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CO2-DISSOLVED: combining CO2 geological storage with geothermal heat recovery

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CO2-DISSOLVED: combining CO2 geological storage with geothermal heat recovery

Storing dissolved CO2 in deep saline aquifers close to small-to-medium-scale industrial emission sources, whilst also recovering geothermal energy: this is the basic idea behind the CO2-DISSOLVED concept, a promising complement to conventional large-scale CO2 storage with a twist.

An international consortium is currently working on preparing the ground for a future full-scale industrial pilot in order to confirm the techno-economic feasibility of this new CCS approach.

Concept

Commercial-scale industrial geological CO2 storage projects generally involve the injection of CO2 in supercritical form, a state where it is both dense -like a liquid, and has low viscosity -like a gas, which maximizes the quantities able to be stored (several million tonnes per year).

A different approach is taken with the innovative concept of CO2-DISSOLVED (CO2 Dependable Injection and Storage System Optimised for Local Valorisation of the Energy Delivered), launched and coordinated by BRGM, the French Geological Survey.

The CO2 produced by small-to-medium-scale industrial facilities (< 150 kt/y) is stored locally on-site by injecting it, in dissolved form, into an underlying deep saline aquifer. The water pumped up via a 'production' well is subsequently reinjected with the CO2 dissolved in the brine via an 'injection' well, the two wells constituting a doublet system (see Figure 1).

When applied in a favourable geothermal context, CO2-DISSOLVED is designed to also recover heat from the extracted brine in order to use it locally for the specific needs of the CO2 emitter and/or to supply a heating/cooling network.

In this manner, in addition to reducing industrial emissions by storing CO2 underground, CO2-DISSOLVED can also offer the added bonus of renewable heat recovery.

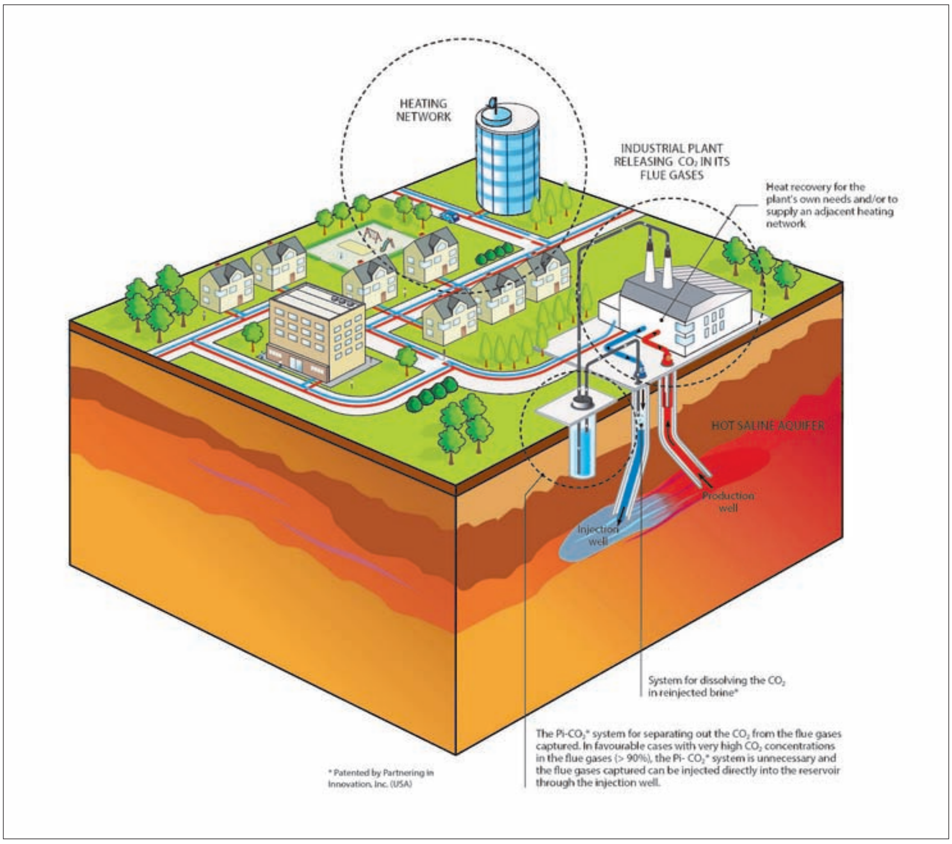

Figure 1 - Schematic diagram showing the CO2-DISSOLVED concept combining local storage of dissolved CO2 and heat recovery through a low-enthalpy geothermal doublet (©BRGM)

Applicability

The CO2-DISSOLVED concept is best-suited to small-to-medium-scale industrial emitters (< 150 kt CO2/y) quite simply because of a physical limitation: the amount of CO2 that can be injected and stored in a dissolved state is limited by both the maximum solubility of CO2 in brine and the maximum possible water flow-rate at the injection well. Based on the typical water flow-rates obtained in geothermal doublets of the Paris basin (200-350 m^3/h), and considering typical downhole pressure, temperature, and salinity conditions in the Dogger aquifer (70°C, 150 bar, 15 g/L, respectively), our calculations reveal that a single doublet could typically dissolve and inject up to 80-150 kt of CO2 per year.

Another basic constraint is of course the existence of suitable aquifers in the right location. The best-case scenario, i.e. combining CO2 storage and heat recovery, would be a 'deep' aquifer (ca. 1,500–2,500 m) with geothermal potential, i.e. temperatures in the region of 60 to 80°C. Nevertheless, a shallower aquifer with lower temperature geothermal resources should not be overlooked as the viability of a CO2-DISSOLVED facility, just like any other standard geothermal plant, should be sized on a case-by-case basis according to the local energy needs.

Urgency and complementarity

While there is no doubt that CO2 Capture and Storage (CCS) has a major role to play in cutting atmospheric greenhouse gas emissions in order to meet the Paris Agreement targets[1], several factors are hindering its deployment in the immediate term, including safety, cost, public perception and regulatory issues.

Although 18 full-scale CCS facilities were in commercial operation in 2018, more than 2,500 will be needed by 2040 to reach the 2°C scenario target[2]. Storing CO2 close to small-scale industrial emission sources could be a complementary option to the 'classic' supercritical CCS approach that generally addresses high-rate emitters. A simple, low-cost and environmentally safe facility injecting small quantities of dissolved CO2 could thus help get the CCS deployment ball rolling.

Whilst at first sight the contribution of a single industrial facility equipped with the CO2-DISSOLVED technology could seem insignificant in terms of climate change impact, things soon escalate when multiplied on a national scale. In France, for example, 650 potentially compatible industrial sites have been identified, accounting for 25% of France's industrial CO2 emissions (Figure 2). Furthermore, let's not overlook the fact that the CO2-DISSOLVED approach brings a decarbonisation solution to an industrial sector that otherwise has few choices for reducing its carbon footprint.

How CO2-DISSOLVED can contribute to CCS deployment

Safety and environmental benefits

• Storing CO2 in dissolved form avoids the formation of a gas bubble in the aquifer and therefore the associated risks of buoyancy, causing the gas to rise and leak to the surface. The risk of the injected CO2 escaping to the surface is thus low-to-inexistent as it remains trapped by dissolution in the brine

• Involves relatively small volumes of CO2 (150 kt/y or less)

• No pressure build-up in the aquifer because the amount of injected water is exactly balanced by the amount of pumped water

• No large distance displacement of the in-situ brine since the vicinity impacted is centred around the foot of the wells

• The 'Pi-CO2' CO2 capture system is aqueous based, thus avoiding hazardous solvents

Cost

• Economy of scale: do small-scale, 'low-cost' local storage onshore in an appropriate region and then, once proven, multiply deployment

• Extra revenue sources: energy produced by geothermal heat recovery and CO2 allowances from carbon credits

• Performed locally, thus avoiding the problems related to infrastructure and cost of CO2 transport

• The 'Pi-CO2' CO2 capture system is cost-efficient compared to other technologies on the market

Public perception

• Synergy between safe CO2 storage and a clean and renewable form of energy production

• Support small-scale deployment and involve from the very beginning local stakeholders and population in the industrial pilot and commercial deployment.

Regulations

• Help clarify and detail regulations for the case of storing CO2 in an entirely dissolved state

Flexibility

Functions with or without capture

CO2-DISSOLVED can be applied to store CO2 that is either captured elsewhere and transported in by pipeline or tanks or, preferably, captured on-site. In the latter case, although any capture technology is compatible, the proposed CO2 capture technology ('Pi-CO2'[3]) is provided by Partnering in Innovation, Inc., our American partner involved in the project since the start.

The main advantages of this innovative capture solution are twofold: (1) environmental, as the only solvent used is water, and (2) economic, with a cost significantly lower than other post-combustion technologies available on the market due to a cheap and abundantly available solvent (water), an optimized energy consumption, and in-process Sox, Nox, Hg, Se removal (thus avoiding expensive gas pre-treatment).

Functions with or without a favourable geothermal context

Although application of the CO2-DISSOLVED concept is by no means constrained to settings with high geothermal potential, it is particularly well suited to such a synergy where heat recovery is considered an extra bonus. In this case, a CO2-DISSOLVED facility comprises a classic low-enthalpy geothermal doublet from which the warm water (ca. 50-90°C) is extracted, thus enabling energy recovery via a heat exchanger system, and then the cooled brine (ca. 30-40°C) is saturated in dissolved CO2 before being injected back into the aquifer for storage.

1. IPCC Special Report ; GCCSI - CCS: A solution to climate change right beneath our feet; IEA – Energy Technology Perspectives 2016
2. Based on a facility with a capture capacity of 1.5 Mt/y of CO2: GCCSI 2018 Status report https://indd.adobe.com/view/2dab1be7-edd0-447d-b020-06242ea2cf3b
3. Carbon Capture Journal March/April issue 68

The journey so far (2013 – 2019) and perspectives

Since the first CO2-DISSOLVED research project launched in 2013, three successive projects have been initiated and a fourth one is in the pipeline (see Table 1 and Figure 3).

The overall objective for the final demonstration stage (last project in Table 1 and red block in Figure 3) is to implement a demonstration pilot at an industrial site. The ground has already been prepared during the 'PILOTE CO2-DISSOLVED' project, and the two current projects, 'CO2-DISSOLVED_INJECTION' and 'GEOCO2', will also contribute to paving the way.

An appropriate site will hopefully be identified during the inventories and pre-feasibility studies. Interestingly, the GEOCO2 project has confirmed a local political support to development of the technology, which is critical to the feasibility of a future demonstrator.

In parallel to these projects, and as a follow-up of the preliminary experimental tests of the first 'Pi-CO2' prototype, a new project is under consideration and design with the objective of running in-well CO2 capture tests at full-scale with a new specifically designed 'Pi-CO2' prototype. Demonstration of the capture prototype in a well setting at high pressure is clearly the missing link to ensure validation of this breakthrough technology. The quality of the international partnership under construction, and the availability of an appropriate experimental site make this project achievable in the relatively short term, compatible with the scheduled launch of a CO2-DISSOLVED demonstration phase.

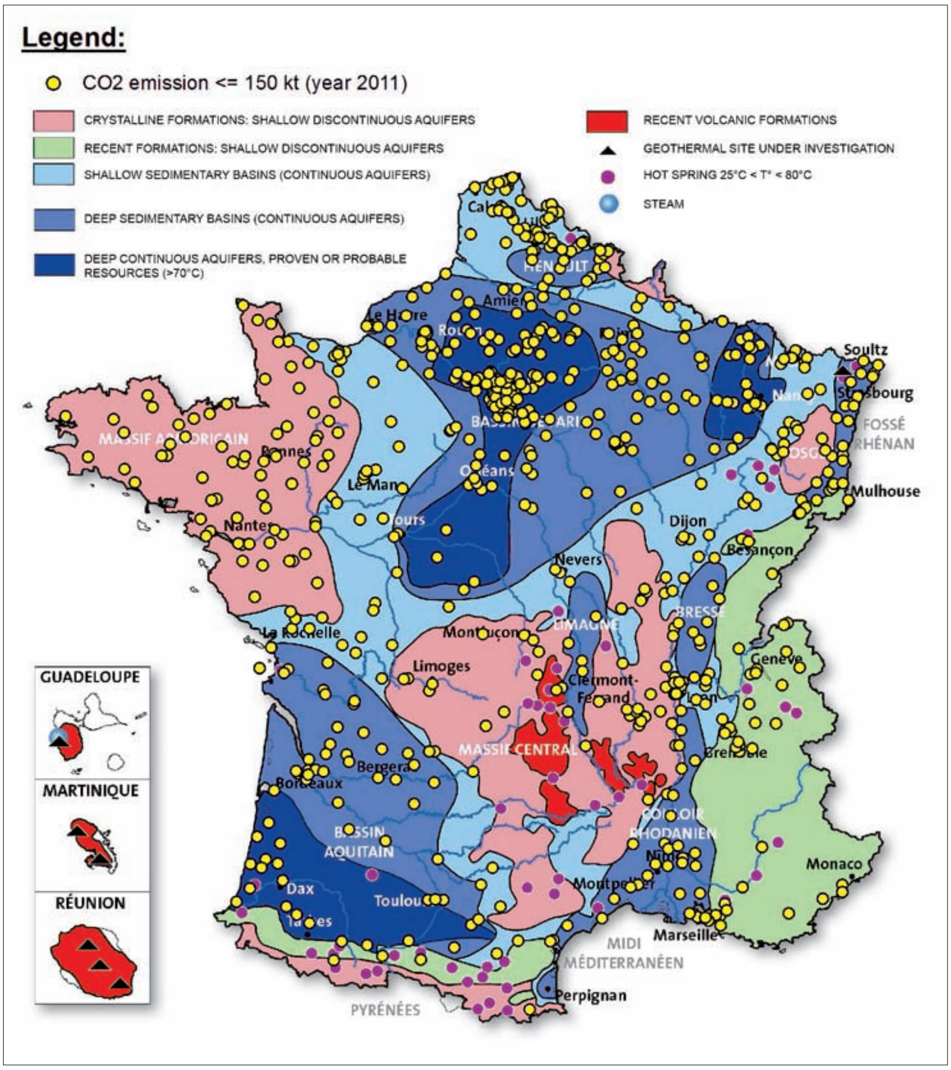

Figure 2 – Location of the small-to-medium industrial emitters on the French metropolitan territory (yellow dots) vs. the most favourable areas for deep geothermal energy resources (dark and medium blue areas) (©BRGM)

The ambitious objective of implementing a commercial demonstration phase in the coming 5-10 years appears feasible as our consortium was recently strengthened by the arrival of major industrial partners and international research institutes.

We are currently seeking to enlarge our consortium to include other international funding partners.

The novelty of this concept is not only technical, but also the target in terms of type (industry) and scale (small-to-medium emitters) meaning that it will complement the existing emission-reduction portfolio.

Conclusions and perspectives

Relying on the well-known geothermal doublet technology, CO2-DISSOLVED is a new CCS approach that is simple, low-cost, and environmentally safe as the CO2 is injected and stored in dissolved form and the concept operates with an innovative water-based capture technology.

All results obtained to date through the past and ongoing 'CO2-DISSOLVED' projects confirm the viability of the concept, which has already been proved to be potentially applicable to small-to-medium industrial CO2 emitters (ca. 100 kt/y) in many areas of Europe and the USA (see key references in the bibliography).

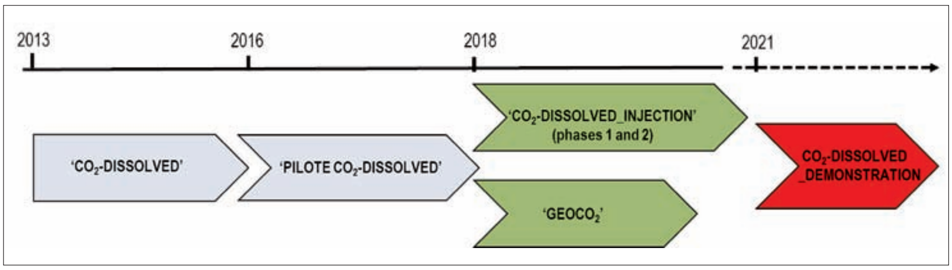

Figure 3 – Past, current, and targeted CO2-DISSOLVED projects: timeline from the first feasibility study to commercial demonstration (©BRGM)

Figure 4 – The 'Pi-CO2' water-based CO2 capture technology prototype undergoing testing at BRGM's experimental laboratory (© BRGM – Rowena Stead)

Table 1. CO2-DISSOLVED research projects (past-ongoing-future): from concept to demonstration	
Title (and funding)	**Duration, Consortium, Aim**
CO2-DISSOLVED (ANR: French Research Agency)	• 40 months: January 2013 - May 2016 • 7 partners • Demonstrate the techno-economic feasibility of combining the storage of dissolved CO2 in an aquifer with the extraction of geothermal heat. Assess the techno-economic feasibility of applying the CO2-DISSOLVED technology to a new industrial target, namely 'small' polluters emitting less than 150 kt CO2/y.
PILOTE CO2-DISSOLVED (Investments for the Future Programme (PIA) with Géodénergies)	• 24 months: June 2016 – May 2018 • 9 partners • Seek and select a suitable site where to construct and operate the CO2-DISSOLVED concept and prepare the ground for a future industrial demonstrator phase. Identify an industrial company with an interest in reducing its carbon footprint and recovering geothermal energy. • Start investigations on the social acceptance and regulatory aspects • Set-up and operate first-of-a-kind prototyping tests of the 'Pi-CO2' water-based CO2 capture technology in BRGM's lab (see Figure 4 and issue no. 68 of Carbon Capture Journal).
GEOCO2 (Region Centre – Val de Loire)	• 24 months: September 2018 - August 2020 • 5 partners • Assess the potential of applying CO2-DISSOLVED in the French Centre-Val de Loire Region. Undertake a detailed inventory of the potential of compatible sites and a prefeasibility study of two sites of interest.
CO2-DISSOLVED_INJECTION (Phase 1) (Investments for the Future Programme (PIA) with Géodénergies)	• 18 months: October 2018 – March 2020 • 14 partners • The final objective is to validate the technical feasibility of injecting CO2 in dissolved form, performing on-site injection tests in an 'old' geothermal doublet. • This first preparation phase aims to (1) find an appropriate site in the Paris basin, set-up an agreement with the owner, and obtain the requested permit from the administration, (2) define the detailed experimental programme, (3) organise the communication strategy for the stakeholders and the public.
CO2-DISSOLVED_INJECTION (Phase 2) (funding pending)	• 12-18 months? Expected start by mid/end 2020 • Consortium to be finalised • Perform the CO2 injection test programme as defined in Phase 1. This project is specifically dedicated to the injection process. A CO2 provider will be sought to supply the required amount of CO2 for the tests (ca. 5 kt). • Measure the actual performance of the geothermal doublet while undertaking CO2 co-injection. • Demonstrate to stakeholders, the administration, and the public the safety of CO2 injection operations through an appropriate monitoring plan.
CO2-DISSOLVED_DEMONSTRATION (funding pending)	• 48-60 months? Expected to start from 2022 onwards • Consortium to be defined • Validation of the technical and economic performance of a coupled operation (geothermal + CCS) at industrial scale • Demonstration of risk management and involving local stakeholders in the process

CO2-DISSOLVED could thus bring a turnkey decarbonisation solution to an industrial sector that has little or no other choice of reducing its carbon footprint.

Successful demonstration at this relatively small scale would certainly contribute to convincing the public and decision-makers on the feasibility of underground CO2 storage, and thus help push larger-scale forms of CCS deployment forward.

Short bibliography

C. Castillo, N. C.M. Marty, V. Hamm, C. Kervévan, D. Thiéry, L. de Lary, J.-C. Manceau. Reactive transport modelling of dissolved CO2 injection in a geothermal doublet. Application to the CO2-DISSOLVED concept. Energy Procedia, 114, pp. 4062–4074, 2017.

X. Galiègue, A. Laude. Combining Geothermal Energy and CCS: From the Transformation to the Reconfiguration of a Socio-Technical Regime? Energy Procedia, 114, pp. 7528-7539, 2017.

C. Kervévan, M.-H. Beddelem, X. Galiègue, Y. Le Gallo, F. May, K. O'Neil, J. Sterpenich. Main Results of the CO2-DISSOLVED Project: First Step toward a Future Industrial Pilot Combining Geological Storage of Dissolved CO2 and Geothermal Heat Recovery. Energy Procedia, 114, pp. 4086–4098, 2017.

J. Royer-Adnot, Y. Le Gallo. Economic Analysis of Combined Geothermal and CO2 Storage for Small-Size Emitters. Energy Procedia, 114, pp. 7118–7125, 2017.

A. Randi, J. Sterpenich, D. Thiéry, C. Kervévan, J. Pironon, C. Morlot. Experimental and numerical simulation of the injection of a CO2 saturated solution in a carbonate reservoir: application to the CO2-DISSOLVED concept combining CO2 geological storage and geothermal heat recovery. Energy Procedia, 114, pp. 2942–2956, 2017.

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