Publishable Summary for 21GRD06 MetCCUS
Metrology Support for Carbon Capture Utilisation and Storage

Overview

Europe must make reductions in CO_2 emissions in order to meet stringent reduction targets related to global warming. Carbon capture utilisation and storage (CCUS) can be used to remove the CO_2 produced by industrial processes for storage either underground or locked in an alternative material. It is versatile, in the sense that the CO_2 removal step can complement any process e.g. production of power, fuels, chemicals and heating. In order to facilitate efficient and safe usage of this technology across Europe and to support the CCUS industry, this project will address key measurement challenges related to flow metering, emissions monitoring, chemical metrology and the physical properties of CO_2.

Need

The European Union set a target to reduce greenhouse gas emissions by 55 % by 2030 and to become carbon neutral by 2050. To support meeting these ambitious targets the Green Deal was introduced which specifically states that “priority areas include clean hydrogen, fuel cells and other alternative fuels, energy storage, and carbon capture, storage and utilisation”. As of the end of 2020, several European countries including Czechia, Finland, France, Germany, Portugal, the Netherlands, Denmark and the UK had included CCUS as part of their national strategies. The European Commission has acknowledged the role that CCUS plays in meeting this target, but have also stated that “the environmental integrity of CCUS is their overriding concern”. Monitoring of carbon dioxide through flow metering within the delivery system and through leak monitoring outside the system is key to quantifying real amounts of carbon dioxide captured (Objective 1). Directive 2009/31/EC on the geological storage of carbon dioxide stated a requirement of a regulatory framework for monitoring CO_2 leakage which was established through the Emissions Trading System (Objective 2). Additionally, as highlighted by the European Metrology Network for Energy Gases in their annual Strategic Research Agenda and in an energy transition report on CCUS measurement challenges authored by NPL with contributions from NEL, new requirements for measurement solutions were identified for CO_2 quality assurance, physical properties and material testing, such as pipeline corrosion and capture solvent degradation (Objectives 3 and 4). The reports were written following direct consultation with over 300 stakeholders from European industry including the key players within the CCUS field. This will be the first metrology for CCUS project that will solve the key metrology challenges for CCUS identified by industry and it will provide the Primary Standards, methods, good practice guides and literature reviews that they require to successfully grow a CCUS industry in Europe.

Objectives

The overall aim of the project is to develop new metrology tools in the form of Primary Standards and methods, as well as the relevant best practice/guidance, necessary to support industry in carbon capture utilisation and storage. The specific objectives of the project are:

1. To develop a metrology infrastructure for monitoring the CO_2 gas-flow and CO_2 liquid-flow as required by the CCUS industry with target uncertainties of 1.5 % – 2.5 %, including development of primary facilities and transfer standards, by investigating existing flow facilities for the possible use with CO_2 and development and intercomparison of new facilities for both intermediate scale (typically below 50 m_3/h and low pressure) and large scale flow (Q_{max} = up to 400 m_3/h and higher pressure).

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2. To develop the metrological support to enable the measurement and reporting of emissions to air from different stages of the CCUS process; including novel methods to determine emissions to the atmosphere through carbon capture processes, infrastructure (leaks), or geological storage.
3. To develop new standards and measurement methods to support European industries with performing the gas composition measurements required for carbon dioxide within CCUS; including primary reference materials with low-level impurities in CO_2, sampling methods to determine the material compatibility of key impurities in CO_2, online gas analysers for monitoring impurities in CO_2 as well as to determine CO_2 quality.
4. To establish the metrological infrastructure to support the design, monitoring and maintenance of industrial infrastructures dedicated to carbon capture, transportation, utilisation, and storage; including development of a coherent empirical model for understanding the thermophysical properties of CO_2, and sensors and procedures to preserve the efficiency of the transportation and utilisation of CO_2.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), standards developing organisations (ISO TC 265) and end users (CCUS industry).

Progress beyond the state of the art and results

The progress beyond the state of the art for the objectives and the planned results from this project are:

Metrology infrastructure for monitoring the CO_2 gas-flow and CO_2 liquid-flow (objective 1)

No independent, traceable, flow calibration facilities are available for calibrating flow meters with carbon dioxide across the full range of conditions which are likely to occur in capture, transport and storage. Carbon Capture and Storage (CCS) streams may be in gas, liquid, dense phase, or possibly supercritical state at metering locations. Investigation is required into the risk of operating near phase boundaries where phase change and two-phase flow could affect accuracy and the effects of impurities could shift the phase boundaries. New traceable flow calibration facilities and primary standards will be developed in this project to evaluate the performance of various flow meter types when used with gaseous and liquified carbon dioxide including an assessment of the lowest uncertainties. The project will also provide guidance on calibrating these meters with alternative fluids that are common in laboratories.

Primary volumetric facilities have been upgraded at the start of the project for intermediate scale (up to 30 m^3/h and atmospheric pressure) and large scale (up to 400 m^3/h and Pmax = 65 bar). In the next phase of the project measurements will start to calibrate flowmeter with pure CO_2 gas and to determine the transferability with alternative gases. Literature research has been performed and first drafts of the reports “Summary on the Current State of the Art in Traceable Liquid CO_2 Flow Measurement” and “CO_2 fiscal metering requirements applicable for CCS fiscal metering at an international and European level” were prepared.

Metrological support for measuring and reporting of CO_2 emissions to air (objective 2)

Methods for accurately measuring emissions from post-capture flue gas (including amines present in capture solvents) have not been developed and validated. The project will develop a facility capable of simulating emissions from post-capture flue gas and new methods to monitor emissions (Proton Transfer Reaction Mass Spectrometry (PTR-MS), Cavity Ringdown Spectrometer (CRDS), Fourier-Transform Infrared (FTIR)).

Potential techniques for monitoring and quantifying carbon dioxide leaks from pipelines and storage sites (including sub-sea) are available (e.g. acoustic imaging, sonar bathymetry and tuneable diode lasers) but these techniques have not been validated as possible methods for quantifying leaks for sites. To ensure the performance of these instruments meets industry requirements, testing must include accuracy, selectivity (against air and other leaks), spatial resolution and repeatability. The project will develop capability to simulate precise CO_2 leaks from pipelines to test and validate commercial new leak monitors. Further, methods will be developed to monitor large scale CO_2 leaks from on-shore and sub-sea storage sites using state of the art gas detection techniques such as LIDAR and other spectroscopic methods.

Input has been collected for several reports: 1) requirements for post combustion carbon capture (PCC) emissions monitoring, 2) methods for nitrosamine monitoring and 3) identification of CO_2 leak scenarios from storage such as sub-sea leaks. The controlled release system has been modified to generate CO_2 test emissions. Work is underway to develop test procedures for the system.

Chemical metrology (objective 3)

For accurate composition measurements, offline analysis will be needed. Some reference mixtures have been prepared previously by research organisations (such as SINTEF); however, these have been mainly high amount fraction inert gases in carbon dioxide to support fluid property measurements. The project will identify the key impurities in CO_2 that need to be measured by industry, and it will develop the analytical methods, Primary Reference Materials and good practice for sampling.

The solvents used in capture materials degrade over time; there is a need for a measurement method that can monitor solvent degradation and for the validation of the analytical techniques that can monitor for the release of additional impurities due to the breakdown. The project will develop a testing rig capable of subjecting capture solvents to high temperatures under controlled CO_2 atmospheres (containing varying levels of impurities). This facility will allow CO_2 capture cycling to monitor degradation and the presence of impurities from the material.

An overview with all the impurities and corresponding amount fractions present in CO_2 in the CCUS industry has been performed that has determined for which impurities the primary reference materials will be prepared by October 2023. During the remainder of the project the stability of the reference materials will be investigated. Two reports have been written: 1) “Literature survey on commercially available cylinders for the preparation of PRMs for CCUS” and 2) “Literature survey on current state-of-the-art for the material compatibility of vessels for the sampling of CO_2 for CCUS”. Both reports are available on the project website.

Understanding the physical properties of CO_2 to support CCUS industrial infrastructure (objective 4)

Knowledge of the thermophysical properties of carbon dioxide mixtures with a range of potential impurities, and within the operational conditions of CCS processes, presents some gaps between the experimental data and the requirements of the system design and operation. Even complex equations of state (Lee-Kesler, SAFT and GERG) do not provide accurate results for the pressure, volume and temperature (PVT) properties and the vapour-liquid equilibrium (VLE) for carbon dioxide mixtures. The development of a specific reference equation of state and mixing rules for CCS is essential and underway (e.g. Equations of State for Combustion Gases (EOS-CG)), for which the density, speed of sound and VLE data of the selected mixtures is needed. Although EMPIR JRP 20IND10 Decarb included a literature review of this data, no laboratory work was performed. One work package in this project will be dedicated to physical property measurements, which includes experimental work to provide traceability for a physical property (density, viscosity, heat capacities and speed of sound) at a specific gas composition (made traceable through the preparation of binary mixtures). Furthermore, activities will be focused on developing new equations of state models and uncertainty budgets.

Three different compositions for binary mixtures of CO_2 with amines have been selected and a measurement protocol has been tested. The first measurements have been performed, measuring the density at (313 and 393) K at ambient pressure only for Methyl Ethyl Amine (MEA) at 30 % with 0.2 mol CO_2/mol MEA, measuring density of MEA at 30 % with 0.2 mol CO_2/mol MEA, for temperatures between (293 and 393) K and pressures up to 10 MPa, and speed of sound measurements starting with MEA at 30 % with 0.2 mol CO_2/mol MEA, for temperatures between (303 and 393) K and pressures up to 12 MPa.

Outcomes and impact

During the first months of the project, to maximise the impact of the project and ensure a wide dissemination of the knowledge generated, the consortium gave 8 presentations at conferences and workshops, as described below. A website (www.metccus.eu) and LinkedIn page (MetCCUS: Overview | LinkedIn) were created. Furthermore, a 24-member stakeholder committee was set up containing members from industry end users, regulation policy makers, standardisation bodies, instrument manufactures and academic institutes. In December 2022 the first stakeholder advisory board meeting took place with around 15 stakeholders from various European countries.

For industrial communities, presentations were given at following conferences: 1) European flow measurement workshop (EFMWS2023), March 2023 in the Netherlands, 2) Carbon Capture Summit Europe 2023, June 2023 in the Netherlands and 3) Emerging Fuels Symposium 2023, June 2023 in the United States. For the metrology and scientific community, presentations were given during following conferences workshops and meetings: 1) Congrès International de Métrologie (CIM), March 2023 in France, 2) EMN energy gases workshop, March 2023 in Portugal, 3) DANIAmet meeting, February 2023 in Denmark, 4) IX Jornades de Investigadoras de Casilla y León, February 2023 in Spain, 5) XV Reuniónde Jóvvenes Investigadores Iberoamericanos, April 2023 in Spain and 6) EURAMET TC-flow meeting, April 2023. Presentations were given

also during the following meetings of standardisation committees: 1) CEN/TC 264 Air Quality and 2) ISO TC 265 Carbon dioxide capture, transportation, and geological storage WG2 transportation.

Outcomes for industrial and other user communities

Using the CO_2 primary standards, the leak monitoring methods and the reports/guides developed in this project, CCS operators will be able to perform flow metering and leak monitoring of CO_2 to accurately quantify amount of CO_2 capture, transported, stored and lost in their process. This is required to operate the facilities safely, but also to quantify CO_2 capture and losses when reporting.

Using the Primary Reference Materials, new gas analysis methods, a materials testing facility, physical property methods and other guidance developed in this project, CCS operators and CO_2 suppliers will be able to determine suitable conditions and materials (e.g. pipelines). In addition, they will be able to monitor these conditions through purity and physical property measurements to ensure safe and efficient operation.

Knowledge will be transferred from the project to users by sharing all reports and good practice guides on the project website as well as to stakeholders by sharing these documents and any other developments (methods and standards) through a LinkedIn profile page.

Outcomes for the metrology and scientific communities

NMIs and DIs will develop Primary Standards for flow metering, gas analysis, physical property measurement and leak detections specifically which can be used to develop new Calibration and Measurement Capability (CMCs) to support national traceability for these measurements in CCUS. Furthermore, these new capabilities can be utilised by other measurement or calibration laboratories to provide their own calibration services for the CCUS community.

Laboratories, research organisations and academia will be able to use the new capabilities developed by NMIs, DIs and the other research participants in this project in order to perform high quality research within the CCUS area. The measurements will be traceable to the SI and suitably accurate so that the results obtained will support the development of new CCUS technologies.

The project will perform fundamental scientific work in the development and uncertainty evaluation of equations of state for CCS conditions.

Outcomes for relevant standards

The consortium will promote the results of the project within the standardisation community and will provide input into the standardisation process (ISO, CEN). For ISO, the standards relevant to the project that are in preparation/revision are identified, and the work on these standards will be suggested to the appropriate working groups or committees. There are plans to establish a new European working group dedicated to CCUS within CEN over the next few years, and the work from this project will greatly support the development of new standards within this working group.

The deliverables of this project are expected to directly support development or revision of standards within ISO/TC 265. The following ISO standards and New Work Item Proposals from ISO/TC 265 include measurements that will be studied in this project, and can be improved through this project, during the next revision: **I**SO 27913:2016 - Carbon dioxide capture, transportation and geological storage - Pipeline transportation systems, ISO 27914:2017 - Carbon dioxide capture, transportation and geological storage - Geological storage, ISO/TR 27915:2017 - Carbon dioxide capture, transportation and geological storage - Quantification and verification, ISO/TR 27921:2020 - Carbon dioxide capture, transportation, and geological storage - Cross Cutting Issues - CO_2 stream composition, ISO/TR 27922:2021 - Carbon dioxide capture - Overview of carbon dioxide capture technologies in the cement industry, and NWIP (approved June 2021) - Performance Index and Standard Test Method of Absorbent Performance for CO_2 Capture.

Longer-term economic, social and environmental impacts

<u>Economic impact</u>

The work of this project will support the flow metering, emissions monitoring, purity analysis and physical property measurements performed directly by CCUS operators.

Flow metering of carbon dioxide is required for monitoring emissions for CCS processes according to the EU Emissions Trading System (ETS). Inaccuracies could lead to errors in the calculations, which could either lead to overcharging of carbon emission costs or fines for providing inaccurate information.

The work of this project will support the monitoring of leaks in pipelines. The early identification of leaks will reduce the risk of extensive damage/loss of CO_2.

Impurities in carbon dioxide if not monitored can provide problems to the CCUS operator through unintended toxic releases, and corrosion or damage to pipelines, equipment and storage sites. These incidents can be costly. Firstly, they will require the operator to stop operation, but there would also be considerable costs for maintenance, repair and equipment replacement.

The work of this project will support CCUS operators, particularly for reducing operational costs. Impure carbon dioxide in CCS processes (e.g. inert gases at volume percent level) can increase energy requirements (for compression) which would inherently increase the cost of operation.

An inaccurate equations of state model (or the lack of one) may lead to issues with meeting CCUS operator conditions by not being able to monitor real physical properties. This could lead to dangerous scenarios for operation such as over-pressurisation or even cases where pure hydrogen could bubble out from the CO_2 and come into contact with pipelines.

Social impact

Developing new capability to monitor for carbon dioxide leaks is imperative for ensuring health and safety in the gas industry and it will protect citizens.

A focus will be made to educate new players (e.g. laboratories and instrument manufacturers) entering the CCUS market on the importance of laboratory accreditation and showing competency through comparisons, either for purity analysis or for the performance of online analysers. This will be a principle aim of the project.

Several technical seminars will be hosted by the participants to disseminate the newly developed standards and methodologies to allow fast uptake by commercial laboratories and organisations.

Several countries across Europe are running their own independent projects implementing CCUS technologies; however, this project will be the first time relevant industrial stakeholders from across Europe will join together in a collaborative effort to progress this topic.

The project, through hosting a website, organising seminars, presenting at conferences and running a Stakeholder Advisory Board will inherently support better networking between gas distribution networks, and the relevant laboratories and instrument manufacturers.

Environmental impact

CCS contributes to reductions of carbon dioxide emissions which support countries to meet targets set by the Climate Change Act. The activities within this project will not only support CCS for decarbonising gas, but all CCS processes including those used in tandem with power production and the direct extraction of carbon dioxide from the air. Many of the measurement requirements specified in this project originate from mandatory legislation, such as the EU ETS or national legislation (that may reference International Standards). Where legislation has not yet been developed, this project will support its development by ensuring the relevant measurement capability is already available.

The direct environmental impact from the metrological infrastructure, methods and guides generated from this project is as follows:

- The entire project is focused on supporting the success of European companies in implementing CCUS technologies; doing so will support the significant decrease in CO_2 emissions from industrial and energy processes or by direct air capture.

- Companies will have the ability to accurately measure carbon dioxide in CCS processes to track their carbon dioxide emissions in accordance with the EU ETS.

The potential future uses of the project are as follows: Calibration facilities for gaseous CO_2 developed in the project will help the CCUS industry to obtain accurate CO_2 flow measurements within the uncertainty requirements of specifications to monitor flow in delivery systems and also for leak monitoring. The project will validate commercial techniques for monitoring and quantifying CO_2 leaks from equipment and CCUS infrastructures such as pipelines but also CO_2 leaks from storage sites. This will help the CCUS industry use leak monitoring equipment with confidence and reduce the risk of extensive damage and loss of CO_2. Primary reference materials for impurities in CO_2 will be developed. These materials can be used to calibrate online and offline measurement systems for CO_2. The use of primary reference materials and accurate gas analysis

methods will help the CCUS industry and laboratories to perform accurate purity measurements for CO_2. Furthermore, the project will set up experimental measurements to determine the physical properties of CO_2 in a mixture with capture solvents and validate equations of state to support the CCUS process and flow metering. This will lead to better understanding of the effect of impurities on the behaviour of CO_2 to ensure efficient and safe usage of the CCUS technology.

List of publications
n/a

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	1 October 2022, 36 months	
Coordinator: Iris de Krom, VSL	Tel: +31152691754	E-mail: idekrom@vsl.nl
Project website address: www.metccus.eu		
Internal Beneficiaries: 1. VSL, Netherlands 2. CMI, Czechia 3. DFM, Denmark 4. FORCE, Denmark 5. INRIM, Italy 6. IPQ, Portugal 7. JV, Norway 8. PTB, Germany 9. RISE, Sweden 10. VTT, Finland	External Beneficiaries: 11. Air Liquide FuE, Germany 12. DNV, Netherlands 13. DTU, Denmark 14. GERG, Belgium 15. NOVA, Portugal 16. RUB, Germany 17. SINTEF ER, Norway 18. UNITO, Italy 19. UVa, Spain	Unfunded Beneficiaries:
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