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Toolbox of effects of CO_2 impurities on CO_2 transport and storage systems

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Abstract

There is a need to gather new knowledge on the fundamental properties of CO_2 mixtures with impurities and their impact on the chain integrity and economics of Carbon Capture & Storage (CCS) chains. One of the main results from the FP7 IMPACTS project is the IMPACTS toolbox, which comprises new experimental data, thermodynamic reference models for CO_2 mixtures relevant for CCS and the framework for CCS risk assessment taking Health Safety & Environment aspects, the impact of the quality of the CO_2 and CCS chain integrity into account, and finally the recommendations report.

Peer-review under responsibility of the organizing committee of GHGT-13.

Keywords:

1. Introduction

CO_2 has been transported for the purpose of enhanced oil or gas recovery for decades, particularly in the USA. While abundance knowledge exists on the topic of CO_2 transport and storage from research and learning-by-doing, it is well-accepted that there is a need to gather new knowledge on the fundamental properties of CO_2 mixtures with impurities and their impact on the CCS chain integrity and economics.

The EU FP7 project IMPACTS [1] was aimed at research into the impact of impurities in captured CO_2, from power plants and other CO_2-intensive industries, on CO_2 transport and storage. At the start of the project, the main uncertainties surrounding impurities in CO_2 transport and storage were related to the following areas:

- There was an incomplete understanding of the relation between impurities in the CO_2 and the properties of the mixture. Experimental data on mixture properties were incomplete; there was a need for verified property models that cover relevant mixtures of CO_2 and impurities;
- There was a limited understanding of the effect of impurities on materials, equipment, processes, operation and safety procedures;
- There was a need for a better understanding of the impact of impurities on storage integrity.

Knowledge about these issues is essential for safe and efficient transport and storage solutions for CCS.

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2. Objectives of IMPACTS project

The objective of the IMPACTS project [1, 2] was to develop a knowledge base on the relation between CO_2 quality and design, construction and operation of CO_2 pipelines and injection equipment. The following research objectives were addressed in IMPACTS:

- To quantify fundamental properties (e.g. phase behaviour, thermodynamics, fluid flow, and chemical reactions) of relevant CO2 mixtures through modelling, experimental work, and collection of existing data.
- To derive CO_2 quality issues while considering integrity of the whole CCS chain.
- To provide recommendations for optimized CO_2 quality on a case-by-case basis in the for CCS chains which are seen relevant for large-scale deployment of CCS.
- To reveal the impacts of relevant impurities in the CO_2 stream on the design and operation of the transport and storage infrastructure through techno-economic assessments.
- To build knowledge critical for implementation of optimized safe and cost-efficient transport and storage of CO2 strengthening the competence within industry, academia and regulatory bodies .

The IMPACTS project did not aim to develop recommendations for CO2 quality; rather, the knowledge base developed in the project is to be used by CCS operators to make decisions about the CO2 quality in their system from an analysis of the trade-offs between CO2 quality and transport and storage infrastructure design. To this end, the IMPACTS project covered a range of technology areas, that are described in some detail below. The COORAL project in Germany [3] also studied the impact of impurities from a whole-chain perspective.

3. Aim of the Toolbox

The IMPACTS Toolbox provides an overview of and an introduction into the IMPACTS project. It provides a point of access to the results obtained in the project on the effects of impurities in the CO2 flow CCS infrastructure in a range of technology areas. The Toolbox highlights the main results and conclusions. For example, the Toolbox summarises and presents the new experimental data that has been developed within the IMPACTS project. This includes thermodynamic reference models for CO2 mixtures relevant for CCS, as well as the framework for CCS risk assessment that takes HSE aspects, the impact of the quality of the CO2 and CCS chain integrity into account.

The Toolbox is available online [4] and contains links to publicly available reports and publications from the project.

4. Key features of the IMPACTS Toolbox

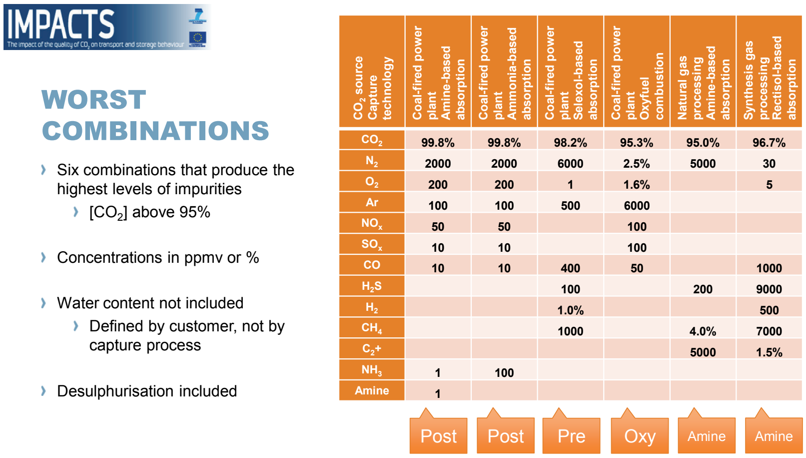
The IMPACTS Toolbox [4] contains a summary collection of the primary results from the project. The contents of the Toolbox is summarized here by showing a series of highlights for each of the technology areas covered by the project.

4.1. Typical CO_2 mixtures

The starting point in the project was an analysis of the range of impurity concentrations that could be expected for realistic combinations of emission sources and capture processes [5]. Fig. 1 shows the range of concentrations of the most common impurities; these ranges were used as guidance in the assessment of CO_2 impurity impact in the technology areas covered in the project.

4.2. Thermophysical behavior of CO_2 mixtures

A key effort in the project was to expand the volume and quality of thermophysical data and models of relevant CO_2 mixtures [6, 7]. The project contributed to a new version of the TREND software from Ruhr University of Bochum [7], which contains the latest set of binary mixture data (part of which was collected in the IMPACTS project [6, 7, 8]. TREND can be linked to other modelling software, making it possible to include in CO_2 transport and injection calculations the most up-to-date knowledge of the thermophysical behavior of CO_2 mixtures. The software also includes a new phase stability algorithm, developed by Ruhr-Univesity Bochum, that automatically handles up to three phases in equilibrium (see [6]); this means that hydrate formation can also be accurately represented in, for example, pipeline flow assurance studies.



CO_2 source Capture technology	Coal-fired power plant Amine-based absorption	Coal-fired power plant Ammonia-based absorption	Coal-fired power plant Selexol-based absorption	Coal-fired power plant Oxyfuel combustion	Natural gas processing Amine-based absorption	Synthesis gas processing Rectisol-based absorption
CO_2	99.8%	99.8%	98.2%	95.3%	95.0%	96.7%
N_2	2000	2000	6000	2.5%	5000	30
O_2	200	200	1	1.6%		5
Ar	100	100	500	6000		
NO_x	50	50		100		
SO_x	10	10		100		
CO	10	10	400	50		1000
H_2S			100		200	9000
H_2			1.0%			500
CH_4			1000		4.0%	7000
C_2+					5000	1.5%
NH_3	1	100				
Amine	1					
	Post	Post	Pre	Oxy	Amine	Amine

Fig. 1. Overview of combinations of emission source and capture process that produce CO_2 mixtures with highest concentration of specific impurities.

Fig. 2 shows the mixtures that can currently be handled by the TREND software.

4.3. Transient fluid dynamics

The detailed properties of CO_2 mixtures were used to compute transient phenomena in CO_2 pipeline structures. It was found that impurities can significantly alter the behavior of the mixture, with important implications for the conditions at which hydrates form or for the development of running ductile fractures. This applies even for small quantities of impurities. A simplifying assumption that CO2 is pure can therefore lead to significant underestimation of the fluid pressure during the decompression, with consequences for the prediction of running ductile fractures. Fig. 3 shows the Toolbox entry for this work.

One conclusion from this work is that the cricondenbar pressure should be the design criterion for operation of CO2 pipelines, to avoid two-phase flow and running ductile fractures, to limit over-specification and to reduce costs [9].

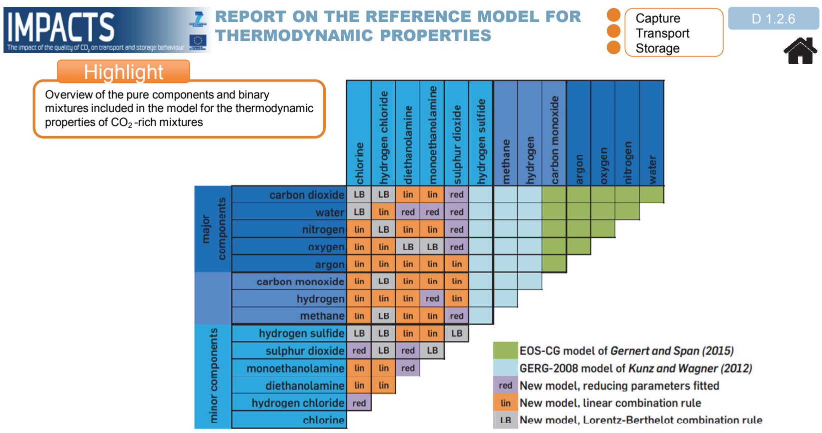


Fig. 2. Binary CO_2 mixtures covered by the TREND model, which was expanded with data during the IMPACTS project. The Toolbox provides a link to the TREND software.

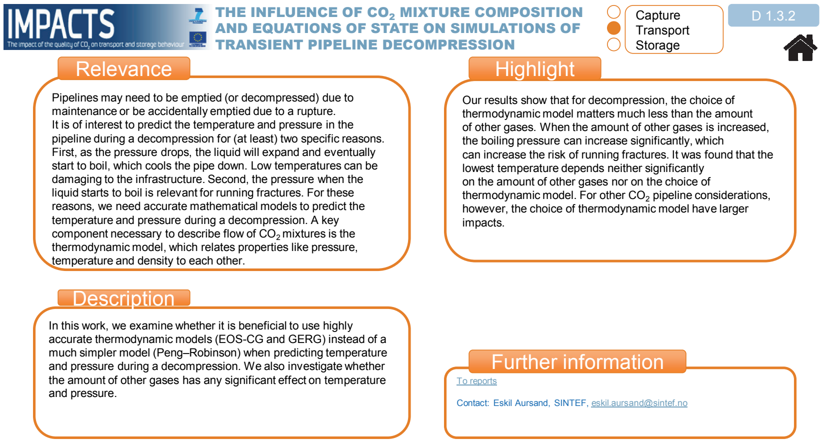


Fig. 3. Toolbox presentation of work related to the impact of impurities on transient phenomena in CO_2 pipelines.

4.4. Impurities and corrosion

The presence of a significant level of water in the CO2 stream causes many problems in pipelines and injection wells and is probably the most important impurity to control. To avoid excessive corrosion and stress corrosion, water levels should be as low as possible to prevent corrosion or hydrate formation. CO2 streams should be dried to levels below 350 ppm H2O, (in some situations suggested to below 50 ppm) to prevent significant corrosion. Water concentrations should be below 250 ppm to ensure no hydrate formation (above 70bar and -30°C). Hydrogen and H2S levels should each be kept to below 100 ppmm if there is significant (>1000ppmm) moisture in the pipeline / injection systems (see [10]). Fig. 4 presents some of the corrosion results obtained in the project.

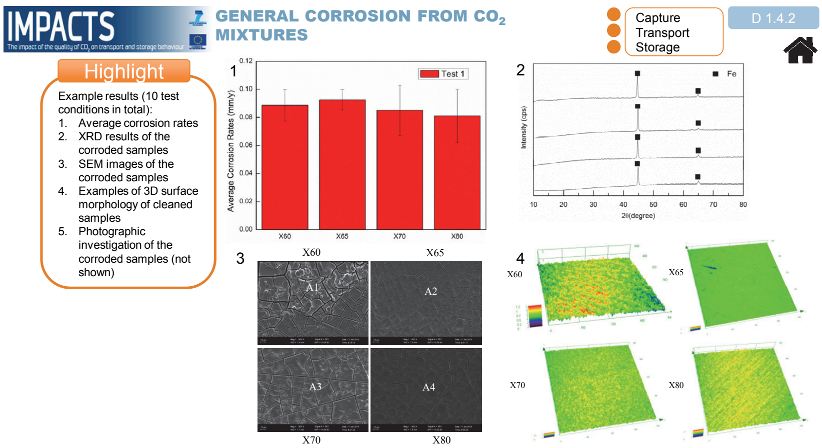


Fig. 4. Corrosion results presented in the Toolbox.

4.5. Impact of impurities on storage

Storage related research in IMPACTS included geochemical interaction between the CO_2 mixture and the storage reservoir, and the impact of impurities on storage capacity [11]. In addition, an injection test of 95% CO_2 plus 5% N_2 was conducted at the Ketzin site [12]. Conclusions were that storage of impure CO2 in formations at depths of around 800 m or less is unlikely to be economic compared to the option of reducing impurities at the source. CO2 for storage in chalk fields should be cleaned upstream – detailed tests needed if impurities should be stored in chalk fields. Generally accepted safe limit for oxygen level in CO2 injected into hydrocarbon reservoirs is 10 ppm [11].

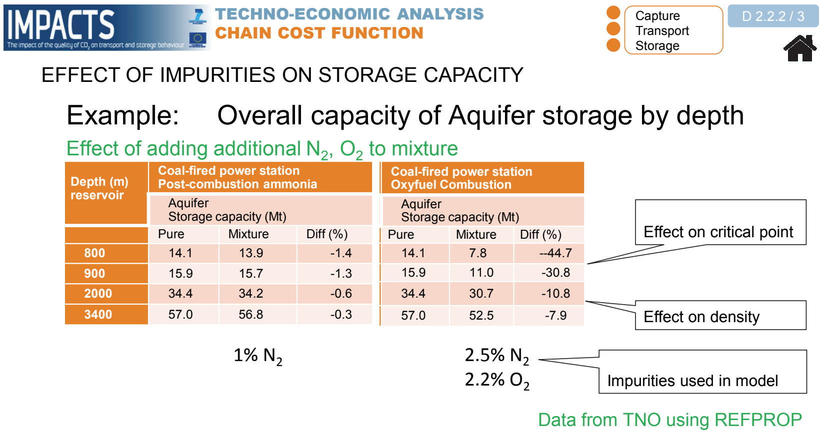


Fig. 5. Example slide from Toolbox that shows the impact of impurities on storage capacity. The effects shown are a combination of density decrease and displacement by the impurities. At shallow depths, 800 – 900 m, effects can be particularly significant when the critical point is shifted to higher pressure.

4.6. Techno-economical analyses of the impact of CO_2 quality on transport and storage infrastructure

The aim of the IMPACTS project was to consider the entire CCS chain, from capture to storage, tob e able to study trade-offs between CO_2 purity delivered by capture facilities and, e.g., material choice in downstream systems. Fig. 6 shows part of this trade-off: the cost of obtaining a specific CO_2 purity at the capture plant. Examples are shown for N_2 and water; the results are based on an estimated relative cost change, using an assumed reference concentration for either N_2 or water and using public cost figures for the capture processes. More specific results can be found in [5, 13, 14].

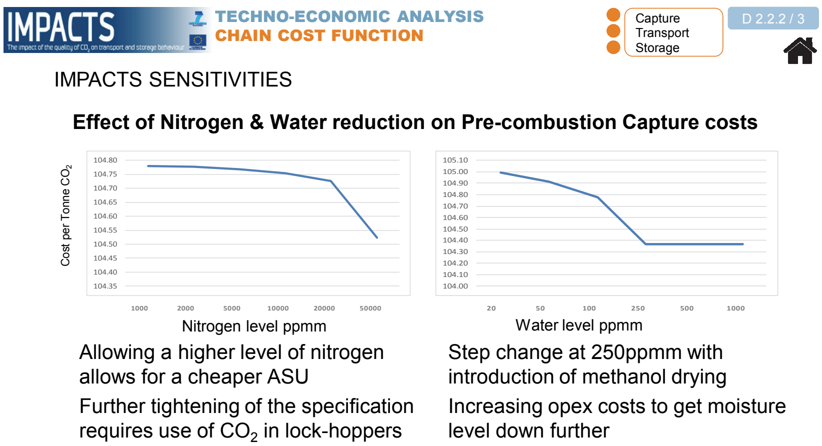


Fig. 6. Examples of techno-economic trade-off study in IMPACTS. Left: trade-off related to N_2 level; right: trade-off related to water content.

4.7. Risk assessment

The risk framework developed in IMPACTS used the purity levels derived from literature sources on existing or planned projects (see, e.g., [5, 13]) and concluded that there are no health issues presenting a ‘Red Line’ for specific impurities. At the levels being considered for the IMPACTS project the health impact of the CO_2 always dominates that of the impurities. In addition, at the levels being considered for the IMPACTS project the environmental impact of the CO_2 always dominates that of the impurities, and will normally be better than the “do nothing” option [15]. Fig. 7 shows an example of the risk material presented in the Toolbox.

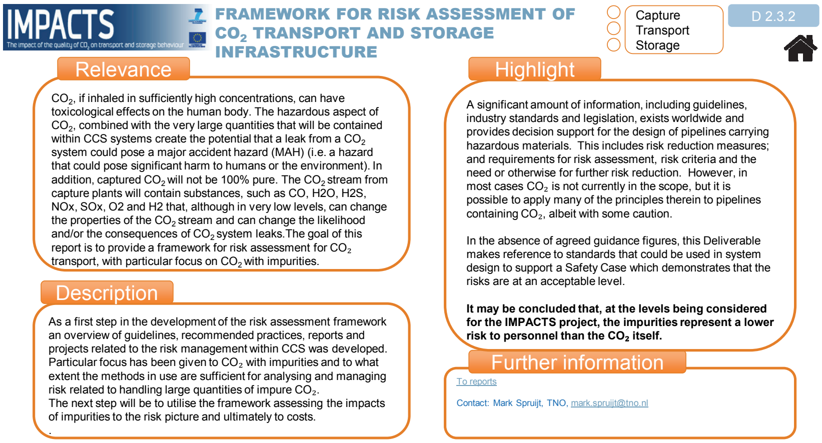


Fig. 7. Results related to risk assessment in the IMPACTS project, as presented in the Toolbox.

4.8. IMPACTS recommendations

The recommendations from the IMPACTS projects are derived from the results obtained in the technology areas addressed in the previous sections. the whole CCS chain analysis performed within the project resulted in recommendations at a more general level (see also [16], for a more extensive discussion). Some of these recommendations are:

- There is no easy, one-size-fits-all solution for the design of a CCS chain or for the definition of CO_2 impurities limits.
- It is generally more economic to clean up the CO2 stream at capture (upstream) than to deal with significant downstream effects.
- Measurements of thermophysical properties of CO2 with impurities should be implemented in models and tools – this should be a primary research focus in CCS. The best data and tools available should be used to design CCS chains on a case-by-case basis.

There are always trade-offs when selecting the optimum CO2 stream quality and deciding when and where to handle the impurities. These trade-offs are case-specific; the knowledge base developed in IMPACTS enables the assessment of the trade-offs for specific CCS chain conditions.

5. Conclusions

One of the main results from IMPACTS project is the IMPACTS toolbox, which gives an overview of and an introduction into the results of the project. The Toolbox is available online and links to the publicly available reports and publications from the project. The aim of the Toolbox is that it will be used by IMPACTS partners and CCS stakeholders as an introduction into the contribution of the IMPACTS project on the knowledge base on the relation between CO_2 quality and the design and operation of CO_2 transport infrastructure.

6. Acknowledgements

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