The IMPACTS project: The impact of the quality of CO₂ on transport and storage behaviour

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Abstract

The project The impact of the quality of CO₂ on transport and storage behaviour, IMPACTS, was kicked off in January 2013. IMPACTS is a collaborative project under the 7th Framework Programme for research of the EU and is addressing the impact of impurities in captured CO₂ from power plants and other CO₂-intensive industries, on CO₂ transport and storage. This encompasses fluid properties, phase behaviour and chemical reactions in the infrastructure complex and at the storage sites. These issues are paramount for ensuring safe and efficient transport and storage solutions for CCS, since capture of CO₂ without safe and efficient transport and storage offers no merit. IMPACTS has 12 research performing partners and 5 funding partners, and a total budget of 5.6 million Euros over three years. This paper outlines the concept, objectives, research approach and organisation of IMPACTS.

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1. Introduction

Carbon Capture and Storage (CCS) is an important element of the SET Plan [1], including the CCS European Industrial Initiative (EII) on CCS [2] and Roadmap for CCS deployment [3]. The impact of the quality of CO₂ on transport and storage behaviour, IMPACTS [4], responds to these by performing research and development of the...
impact of impurities in captured CO\textsubscript{2} from power plants and other CO\textsubscript{2}-intensive industries, on CO\textsubscript{2} transport and storage. This encompasses fluid properties, phase behaviour and chemical reactions in the infrastructure complex and at the storage sites. These issues are paramount for ensuring safe and efficient transport and storage solutions for CCS, since capture of CO\textsubscript{2} without safe and efficient transport and storage offers no merit.

IMPACTS was kicked off in January 2013 and has a duration of three years. Twelve research performing partners are involved as well as five funding partners. The project has a total budget of 5.6 million Euros over three years.

2. IMPACTS Concept

The main idea of IMPACTS is to close identified knowledge gaps related to transport and storage of CO\textsubscript{2}-rich mixtures from various CO\textsubscript{2} sources to enable realisation of safer and more cost-efficient solutions for CCS. Already a decade ago, it was pointed out by Span [5] and Austegard and Mølnvik [6] that CO\textsubscript{2} transport implies specific challenges that must be addressed through fundamental research.

The main problems of impurities in CO\textsubscript{2} transport and storage are:

- Lack of experimental data and verified property models for mixtures of CO\textsubscript{2} and impurities related to CO\textsubscript{2} capture
- Understanding the effect of impurities on materials, equipment, processes, operation and safety procedures
- Understanding how impurities will affect the storage integrity

CO\textsubscript{2} has been transported for the purpose of enhanced oil or gas recovery for decades, particularly in the USA. Further, several CCS chains are currently in operation and more are planned\textsuperscript{1}. Thus, much knowledge exists on the topic of CO\textsubscript{2} transport and storage. Nevertheless, during the last few years, numerous research projects on CCS conducted by research and industry actors and other relevant work\textsuperscript{2} have concluded that there is a need to build new knowledge on the fundamental properties of CO\textsubscript{2} mixtures with impurities and their impact on the CCS chain integrity and economics [7]. Further, the 2010 Carbon Sequestration Leadership Forum (CSLF) Technology Roadmap [8] sets forth these issues as priority activities to enable deployment of CCS.

The concept of IMPACTS is illustrated in Fig. 1. An iterative process will be employed to reveal the consequences of the CO\textsubscript{2} mixture composition on transport and storage infrastructure.

- First, the fundamental properties of relevant CO\textsubscript{2} mixtures will be investigated. This will provide new and necessary knowledge for CO\textsubscript{2} transport and injection regarding thermodynamics, fluid dynamics and corrosion potentials in the infrastructure. New insights regarding the chemical and physical effects of impurities on geological storage of CO\textsubscript{2} will be given (SP1).
- Large-scale experiments will produce data on the effect of impurities on CO\textsubscript{2} transport and storage. The results will then be employed to assess the techno-economic impacts of CO\textsubscript{2} mixture composition on the transport and storage infrastructure design and operation, and also to evaluate possible consequences for HSE (SP2).
- These findings will provide feedback to SP1 regarding alternative CO\textsubscript{2} mixture to study. The results achieved in the whole process will constitute a technical knowledge base (see Fig. 2) for developing future standards, protocols, performing techno-economical trade-offs and developing practices for design and operation of CO\textsubscript{2} pipeline and storage site infrastructures (SP3).

\textsuperscript{1} Weyburn, Slepiner, Rangeley, In-Salah and Snøhvit.
\textsuperscript{2} Carbon Sequestration Leadership Forum, Det Norske Veritas, national projects
In addition to the research establishments, industry actors and standardisation organisations will participate actively in directing the research in IMPACTS, since they have large interests in exploiting the results beyond the project.

![Fig. 1. The concept of IMPACTS.](image)

**3. IMPACTS objectives**

The objective of IMPACTS is to develop the CO₂ quality knowledge base required for defining norms and regulations to ensure safe and reliable design, construction and operation of CO₂ pipelines and injection equipment, and safe long-term geological storage of CO₂. By this, IMPACTS support the objectives of the Innovation Union³ and contributes to the implementation of large-scale CCS and the competitiveness of the European CCS industry. The following S&T objectives will be pursued in IMPACTS:

- To quantify fundamental properties of relevant CO₂ mixtures. This includes, but is not restricted to, phase behaviour, thermodynamics, fluid flow and chemical reactions.
- To reveal the impacts of relevant impurities in the CO₂ stream on the design and operation of the transport and storage infrastructure through techno-economic assessments.
- To derive CO₂ quality issues while considering integrity of the whole CCS chain.

To provide recommendations for optimized CO2 quality on a case-by-case basis in the form of tolerance levels, mixing protocols, material selection which are seen relevant for large-scale deployment of CCS, abating CO2 from power plants and other CO2-intensive industries.

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.

To disseminate IMPACTS results externally at international conferences and internally at annual seminars.

To pursue innovation and uptake of results in the industry by close integration of vendors, standardization bodies and end-users in the project.

4. Research approach and project structure

The IMPACTS project structure is developed to support the proposed strategy and to ensure achieving the project objectives. IMPACTS comprises three R&D subprojects (SPs) and 11 subordinated work packages (WPs), see Fig. 3. In addition, IMPACTS includes a sub project dedicated to overall project co-ordination, operational management including legal, financial and administrative issues, and dissemination (SP4). The IMPACTS project structure is designed to enable good integration of the topical research to be conducted by the partners allowing optimal information flow, extensive knowledge sharing and to some extent researcher mobility. Fig. 3 illustrates the overall structure of the IMPACTS project by outlining how the subprojects and work packages are interlinked by the main routes for the IMPACTS information flow. The different subprojects and work packages are described below:

**Fig. 3. IMPACTS work breakdown structure and information flow.**

Subproject 1 Fundamental properties of CO2 mixtures (SP1): The primary objective of SP1 is to gain knowledge on fundamental properties and behaviour of relevant CO2 mixtures. This will be achieved by collecting existing data, acquiring new data and developing accurate property models. Furthermore, transient flow dynamics, chemical reactivity and corrosion, as well as physical interactions with materials at various storage sites will be studied. The knowledge of fundamental properties and behaviour of CO2 mixtures gained in SP1 will provide input to SP2 and SP3.
Work package 1.1 Typical CO₂ mixtures and framework for characterisation: In WP1.1, typical CO₂ mixtures from power production and industry will be defined, together with how these mixtures may vary with differing technological solutions. Knowledge gaps regarding relevant CO₂ mixtures will be mapped. A framework for CO₂ mixture characterisation will be defined, forming a basis for classification of impurities in CO₂ streams and for the assessments made in SP1 and SP2.

Work package 1.2 Thermophysical behaviour of CO₂ mixtures: In this work package, thermophysical properties of relevant CO₂ mixtures will be experimentally investigated and modelled. Existing experimental facilities at Ruhr University Bochum, SINTEF Energy Research and Tsinghua University will be employed. Ruhr University Bochum maintains laboratories able to measure densities in the gas and supercritical region and of the saturated and subcooled liquid speed of sound and viscosity. SINTEF Energy Research has a set-up to provide vapour-liquid equilibrium data of CO₂ mixtures relevant for CCS. Tsinghua University has a set-up to measure densities of relevant CO₂ mixtures and compositions at pressures and temperatures relevant for CCS.

Work package 1.3 Transient fluid dynamics of CO₂ mixtures: In WP1.3, work will be undertaken to lay the foundation for sensitivity studies on the effect of varying CO₂ mixtures and compositions for relevant transient situations in CO₂-transport pipelines such as first fill and depressurization. Herein, algorithms will be developed to include the thermodynamic reference model from WP1.2 in a pipeflow model. The work will employ an existing numerical code at SINTEF Energy Research as a starting point. The WP comprises model development and validation and benchmarking. In the benchmarking task, available tools such as Olga, LedaFlow and Fluent will be employed. Results will be provided as input to the SP2 activities, in particular depressurization experiments in WP2.1 and the whole-chain analyses performed in WP2.2.

Work package 1.4 Corrosion potentials in CO₂ infrastructure: WP1.4 will evaluate the corrosion and stress corrosion degradation risks for pipeline transport of CO₂ mixtures. The work package comprises three tasks. The first task is a literature survey, analysis of existing data and selection of materials-environment matrix. The second task is an experimental investigation of uniform corrosion from CO₂ mixtures. The third task is an investigation of stress-corrosion cracking from CO₂ mixtures.

Work package 1.5 Chemical and physical effects of impurities on CO₂ storage: Chemical reactions between the impurities and the reservoir rocks may modify the porosity, thus altering injectivity, or affect the caprock integrity. Physical effects like phase behaviour, storage capacity, permeation flux and buoyancy may also affect injectivity. These effects will be studied, which will result in improved models for the short- and long-term effects of impurities on CO₂ storage. This will allow sensitivity studies to be made. The work package comprises five tasks. First, knowledge gaps will be mapped, based on the results of WP1.1. Second, small-scale experiments will be performed to unveil chemical and physical effects of impurities on storage properties and technical installations. Third, numerical models accounting for the effects of impurities on CO₂ storage will be developed. Fourth, sensitivity studies to study the short- and long-term effects of impurities will be carried out. Finally, knowledge-based recommendations concerning impurities in the CO₂ feed will be provided.

Subproject 2 Techno-economic assessment of CO₂ chains (SP2): The primary objective of SP2 is to evaluate the effects of CO₂ quality on the design and operation of CO₂ transport and geological storage infrastructure with focus on the technical, economical and safety issues. The work will be based on the improved knowledge of fundamental properties and behaviour of relevant CO₂ mixtures gained under SP1 and will form the basis for deriving the project recommendations in SP3. This will be achieved by the means of experimental investigations of the impacts of CO₂ quality in pilot rigs and verification against field data (WP2.1) as well as theoretical techno-economic analysis (WP2.2) and risk assessment (WP2.3) of specified case studies.

Work package 2.1 Operational and material effects of impurities in CO₂ streams: In this WP, the effect of impurities on operation and materials along the transport and storage line will be studied on larger scale. Field
studies and experiments on semi-industrial scale will be conducted to complement the fundamental lab-scale studies performed in SP1. Various work packages under SP1 will provide input to the present work package on the CO₂ compositions, materials, and operational conditions to be studied. The industrial partners will also assist in collating the envelopes of operational regimes within which certain mixtures have impacts on flow or materials in transport and on the reservoir and storage stability. The data collected under the present work package will produce actionable impacts about effects of impurities on transport and storage to other work packages, in particular WP2.2.

**Work package 2.2 Techno-economic analyses of impacts of CO₂ quality:** In this work package, a number of reference CCS chains will be defined that contain elements representative of all operationally relevant issues for CO₂ mixture behaviour in the system. The chains represented in the project will be used as benchmarks. A set of representative techno-economic parameters for these chains will be assembled. The range of parameters will be guided by the chosen regimes in WP1.1 and results emerging from SP1. The performance of a CCS chain will be computed by linking models of each element of the chain, including transport and storage, using the properties of the CO₂ flow. The changes in the elements of the CCS chain will then be quantified by deriving parameter variations for the techno-economic analysis. The goal will be to produce impact assessment tables and trade-off proposals, based on the economic impacts associated with the technical performance changes along the whole chain.

**Work package 2.3 Risk assessment:** The objective of this work package is to develop a framework for CCS risk assessment taking HSE aspects, the impact of the quality of the CO₂ and CCS chain integrity into account. The aim is to further develop the knowledge base and guidelines that help the users to identify optimal case-to-case solutions rather than limiting the operating window through tight specifications. This should make the users able to identify the optimum of the three-dimensional trade-off between cost, material choice and safety.

**Subproject 3 Synthesis and recommendations (SP3):** The main objective of SP3 is to synthesise the results of the project and to make them easily available to the users, both to the IMPACTS partners and the CCS community. This will be achieved by summarizing the obtained results (collected and acquired experimental data, developed models, and quantified operational and safety impacts of impurities) to form a common platform for the IMPACTS toolbox (WP3.2) and further by interpreting the results and deriving the recommendations for safe and reliable design and operation of the CO₂ infrastructure (WP3.1) as well as formulating the guidelines for the implementation of the project findings (WP3.3).

**Work package 3.1 Overall assessment of impacts of CO₂ quality:** The objective of this work package is to make a synthesis of the findings of the IMPACTS project and to point out the central challenges related to transport and storage of CO₂ with impurities. The synthesis will in addition to pointing at the central challenges also include an overview of competing issues and key quality requirements. Practical recommendations will be provided where possible for cost-efficient operational purity specifications and any necessary resultant precautions. Further, the impacts of impurities concentration on the capture side requirements will be assessed. Finally, the work package will develop the final report, IMPACTS Recommendations. The report will include:

- Guidelines on the need for upstream conditioning of CO₂ stream (based on input from WP1.2)
- Guidelines on the transient operation of pipelines (based on input from WP1.3)
- Guidelines on the need for anti-corrosion measures in the CCS chain (based on input from WP1.4)
- Guidelines on the operation and integrity of injection wells (based on input from WP1.5 and WP2.1)
- Guidelines on the choice of storage site and on assurance of reservoir integrity and stability (based on input from WP1.5 and WP2.1)
- Guidelines on the trade-offs between CO₂ composition, CCS system performance targets and the design and cost of the CCS chain (based on input from WP2.2)
- Rules of thumb for mixing different of CO₂ qualities in a multi-user transportation system (based on input from WP2.2)
Framework for risk assessment of CCS considering CO₂ stream with impurities (based on input from WP2.3)

Work package 3.2 Technical knowledge base for CO₂ transport and storage: The aim of this work package is to collect the results from the work packages in SP1 and SP2 and to make them available to the partners in the project and to the CCS community. This includes the data and models developed as well as the results of the techno-economic and risk assessment. A new, internationally accepted standard CO₂ property reference model will be made available to the industry and academics, using the internationally accepted reference data bases of the American National Institute of Standards and Technology (NIST). The ISO standard ISO20765-2, Natural gas – Calculation of thermodynamic properties will also be developed. Further, the IMPACTS Toolbox will be built, collecting the results from the work packages. The collection will include data both from the literature and acquired during the project on the fundamental research of SP1, as well as results from the techno-economic studies, trade-off analyses and risk assessment performed in SP2. The Toolbox is aimed to be easily accessible from a CD or a web page.

Work package 3.3 Implementation of results: The objective of this work package is to develop a plan for implementation of the findings of the IMPACTS project in order to ensure effective exploitation of the results and efficient transformation into a real contribution to the realization of CCS as targeted in the European Industrial Initiative (EII) on CCS. The ambition is to implement internationally recognised standards, which the industrial partners will use in their commercial projects. To ensure a short lead time from the generation to the utilisation of the results, a synthesis, implementation and dissemination workshop will be organised as a side-event of TCCS-8. Finally, a CCS course will be arranged in Romania, adjusted to the level of Master students.

Subproject 4 IMPACTS project management, dissemination and facilitation of international (SP4): The objective of the SP4 is to coordinate the project and take care of the operational management including legal, financial, and administrative issues and to ensure efficient dissemination of the project results.

Work package 4.1 Project management and co-ordination: This work package is dedicated to the management of the project, to ensure the organisational efficiency of the project.

Work package 4.2 Project dissemination: This work package will encourage and accompany dissemination activities, like workshops, CCS courses, scientific and popular science publications. In the work package, the website will be developed and newsletter will be written and published.

5. Organisation

IMPACTS is set up with an Executive Board, where the research-performing and the funding partners are full and equal members, with one representative each. The management of the project is delegated to the project coordinator, who chairs the Project Management Team. The latter comprises Project Coordinator, the Project Manager and the Subproject leaders. Decisions are delegated as extensively as possible to the lowest level, the work package level, and in particular, the allocation of working capacity and other resources to the planned activities. The structure of the project organization is shown in Fig. 4. The research partners consist of twelve legal entities:

- six research and technologic development partners:
  - SINTEF Energy Research, Norway,
  - Ruhr-University Bochum (RUB), Germany,
  - The Fundación Ciudad de la Energía (CIUDEN), Spain,
  - Netherlands Organisation for Applied Scientific Research (TNO), Netherland,
  - Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum (GFZ), Germany,
  - The Tsinghua University, China,

- three engineering companies:
The IMPACTS project aims at identifying and filling knowledge gaps within transport and storage of CO₂ with impurities. Basic-oriented research on the impacts of impurities on thermodynamics, fluid dynamics in pipelines, corrosion and reactivity of reservoir rocks will be performed in order to build models for techno-economic analyses and risk assessment. The results from the project will enable the industry to evaluate trade-offs between the cost of removing impurities at the capture site, and the cost of handling the impurities in the transport and injection networks.

The project concept will enhance the communication between the work packages and the subprojects, and ensure that the fundamental research performed will respond to the specific industry needs and challenges. A dedicated subproject will synthesise and make the knowledge generated in the project available to the IMPACTS partners and the CCS community.
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