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Contents

Steel slag wastes to fight the climate change

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Abstract. Steel slags are solid by-products generated from the steel-manufacturing industries. They are considered valuable wastes for capturing of carbon dioxide (CO_2) directly from the air and industrial sources and storing it permanently in the form of mineral carbonation. In this study, two historic steel slags are presented as sustainable materials for mineral carbonation. The effects of contacting time between CO_2 and slags as well as temperature were investigated as two important parameters during mineral carbonation. The amount of carbonation, chemical and physical properties of carbonated samples have been characterised using Calcimeter, Fourier-transform infrared spectroscopy (FT-IR) and Scanning Electron Microscopy (SEM). The results showed that depending on the source and composition of the steel slags, the maximum CO_2 sequestration after 4 days at 60 °C is reached as high as 300 kg per tonne for samples. The FT-IR results showed the symmetric stretching of O-C-O bonds at 1400-1500 cm^{-1}, gradually increased with increasing temperature and contacting time, indicating the significant capture of CO_2 due to the carbonation process. SEM images confirmed that for both samples after the mineralisation, several carbonate layers were created in the structure of steel slags. The results indicated that CO_2 sequestration in steel slag is positively correlated with contacting time and temperature, hence the current study provides the optimal conditions to accelerate the process of carbonation for industrial application. It is estimated that these steel slags alone could carbonate about 150-200 million tonnes of CO_2 emissions which is equivalent to one third of annual UK greenhouse gas emissions.

Keywords: CO2 sequestration, steel slag, carbonate mineralisation, carbonate characterization, contact time impact, temperature impact.

MAGNEX and PILCCU in Finland: deployment of CO_2 mineralisation in circular economies

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Abstract. Two ongoing projects in Finland, MAGNEX (*Viable magnesium ecosystem: exploiting Mg from magnesium silicates with carbon capture and utilization*) and PILCCU (*Piloting of ÅA CCU*) aim at using CO_2 mineralisation technology for the overlapping purposes of large-scale CO_2 emissions mitigation and bringing several valuable material streams into circular economies, including construction. Of central importance are magnesium-based materials, such as magnesium carbonate hydrate (MCH), besides (amorphous) silica and several metallic species. On top of revenues from these, CO_2 emissions mitigation lowers the financial penalty from CO_2 emission rights under for example the European ETS.

The ÅA process routes are stepwise processes based on extraction of magnesium (and other species) from serpentinite-containing mining tailings from Finland, followed by precipitation of metallic species, carbonation using a CO_2 containing gas-stream (no separate capture step needed) and recovery of solvent salt, respectively. Several separation steps involve (ion-selective) membrane electrodialysis. Besides ongoing mapping and characterisation of Finnish rock resources as tailings or other side-streams at metal and mineral mines in Finland, the projects address public acceptance, legislation and other non-technical issues related to large-scale roll-out of this type of CCU technology.

For the use of the solids, magnesium-based cement binders and plaster-like recipes are investigated as well as applications for the (amorphous) silica and other residues, including the use of MCH for cyclic thermal energy storage (TES). Special focus is on accelerating the carbonation step and the final outcome of MCH production, considering pressure (including supercritical CO_2 levels), and the role of recoverable catalysts and other additives.

The work receives funding from the Academy of Finland (2022-2025) and from Business Finland plus industry partners (2022-2024), respectively.

Keywords: CO_2 mineralisation, Finland, technology deployment, circular economies, public acceptance, rock resources, process chemistry.

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Economic, regulatory, policy and carbon-accounting considerations for implementation of CCUS in the Baltic Sea Region

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Abstract. Successful development of CCU and CCS hubs and clusters is as much a technological challenge as it is a non-technical challenge. Non-technical challenges across social and political aspects, economics, monitoring, reporting and verification (MRV), as well as legal, regulatory and contractual aspects all can become showstoppers if they are not given the due careful attention.

Non-technical challenges tend not to predetermine success. Instead, they represent malleable and dynamic factors that evolve over time in response to broader changes in narratives, politics, evolving planning processes, and other regulatory requirements. Attending to non-technical challenges – particularly through proactive measures (e.g. engaging with regulators) requires time, which unless planned for carefully – alongside engineering and business development efforts – may add to the time required for achieving operation through the stages of scoping, planning, and implementation.

The proposed talk will outline some of the most prominently discussed challenges across the various non-technical areas – as identified in the first part of the project CCUS ZEN toward identification of promising CCUS hubs and clusters in selected European regions especially regarding potential challenges in the Baltic Sea region.

Keywords: policy, economics, public perception, social acceptance, carbon markets, monitoring reporting and verification.

Perspectives of the offshore CCS development in the polish EEZ on a Baltic Sea: insights from ongoing preliminary research for pilot CO_2 injection

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Abstract. The key to effectively combatting progressive climate change lies in promptly reducing greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), whose concentration continues to rise due to human activities. The European Union (EU) has established legally binding targets, including achieving climate neutrality by 2050, with an intermediate goal of reducing GHG emissions by 55 % by 2030 compared to 1990 levels. Poland, one of the major CO_2 emitters in Europe, also possesses significant storage potential in terms of projected CO_2 capacity within its sedimentary basins. Considering this, the implementation of Carbon Capture and Storage (CCS) technology could play a crucial role in Poland's efforts to decarbonize its economy. For several years, the Oil and Gas Institute – National Research Institute (INiG – PIB) has been at the forefront of domestic research activities concerning underground CO_2 injection. The involvement dates back to 1996 by pioneering the development of a concept, design, and implementation of one of Europe's earliest industrial installations for reinjecting acid gas, consisting of approximately 80 % CO_2 and 20 % H_2S, into the reservoir water underlying a productive natural gas field. This facility in Borzęcin operated by PGNiG (now part of ORLEN GROUP), is a unique testing ground where the injection process has been running continuously for 27 years. The research conducted at INiG – PIB has played an important role in identifying appropriate geological structures in Poland with a total storage capacity of 10-15 Gt CO_2. Around 90-93 % of the CO_2 storage capacity is found in saline aquifers, with a significant portion of approximately 7-10 % identified within mature hydrocarbon fields.

Despite recent progress in managing industrial CO_2 emissions, the peace of CCS development falls short of meeting the objectives set by the Paris Agreement. The main hindrance lies in the absence of a suitable regulatory framework for CO_2 transport and storage infrastructure. Recognizing this challenge, the national offshore operator, Lotos Petrobaltic (LPB), presented in 2021 a Green Paper on CCS development in Poland. This document outlines a set of recommendations for legislative alternations to facilitate the initiation of large-scale, commercial CCS projects within the country. Given the current national regulations and assumptions regarding low social barriers, the most expeditious approach to implementing a First-of-a-Kind (FOAK) large-scale CCS project in Poland seems to involve deploying depleted hydrocarbon reservoirs located at the Polish Exclusive Economic Zone (EEZ) within the Baltic Sea. The LPB, with research and scientific support from INiG – PIB, has launched a program aimed at conducting a preliminary assessment of CO_2 injection in Middle Cambrian sandstones. The project is scheduled to begin with a pilot injection into the well-identified, depleted structure of the B3 oil reservoir. Subsequently, it may be expanded to include adjacent hydrocarbon reservoirs and could ultimately

encompass the entire Cambrian aquifer.

The Cambrian aquifer is characterized by complex tectonics, comprising several blocks separated by fault zones. These fault zones may act as barriers to the propagation of reservoir fluids, as demonstrated by the presence of hydrocarbon traps in the vicinity of some fault zones.

The B3 oil field, covering an area of 36,2 km^2, is an elongated SW-NE, asymmetric anticline, cut on the west side by an inverted fault zone. The reservoir interval, with an average depth of 1450 meters below sea level comprises of sandstones of the Paradoxides Paradoxissimus (Middle Cambrian Zone) horizon showing a monoclinal dip towards the south-east. The reservoir formation exhibits heterogeneity in both within the vertical profile and the horizontal direction, characterized by a wide range of petrophysical parameters values. According to preliminary assessments, the CO_2 storage capacity of the B3 site is estimated to be around 7 Mt CO_2. The expansion of CO_2 storage to the remaining hydrocarbon fields and the overarching Cambrian aquifer megastructure could potentially increase the total storage capacity to more than 150 Mt.

The envisioned CO_2 sources include emitters from the chemical industry, where CO_2 is a by-product of the fertilizer production process. During the project's pilot phase, the predicted CO_2 injection rate is expected to be between 25-50 kt CO_2 per year. As the project transitions to the upscaled phase, the injection rate is projected to increase significantly, reaching approximately 2 Mt CO_2 per year. The transportation of CO_2 for full-scale injection is planned through multimodal means, considering potential synergies with the multimodal CO_2 Terminal in Gdansk, which is being planned under the ECO2CEE project (formerly EU CCS Interconnector). A pipeline connection between the offshore storage area and the CO_2 Terminal is under consideration.

The main research problems addressed within the INiG – PIB and LPB joint initiative include determining the sequestration potential of the Cm2pp aquifer, assessing the feasibility of the CO_2-EOR process, recognizing the effects of injected CO_2/reservoir rock/caprock interactions on injectivity, geomechanical parameters, and sealing integrity, as well as investigating CO_2-induced corrosion of steel components in the transport and injection plant.

Keywords: CCS, CO_2, sequestration, depleted oil field, Cambrian sandstones, Cm2pp, CO_2-EOR.

Public perceptions of CCUS in Central and Eastern Europe – implications for community engagement

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Abstract. Carbon capture, utilization, and storage (CCUS) is emerging as a subject of major interest for EU climate policy due to their potential role in avoiding hard-to-abate CO_2 emissions, as well as to lead to "negative emissions" through direct air capture or bioenergy with carbon capture and storage. Despite CCUS technologies being deployed since the 1970s, their widespread implementation is still challenged by a range of factors, including policy inertia, high costs, and relative novelty in the public discourse. In particular, as CCUS emerges slowly into the realm of public and political debate, opinions on these technologies and associated projects are easily changeable and affected by a range of factors, which make concerted public and community engagement extremely important for deploying them where they matter most.

The Central and Eastern Europe (CEE) region is characterized by a higher-than-average economic dependence on heavy industry, old assets and infrastructure, and a high occurrence of regions where the transition to climate neutrality will have a significant impact on local economies, employment, and social welfare [1]. CCUS could play an important role in decarbonizing the heavy industry sectors of the region, particularly given the potentially significant storage capabilities of countries such as Romania and Poland, as well as emerging storage potential in the Black Sea and Eastern Mediterranean Sea. However, climate policy in these jurisdictions is sluggish, and there is a general failure to approach CCUS in a systematic way, with targeted application to sectors where it can have the highest impact, such as cement and oil refining. As a result, the public debate around CCUS is practically non-existent, and where public opinions do emerge, they may be significantly influenced by the context of a particular project and generate significant resistance based on the relationship with project developers, the amplification of perceived risks, and the lack of appropriate explanations of costs, benefits and risks. This in turn can lead to a reticence of political stakeholders to commit to deploying CCUS, causing the public debate to further stagnate and creating a vicious circle whereby opportunities to familiarize the public with these technologies (well in advance of their deployment) are missed.

In order to deploy CCUS at pace and scale, as part of the catching-up climate policies of CEE countries, public perception of CCUS must be thoroughly researched and developed into appropriate guidelines for community engagement by project developers. There is experience in the region – the feasibility study for Romania's planned Getica CCS demonstrator (subsequently abandoned) included comprehensive research into the perceptions of local communities, and a toolkit for communications around CCUS by project developers. Similarly, learnings from Poland's failed Belchatow CCS project can serve to re-assess the state of public opinion on CCS, and how the local and national-level contexts for CCUS perceptions interact. The CEE region has significant potential for deploying CCUS, and public perception must be an integral part of planning as the region moves into the key decade of 2030-2040 for implementing large-scale projects.

Keywords: carbon capture, carbon storage, carbon utilization, public perception, social acceptance.

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CO_2 geological storage prospects of Lithuania – update

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Abstract. The CO_2 geological storage assessment in the Cambrian saline aquifers in west Lithuania is considerably improved by 3D seismic survey of the Gargždai Elevation and Syderiai Uplift. The CO_2 storage capacity of the Syderiai site is assessed as large as 56.7 Mt (area 62 km^2) owing to the high reservoir properties (average porosity 17 % and permeability 400 mD) of the Middle Cambrian saline aquifer of 50 m thick and 1458-1508 m deep. The tectonic uplift is controlled by the large-scale Telšiai strike-slip fault. The Syderiai site was initially considered as the potential UGS site. The acreage of the Gargždai Elevation, comprising six depleting oil fields, is assessed 133 km^2 and the storage volume is evaluated 31.3 Mt. The main challenging parameter is a poor average porosity (7 %) and fractured type of reservoir (permeability about 10 mD) about 70 m thick and 2200 m deep. A residual oil zone (ROZ) assessment suggests are very high protentional for CO_2 combination in west Lithuania which is the only prospective site known in the Baltic region of this kind.

Keywords: CO_2 geological storage, saline aquifer, seismic, EOR, ROZ, Cambrian, sandstone.

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Experimental tests and modeling of H_2S-CO_2-brine systems – a case study

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Abstract. A geochemical study aimed to determine the impact of CO_2 and H_2S, mixtures on the representative formation rocks from the Dębowiec Fm. and Paralic series of the Upper Silesian Coal Basin, and the adjacent Małopolska Block (Poland) was performed.

In the way of experiments and hydrochemical modeling the following goals were achieved: determination of the impact of acid gases on the mineralogical composition and porosity, and the assessment of mineral trapping capacity of cap rocks.

Dissolution of skeletal grains, as the dominant process (the most distinct in carbonates and chlorite) was determined by means of SEM analysis in all of the samples.

The increase in porosity at the injection stage, depending on the mineralogy of samples was caused by the decomposition of calcite and siderite or ankerite (Dębowiec Fm.), daphnite, clinochlore, and siderite (Paralic series) and hematite, ankerite, dolomite (Małopolska Block).

After 10 000 years of simulated storage, the total porosity decreased in the cap rocks by several percent points, mainly due to precipitation of saponite, muscovite, gibbsite, phlogopite and dawsonite, in favor of the rock insulating properties. Among the secondary minerals enabling the trapping of CO2 and S in simulated storage there were observed: dolomite and pyrite (Dębowiec Fm.), dolomite, calcite and pyrite (Paralic series) and siderite, anhydrite, pyrite (Małopolska Block).

Maximum calculated mineral-trapping capacity, calculated based on the results of kinetic modeling, reached 43.4 kgCO2/m3 and 44.9 kgS/m3 for CO2+ H2S co-injection into the Dębowiec Fm. Miocene rock.

Keywords: acid gas, H_2S, CO_2, geologic sequestration, gas-rock-water interactions, geochemical modeling.

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Sustainability assessment of CO_2 valorisation routes for Latvia: LCA, S-LCA and LCCA

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Abstract. To initiate and maintain the European Green Deal transformative policies, an evident-based multi-sectoral forecasting model needs to be timely and effectively deployed. The overall decarbonisation solutions proposed in this research can be defined as regional CO_2 "value spots"– areas in regions where CO_2 can be directly (CO_2-based new products) or virtually (change in planning and implementation) utilised for the development of high-added value products, ensuring decarbonisation of rural areas, as well as promoting economic growth of the regions.

Within the framework of this work, three scenarios for using carbon dioxide are analysed – its use in methanol production, cement production and open-air algae ponds. The analysis aims to assess the potential environmental impacts of CO_2 utilisation and consider the impact on the environment, human health, labour rights, working conditions, social equity, and other social factors, as well as costs and economic sustainability.

LCA provides a decision-making platform to understand the mid-term and long-term environmental effects of CO_2 valorisation scenarios according to the ISO Standard 14044 standard requirements. Sensitivity analysis is performed to exclude high input data uncertainties (if any) and identify model behaviour factors. Effects of CO_2 valorisation scenarios on social endpoints (well-being of stakeholders) are identified via S-LCA based on multi-regional input/output methods of qualitative and quantitative generic data. The S-LCA include health and safety, cultural heritage, and governance impact categories covering the interests of such stakeholder groups as workers, the local community, society, and consumers.

Cost-effectiveness of CO_2 valorisation scenarios is performed. Regional valorisation scenarios are assessed and benchmarked via regional development sustainability indicators. A comparative assessment of core indicators is performed.

Keywords: CCU, decarbonisation, methanol production, cement production, open-air algae ponds, full sustainability assessment.

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The CCS greensand project: CO_2 pilot injection and monitoring

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Abstract. Carbon capture and storage (CCS) is a proven, safe, reliable and affordable technology. CCS entails the capture of CO_2 (e.g. from power plants or industrial facilities) as well as its long-term storage in subsurface geological structures, such as depleted gas and oil reservoirs or deep-lying rock strata known as saline aquifers. This technology enables the reliable and cost-effective decarbonisation of industrial sectors with CO_2 emissions that are difficult or impossible to avoid. The International Energy Agency (IEA) and other leading organisations believe that CCS will play a key role in climate protection efforts and emphasising that ambitious climate targets cannot be achieved without CCS.

In February 2023 INEOS Energy Denmark (Op.), Wintershall Dea and Nordseafonden (Danish State Participation) have been awarded the first Carbon Storage Exploration License (Iris) that covers the Siri oil fairway, a depleting oil production infrastructure hub, offshore Denmark. As part of the License work program it is planned to submit a Storage License Application by February 2024 to commission the first CO_2 permanent storage facility in Denmark by 2025.

Initial research studies to convert the depleted oil field Nini West, one of many oil segments in the Siri Fairway, into a permanent CO_2 storage site started already in 2020 and is called Project Greensand Phase 1 and Phase 2, co-funded by the Danish Energy Development and Demonstration Programme (EUDP).

Project Greensand Phase 2 is a large and comprehensive research and pilot project, consisting of 13 work packages and 120 individual tasks that are worked through by a consortium of 23 research partners, led by INEOS Energy Denmark, with altogether some hundreds of researchers and contributors involved. The project scopes are aiming to de-risk and specify all aspects related to carbon storage in the Nini West segment and to provide key documents ready for submission to the Danish mining authorities. Wintershall Dea is key partner in the research consortium, contributing to all work packages and is leading the monitoring related research scopes.

The Greensand project has cleared a first major hurdle in fall 2020 with the independent 3rd Party certification of the Nini West reservoir as a feasible CO_2 storage. This certification confirms that the reservoir is conceptually suitable for injecting 0.45 million tonnes CO_2 per year per well for a period up to 10-years and that it can safely contain the CO_2 injected.

In August 2021, the consortium moved ahead to the pilot phase. The pilot's first offshore injection was successfully conducted in winter 2022/2023 by injecting 4.000 tons of CO_2 into the depleted Nini West oil field and demonstrating the full value chain across international borders. This operation lasted 90 days and included 7 shipments of CO_2 to the Nini site.

The CO_2 was captured and liquified in a chemical plant in Antwerp and loaded into 40 ISO-tanks that were mounted and piped together to an installed rack on a conventional coastal carrier. This low cost custom made transport concept successfully demonstrated temporary carrier solutions for CO_2 shipments until dedicated low-emission CO_2 cargo ships have been designed and constructed.

The pilot injection was accompanied by a focused seismic monitoring program. Despite unfavorable weather conditions one baseline and two monitor seismic acquisitions have been successfully completed as part of Project Greensand to monitor the CO_2 plume migration more frequently and with less impact on the environment [1, 2, 3].

The seismic data has been retrieved, processed and analyzed. Based on the results it is possible to detect the CO_2 presence inside the reservoir [4, 5]. Prior to injection a dynamic simulation provided results on the expected areal coverage of the CO_2 plume. A pattern of 7 spots was planned to detect the presence of the CO_2 with our novel focused seismic concept. Some locations were expected to show an effect caused by the CO_2 plume, some spots should confirm the absence of CO_2. After processing of the monitoring spot gathers and evaluation of the difference traces, a qualitative result was provided for the individual spots. All spots were targeted more than once by different source and receiver locations to get a confirmation from measurements at different offsets and/or azimuths. A strong positive response can be seen directly at the injection location, a medium amplitude response for an up-dip spot towards north-east. All other spots do not show presence of CO_2 in their spot seismic monitoring results as predicted by dynamic simulation.

This spot seismic method has the potential to replace 4D seismic for CO_2 plume monitoring and verification during the full field injection and post injection phases and could thus significantly reduce cost and environmental impact.

Further, the partners in the Greensand research consortium of monitoring scopes are developing sea floor sensors [6] that are able to detect and record CO_2 leakage and seismicity. These sensors will be connected to a power and data hub offshore to ensure data communication in real time.

For INEOS Energy and Wintershall Dea, Greensand is a pioneering CCS project as it ranks among the most advanced CCS projects in EU. Beyond the Nini West storage complex, work is ongoing to mature the remaining depleted oil field and aquifer potential in the Siri Fairway with the view to expand the capacity to up to 8 MTA until 2030. The entire CCS value chain (capture, transport, and storage) will be implemented across borders.

Keywords: CCS, greensand, monitoring, focused seismic, water column sensors.

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Exploring CO_2 storage potential in Lithuanian deep saline aquifers using digital rock volumes: a machine learning guided approach

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Abstract. The increasing significance of carbon capture, utilization and storage (CCUS) as a climate mitigation strategy has underscored the importance of accurately evaluating subsurface reservoirs for CO_2 sequestration [1]. In this context, digital rock volumes, obtained through advanced imaging techniques such as micro-Xray computed tomography (MXCT), offer intricate insights into the porous and permeable structures of geological formations [2]. This study presents a comprehensive methodology for assessing CO_2 storage viability within Lithuanian deep saline aquifers, namely Syderiai and Vaskai, by utilizing petrophysical properties estimated from digital rock volumes [3, 4]. These petrophysical properties were derived from core samples collected from these formations. Utilizing machine learning algorithms, porosity was estimated while the Lattice Boltzmann method (LBM) was applied to determine permeability [5]. The methodology employed for estimating these petrophysical parameters was initially validated using samples from formations analogous to Lithuanian formations. Subsequently, it was applied to rock samples specifically obtained from Lithuanian formations. The estimated petrophysical properties were compared with peer-reviewed data from published literature. When fluids such as CO_2 or H_2 are injected into sub-surface reservoirs, they can alter pore and grain characteristics. Therefore, it is crucial to extract representative element volumes (REVs) from segmented volumes to study the impact of fluids on porosity and their distribution [6]. These mini models, representing small portions of the larger formation, assist in predicting fluid flow within the formation, which is vital for assessing the efficiency and safety of carbon capture and storage (CCS) operations. Subsequently, numerical modelling was conducted using the petrophysical parameters as inputs to assess the storage capacity of the Lithuanian formations using tNavigator software [7]. This research contributes to an enhanced understanding of pore space distribution and its role in various aspects of long-term CO_2 storage. It also demonstrates the potential of integrating advanced imaging techniques, machine learning, and numerical modeling for accurate assessment and effective management of subsurface CO_2 storage. This study shall aid in enhanced understanding of pore space distribution and their contribution towards various aspects of long-term storage. The results can be extended to study the geochemical reactions and geo-mechanical behaviour of the rocks. Such studies shall further facilitate identification of reservoir(s) wherein sequestration potential can be reliably explored.

Keywords: carbon capture, utilization and storage (CCUS), saline aquifers, storage potential, digital rock volumes, machine learning, lattice Boltzmann method, numerical modeling.

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Assessment of CO_2 leakage using mechanistic modelling approach for CO_2 injection in deep saline aquifer of Lithuanian basin in presence of fault and fractures

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Abstract. Injecting CO_2 into deep saline aquifers is a prominent strategy for carbon capture and storage (CCS) to mitigate greenhouse gas emissions. However, ensuring the long-term integrity of CO_2 storage is crucial to prevent leakage and potential environmental hazards. This paper investigates the impact of fracture permeability on CO_2 leakage volumes in the context of CO_2 injection into Syderiai deep saline aquifer for carbon capture and storage (CCS) applications. It explores the relationship between fracture permeability and the potential for CO_2 leakage, as well as the volume of CO_2 dissolved in water above and below the cap rock. Furthermore, the study examines how the leakage volume may evolve over time in Syderiai deep saline aquifer. A mechanistic model of Syderiai deep saline aquifer, of Lithuanian basin, was developed based on average permeability, porosity, NTG and thickness (Fig. 1) and is used in this analysis.

Keywords: carbon capture and storage, CO_2 leakage, leakage risk, faults and fractures, modeling, Lithuania.

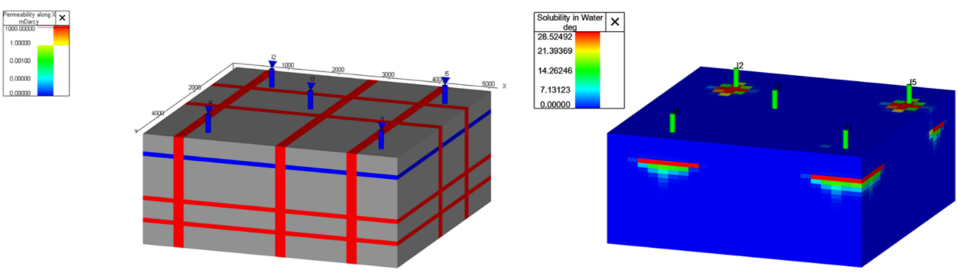

Fig. 1. Permeability distribution Grid block for 1000 md Fracture and Soluble CO_2 in water for 1000 md Fracture after 100 year

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Status on CCS in Denmark

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Abstract. The presentation “Status on CCS in Denmark” will focus on the recent progress made in Denmark on CCS and provide insight into new initiatives underway.

The CCS technology enjoys ample political support in Denmark. Since 2020 a number of political agreements has been reached, introducing three subsidy funds for CCS as well as a range of legislative and regulatory changes that has enabled Denmark to work towards establishing a full-scale CCS value chain with the aim of reaching its climate targets.

It follows from the Danish CCS strategy that Denmark also strives to become a future European hub for CO_2 storage. In that context, Denmark has entered into collaboration agreements with Belgium, the Netherlands, Norway, and Germany to promote CCS as a climate mitigation tool. Additionally, in 2022, Denmark signed an agreement with Belgium for the cross-border transportation of CO_2 with the purpose of geological storage beneath the seabed. This agreement was the first of its kind in an international context.

This year has been a particularly important year for CCS in Denmark. Recent developments include the awarding of the first full-scale offshore exploration licenses for CO_2 storage, the first injection of CO_2 in the Danish part of the North Sea has been completed in a pilot project, and the energy company, Ørsted, has secured a state-sponsored contract to establish the country's first full-scale CCS project. This initiative, valued at approximately 1.1 billion EUR, plans to commence CO_2 capture in 2025.

Moreover, a new tender for the NECCS (“Negative Emissions CCS”) subsidy fund was published in late August. The aim of the NECCS-fund is to achieve 0.5 million tons of negative CO_2 emissions per year, through BECCS and/or DACCS by granting financial support to one or more projects at any scale. Also in late August, a new political proposal was introduced, containing new CCS-initiatives. Finally, new tenders for exploration and storage licenses are planned in the future.

Keywords: CCS, NECCS, Denmark, subsidy fund, full-scale offshore CO2 storage licenses, full-scale CCS project, CO2 capture in 2025, cross-border transportation of CO2, collaboration agreements.

Intermittent CO_2 injection: injectivity and capacity

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Abstract. Carbon capture and storage (CCS), especially offshore, involves a chain of complex and expensive infrastructure connecting emitters to the disposal site. The classic example of an industrial cluster sending CO_2 by a large pipeline to a nearby storage site is considered the most favorable solution in term of techno-economics. However, many emitters are located either too far from suitable offshore geology or are dispersed in harder to reach locations, making pipeline transport uneconomical. In these instances, ship transport is a viable option for shuttling CO_2 from source to sink. The Northern Lights project in Norway will implement this approach, using shuttle tankers to deliver CO_2 to an onshore receiving terminal. One should note that onshore terminals add significant cost to CCS, and their permanence can hinder flexibility and delay future expansion to new regions. High costs can also hinder small emitters to embark on CCS journey until the larger infrastructure is in place and the price for joining the value chain drops. Direct injection from ships can be a good supplement to the offshore transport portfolio, allowing ships to offload CO_2 directly to the injection well on a periodic basis. While direct ship injection introduces a planned intermittency into the CCS chain, intermittency can also be caused by planned maintenance and technical issues along the value chain; energy supply and demand (where either less emissions are available due to, for example, higher renewables production or less energy is available for injection, in, for example, offshore renewable energy driven case); seasonal variations (part of CO_2 used in agriculture or seasonal variation of injection temperature). The effect of intermittency, in general, is not fully understood.

Part 1: aspects of intermittency on the storage reservoir

Little is known about the impact of injectivity CO_2 injection on storage performance, i.e. injectivity and capacity. Recent studies indicate that cycling injection can delay bottom-hole pressure build-up, thus increasing capacity of the reservoir. On the other hand, evidence from field tests show that pressure relief can cause dissolved CO_2 to exsolve into bubbles that block pores and reduce injectivity. Salt precipitation is another aspect that can be either positively or negatively impacted by flow cycling. In this case, repeated drainage-imbibition cycles may dissolve salt crystals formed in a previous cycle, improving injectivity, or it may continue to feed the system with new saltwater, thus impairing injectivity. The topic of salt precipitation is an active area of research.

Part 2: how to deal with it

We present results of the recent study down for NEMO Maritime AS in a research council of Norway sponsored NEMO project. The talk will briefly highlight simulation outcomes on the near wellbore and field scale.

Part 3: where do we go from here

Finally, we shortly introduce a recently funded CTS project which will focus on several aspects of direct injection from ships, including full-chain LCA/TEA based on Strategy CCUS H2020 project approach and scenarios. The project focuses on four different regions of Europe, including Baltics.

Keywords: intermittent injection, direct injection from ship, pressure impacts, salt precipitation, injectivity, capacity.

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Synergy scenario for renewable energy production, CO_2 and H_2 storage in the Baltic offshore structure

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Abstract. CO_2 Capture, Transport, Use and Storage (CCUS) is one of the core technologies to mitigate climate change. New techno-economic and techno-ecological concept of a synergy of CO_2 geological storage (CGS), CO_2 use, hydrogen (H_2) production from different eco-friendly renewable energy recovery technologies and underground H_2 storage (UHS), which we call here Geological Power Bank (Geo-PB), in Cambrian Deimena Formation sandstones in different compartments of the E6 structure offshore Latvia is presented for the first time.

A five-phase circular economy concept of E6 geological structure energy and CO_2 storage hub was developed in this study. The workflow is techno-ecological, eco-friendly, self-supporting, cost-competitive, and economically feasible. It consists of (1) CO_2 transport by ships to the rig, (2) CO_2 injection for CGS and CO_2 Plume Geothermal technology (CPG), (3) H_2 production, (4) Geo-PB, and (5) H_2 transport by the same ships to the customers. The concept is supporting a win^8 situation - innovative elements of techno-ecological synergy in one site: (1) CGS, (2) CPG, (3) solar energy, (4) wind energy, (5) sea currents energy, (6) H_2 production (7) Geo-PB and (8) H_2 transport to consumers. The proposed cycle is closed, demonstrating the principles of circular economy, which will increase the total efficiency of the concept. CGS and CPG are planned in the E6-A compartment of the E6 geological structure with an average CO_2 storage capacity of 365 Mt in an optimistic approach and Geo-PB is planned in E6-B with an H_2 storage capacity of 119 kt.

The Baltic offshore scenario is ambitious and innovative, proposed new technologies, synergy with renewable energy (geothermal, solar, wind and sea current), large storage capacity, including CO_2 storage and use captured by a CCUS clusters of emission sources from energy production, cement industry and bio-emissions from Estonia, Latvia and Lithuania. The concept aimed to decrease the artificial impact of climate change by avoiding CO_2 emissions to the atmosphere and implementing circular economy principles. It will increase public and policymakers' acceptance of new underground CO_2 and energy storage technologies. The proposed synergy solution for CGS and energy storage projects will make such a business economically feasible and attractive for investors. Our study demonstrates a new era, the next generation of cost-competitive, self-supporting conceptual techno-ecological examples of a possible synergy of storage concepts with renewable energies combined using circular economy approaches.

Keywords: CO_2 geological storage, CO_2 use, hydrogen production, renewable energy recovery, underground H2 storage, Geological Power Bank, hydrogen transport, E6 geological structure, Baltic offshore scenario, techno-economic, techno-ecological, synergy concept.

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Lithuanian renewable energy landscape: CCUS, hydrogen and geothermal

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Abstract. Lithuanian energy landscape is changing because of as strong push to reduce carbon emissions and reliance of fossil based energy production. EU climate directive promotes investments into carbon capture and storage technologies along with renewable energy resource development. CCUS, hydrogen and geothermal are some technologies which could promote reduction in carbon emissions and along with reducing dependence on fossil based energy sources. Lithuania already has large potential for carbon and hydrogen storage and in past had a working geothermal power plant for district heating.

In this work we revisit the carbon storage potential in Lithuania subsurface and also provide a high level estimates of potential of generating hydrogen energy from depleted hydrocarbon fields using in-situ methods. We also evaluate the prospects of development of geothermal energy production from deep Cambrian reservoirs where temperature above 85 degrees C have been documented.

Keywords: CCUS, Hydrogen production, hydrogen storage, carbon storage, geothermal energy.

The Helsinki Convention – a legal obstacle for carbon storage in the Baltic Sea?

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Abstract. The Convention on the Protection of the Marine Environment of the Baltic Sea Area – also known as the Helsinki Convention – was originally signed in 1974 by all Baltic Sea coastal countries, seeking to address the increasing environmental challenges from industrialisation and other human activities and that were having a severe impact on the marine environment. It entered into force on 3 May 1980. The Convention includes the protection of the Baltic Sea from all sources of pollution from land, air and sea. The Helsinki Convention was updated in 1992 to take into account the geopolitical changes and emerging environmental challenges in the region and was extended to ten Contracting Parties, including the European Union. The updated Helsinki Convention of 1992 entered into force on 17 January 2000.

According to the articles in the Helsinki Convention [1] dumping in the Baltic Sea is generally forbidden. Carbon storage can be seen as dumping when regarding it as "deliberate disposal at sea or into the seabed of wastes or other matter" (article 2.4 a (i)). If there is not an applicable exemption (article 2.4 b – not seen as dumping, or 11.4 – exception from prohibition due to that safety of human life is threatened, or 29 – prohibition not applicable due to the relation to other Conventions) carbon storage then is forbidden (article 11.1), and that prohibition shall be implemented in national law through its national authorities (article 4.2).

There is though a common interest among several countries around the Baltic Sea to be able to store carbon in the Baltic Sea in the future, in order to reduce CO_2 emissions and reach the common climate goals. For example, Sweden is right now, through its authority Geological Survey of Sweden, investigating the possibility of storing carbon within Swedish territory in the Baltic Sea.

Therefore, there is also a discussion among the countries who have signed the Helsinki Convention about how to go forward making sure carbon storage is in agreement with the Convention. One way could be to look at how this problem was dealt with in the London Protocol – 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (see article 4.1, and Annex I 1.8 and 4) [2], where carbon dioxide was added to the list of matter that may be considered for dumping if certain conditions are being met (disposal into a sub-seabed geological formation, consisting overwhelmingly of carbon dioxide, no wastes or other matter are added for the purpose of disposing of those wastes or other matter).

Keywords: Helsinki Convention, Helcom, Baltic Sea, carbon storage, dumping, CO_2, London Protocol, Sweden.

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Carbon capture and storage (CCS) in the Swedish cement industry – logistics collaboration potentials in the Baltic area

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Abstract. The cement industry in Sweden is facing a major climate change. A central part of the transition is carbon capture and storage (CCS), which is to be implemented in the Swedish largest cement production site on Gotland by 2030. For CCS to be realized, a reliable cost- and environmentally efficient logistics system for CO_2 is required, which for the Swedish cement production on Gotland means CO_2-transport by ship. A research project has been initiated during 2023 with the aim of increasing the cement industry's knowledge and understanding of possible CO_2 logistics systems for CCS. The project takes a larger innovation system approach of CCS by mapping current knowledge about CO_2-logistics for CCS and emerging industrial and logistics actors in the Baltic area and North Sea. Further, logistics scenarios from the perspective of the cement industry will be investigated as well as opportunities for fossil-free CO_2-shipping and business models for the cement industry's CO_2-logistics. The Baltic area includes heavy CO_2 emitting industries both from cement production as well as steel, pulp & paper, power & heat with locations nearby a port, in which there are several initiatives to apply CCS. Further research will investigate how different types of cross-border collaborations could influence the efficiency of the CO_2-logistics system. The project supports the cement industry's decisions regarding processes for the design of CO_2-logistics arrangements for CCS.

Keywords: CO_2 logistics, cement industry, carbon capture and storage, CCS.

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SHORT DESCRIPTION ABOUT THIS CATEGORY

Climate change is a serious environmental issue facing the world today. Most promising technique to tackle climate change is through Carbon capture utilization and storage commonly known as CCUS. It is a unique technique, which could enable human race to tackle climate change. The aim of the journal is to publish high quality articles targeting full value chain associated with Carbon capture, transport, storage, utilization and modelling.Climate change is a serious environmental issue facing the world today.

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