experiment. During the back-production experiment, the N_2 was detected ab initio, although the N_2-CO_2 co-injection terminated with pure CO_2. Besides N_2, also the tracers Kr and SF_6 from the N_2-CO_2 co-injection experiment were detected with low concentrations of < 0.001%. First data on the composition of the back produced reservoir fluid suggest slightly increased potassium, magnesium and iron concentrations compared to pre-injection baseline data.

For more information about the Ketzin project, see the project web site.

WP2.2 Techno-economic analyses of impacts of CO_2 quality

The main activity within this work package has been to develop the ways in which the chemical and physical effects of impurities in the CO2 stream, derived from other work packages can be represented as cost influences within the techno-economic modelling work. This has been discussed carefully at the workshops in Utrecht (see above) and the model is being prepared to accept the expected results.

Another focus is improving the CCS chain cost database for the modelling work; this is being derived from both public and partner information and will be used to populate the basic economic model and the detailed cost influences.

WP2.3 Risk assessment

August 2014, WP2.3 participants delivered a comprehensive report, mapping the state-of-the-art in CCS risk assessment, existing recommended practices, guidelines and software. Considering the IMPACTS project scope, particular focus is placed on CO_2 with impurities. See below, report D2.3.1 under Publications, for a brief summary.

In 2015 work will be carried out to improve modelling of a worst case accidental release scenario, for instance a transport pipeline failure. The common practice with respect to quantitative risk assessment will be fine-tuned, will focus on the influence of impurities on CO_2 release behaviour. Thereto IMPACTS project aims for available datasets (release experiments of pure CO_2, not performed within the IMPACTS project), and make use of the equations of state produced by Ruhr Universität Bochum.

WP3.1 IMPACTS recommendations

This work packages, which started in the second half of 2014, aims to combine all results in IMPACTS into a set of recommendations for CCS projects. The recommendations will summarise the impact of the CO_2 composition, or of changing composition, on the design, operation and performance of CCS chains.

The recommendations will be presented in an IMPACTS report.

In 2014 the definition of the framework for the recommendations has started.

WP3.2 IMPACTS Toolbox

One of the deliverables from IMPACTS will be a 'Toolbox', which will contain all relevant results, conclusions, guidelines, rules of thumb, etc. from the various work packages in the project. Together with the recommendations from the overall project, which will be defined in WP3.1, this Toolbox aims to provide the data and results that can be used by CCS projects to establish the impact of impurities on their intended or ongoing project.

One element of the Toolbox is a new CO_2 properties reference model, which will contain all results obtained by Ruhr Universität Bochum, on the physical properties of CO_2 mixtures.

The work in the part of the project started in the second half of 2014, with a preliminary inventory of potential elements of the Toolbox.

WP3.3 Dissemination plan and IMPACTS workshop

This work packages contains the key dissemination activities in IMPACTS in 2015. These include:

- A workshop at the TCCS-8 conference in Trondheim, in June 2015. Prior to the conference, a workshop for stakeholders will be organised, to present the results obtained until that time (including the Toolbox, see WP3.2) and to discuss the framework for the formulation of recommendations (see WP3.1).
- A CCS course will be organised in Rumania in the Fall of 2015. Adjusted to the Master student level, the course will be open to both academia and people from industry. IMPACTS researchers will give lectures at the course.

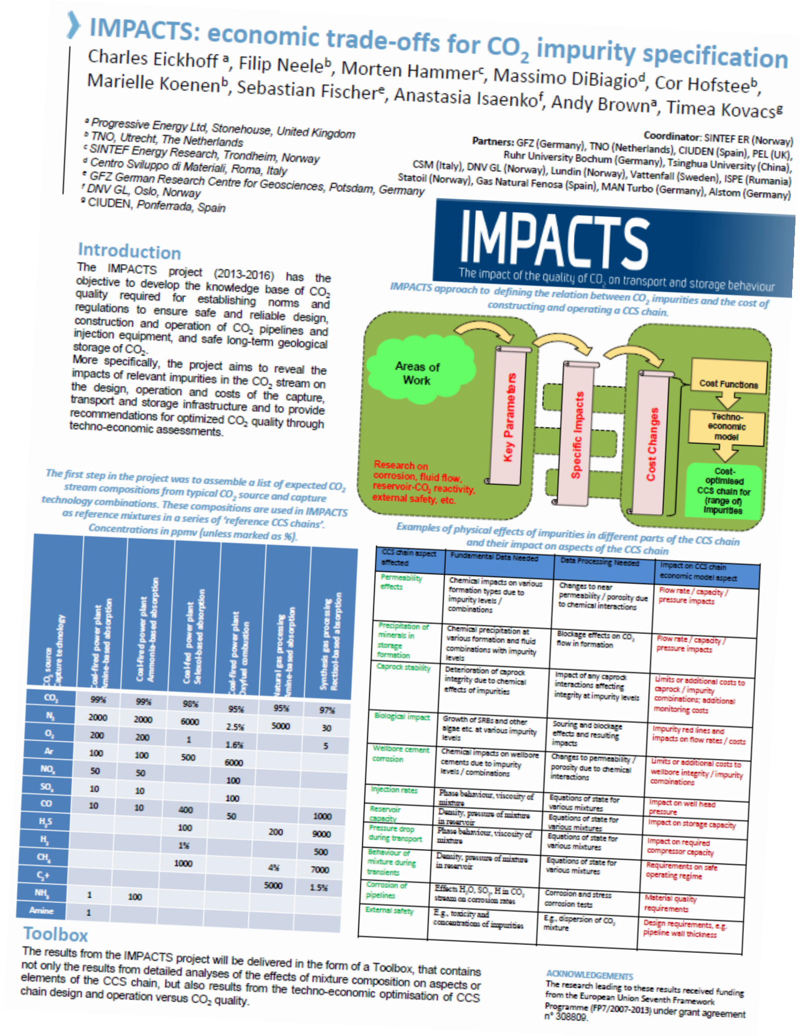
These activities form the first steps towards the definition of the IMPACTS results exploitation plan, which will be set up in this work package.

Publications

In the past period the following deliverables were produced.

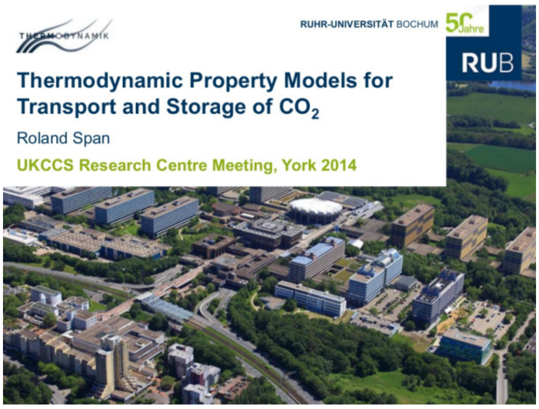
Poster at GHGT12 conference (October 2014, Austin TX), *IMPACTS: economic trade-offs for CO_2 impurity specification* by Charles Eickhoff (PEL), Filip Neele (TNO), Morten Hammer (SINTEF), Massimo DiBiagio (CSM), Cor Hofstee (TNO), Marielle Koenen (TNO), Sebastian Fischer (GFZ), Anastasia Isaenko (DNV-GL), Andy Brown (PEL), Timea Kovacs (CIUDEN)

The poster gives an overview of the IMPACTS project, with a focus on the techno-economic analysis that aims to analyse the trade-off between efforts at the capture side to deliver pure CO_2 and investments in transport and storage to deal with CO_2 with impurities.



Poster at GHGT12 conference (October 2014, Austin TX), *N_2-CO_2 co-injection field test at the Ketzin pilot CO_2 storage site* by Sebastian Fischer (GFZ)

This poster presented the injection of CO_2 and N_2 at the Ketzin site in Germany, also described above.



Keynote lecture, *Thermodynamic Property Models for Transport and Storage of CO_2* - Roland Span, Ruhr-Universitat Bochum, Germany, Presented at CO2 Properties and EoS for Pipeline Engineering, 11th November 2014

Roland Span presented on property model of CO_2 mixtures. *More*…

D1.3.1 *Report assessing the influence of CO2 mixture composition in relevant cases, using preliminary model* by Eskil Aursand (SINTEF)

This work is a computational study of the depressurisation of high-pressure pipelines containing CO_2 with the major (>1%) impurities expected from typical carbon capture technologies (N_2, O_2, H_2, CH_4 and C_2H_6). The focus was the effects these impurities may have on the temperature drop occurring close to and within the depressurization valve, as low temperatures could pose a safety hazard. *More*…

D1.3.4 *Benchmark study including commercially available tools and the model developed in Task 1.3.1.* by Jérémy Veltin (TNO), Halvor Lund (SINTEF) and Marco Bertoli (CSM)

Simulation of pipe flows with CO_2 and CO_2 mixtures is not yet current practice. A number of codes originally developed for the oil and gas industry can be used for this purpose. This report presents a comparison between different codes. Especially when phase change is expected, large deviations can be seen between codes. However such operational conditions are unlikely to occur very often during the lifetime of a pipeline. *More*…

D2.3.1 *Existing practice in risk assessment for CCS* by Angun Engebo (DNV-GL), Anastasia Isaenko (DNV-GL), Mark Spruijt (TNO), Ingrid Raben (TNO), Andy Brown (PEL)

There is an urgent drive to implement Carbon Capture and Storage (CCS) on a commercial and global scale. For success this needs to be done in a demonstrably safe and responsible manner that gains widespread acceptance of stakeholders, most notably regulators and the public. The goal of this report is to map state-of-the-art in CCS risk assessment, existing recommended practices, guidelines and software. Particular focus is placed on CO_2 with impurities. *More*…

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