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CO2-Dissolved - A Novel Approach to Combining CCS and Geothermal Heat Recovery

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SUMMARY

This paper presents the outline of the CO2-DISSOLVED project whose objective is to assess the technical-economic feasibility of a novel CCS concept integrating geothermal energy recovery, aqueous dissolution of CO2 and injection via a doublet system, and an innovative post-combustion CO2 capture technology. Compared to the use of a supercritical phase, this approach offers substantial benefits in terms of storage safety, due to lower brine displacement risks, lower CO2 escape risks, and the potential for more rapid mineralization.

However, the solubility of CO2 in brine will be a limiting factor to the amount of CO2 that can be injected. Consequently, and as another contributing novel factor, this proposal targets low to medium range CO2 emitters (ca. 10-100 kt/yr), that could be compatible with a single doublet installation. Since it is intended to be a local solution, the costs related to CO2 transport would then be dramatically reduced, provided that the local underground geology is favorable.

Finally, this project adds the potential for energy and/or revenue generation through geothermal heat recovery. This constitutes an interesting way of valorization of the injection operations, demonstrating that an actual synergy between CO2 storage and geothermal activities may exist.

Introduction and background

The general question of the synergy between CCS and geothermal energy is of great concern as underlined in a recent IEAGHG report by Basava-Reddi (2010). The most extensively described strategy for combining CO_2 storage and geothermal energy recovery relies on using supercritical CO_2 as a working fluid in an Enhanced Geothermal System (EGS). Initially proposed by Brown (2000) as a potentially more efficient energy recovery strategy for producing electricity, this concept was later considered as a possible theoretical way of combining CO_2 storage and energy production (e.g. Pruess 2006). However, this CO_2 storage strategy has only been investigated theoretically and would need further research and future pilots to reach industrial maturity. On the other hand, the concomitant availability of deep geothermal resources and of large CO_2 emitters potentially reduces the actual possibilities of implementation.

Two other projects aiming at combining CCS and exploitation of geothermal energy are described in the literature (Torp, 2010). The first one (GEOSYNERGY), is conducted in Denmark by Vattenfall and recently changed its objective from pure CCS to combined surface heat recovery from the warm brine extracted (Christensen, 2010). The brine will be first extracted to provide available space for the supercritical CO_2 planned to be injected later, and thus to mitigate the pressure build-up in the aquifer. The question of the disposal of the cooled brine has to be solved however (released to the sea or injected in another aquifer?). The second pilot project (CarbFix) aims at capturing the CO_2 emitted by a geothermal power plant in Iceland and then injecting it in a nearby basaltic reservoir, expecting permanent and safe CO_2 storage by mineral carbonation (Matter et al., 2011). It is interesting to notice that the carbonation process is enhanced by injecting CO_2 as being entirely dissolved in previously extracted water. The quantities of CO_2 involved in this pilot project are very low however (2.2 kt/yr).

Other options do not consider injection of supercritical CO_2 anymore, since buoyancy still remains a risk for potential leakage. The recommended strategy is then to inject CO_2 as being entirely dissolved in a previously extracted brine (e.g. Burton, 2008; Jain and Bryant, 2011; Emeka Eke et al., 2011). In this case, and even though the original brine might be extracted from a distinct deep aquifer, extraction and injection are generally planned to be conducted in the same geological formation (via a doublet system). Though very seducing in terms of safety of the CO_2 storage facility, this option has nevertheless some disadvantages. The main one being the limited quantities of CO_2 that could be injected this way, compared to the supercritical option. Consequently, injecting several million tons of CO_2 per year, as required when attempting to mitigate the CO_2 emissions of large fossil fuel power plants, would probably necessitate tens of doublets. Most of these above mentioned authors (e.g. Burton, 2008) generally consider this option as being economically viable (at least in the USA), though more expensive than the standard supercritical CO_2 approach. Moreover, it requires the availability of large empty surface fields above favorable deep geological structures, which clearly is another significant drawback of this approach, specifically in densely populated areas where conflicts related to the surface land use would probably arise.

It is then generally assumed that CCS is going to be implemented only on large emission sources like power plants fed by coal or natural gas. One of the major issues regarding CCS economics is indeed the capital cost of this technology and more precisely, the capture cost. However, small sources could become a bridge between pilot projects and a mature CCS market. In the CO_2-DISSOLVED project, we consider that small CO_2 emitters are a key target to consider for the future of CCS. This project, which was launched in January 2013 as part of the SEED (Efficient and Decarbonized Energy Systems) program of the ANR (French National Research Agency), proposes an original approach to combining CCS and geothermal heat recovery. It is coordinated by BRGM (French Geological Survey) and the consortium is composed of four French and two foreign partners, which are respectively: CFG Services, GeoGreen, GeoRessources (Université de Lorraine), LEO (Université d'Orléans), Partnering in Innovation Inc. (USA), and BGR (German Geological Survey).

Objectives and outline of the project

CO_2-DISSOLVED stands for "CO_2 Dependable Injection and Storage System Optimized for Local Valorization of the geothermal Energy Delivered". The objective of this project is to assess the technical-economic feasibility of a novel CCS concept integrating geothermal energy recovery, aqueous dissolution of CO_2, and an innovative post-combustion CO_2 capture technology. The approach (see Figure 1) includes:

- CO_2 capture and separation in an innovative aqueous based technology.
- Extraction of aquifer brine in a doublet designed for heat extraction via a surface heat exchanger system similar to that used in classical low energy geothermal facilities.
- Re-injection of the cooled brine in the injection well of the doublet equipped with a patented novel CO_2 capture system designed to separate and dissolve the CO_2.

The proposed concept combines several objectives including greenhouse gas reduction, renewable energy production, and the assessment of a novel, low cost capture and storage method. Further, the proposed use of dissolved CO_2 versus injection in a supercritical phase offers substantial benefits in terms of lower brine displacement risks, lower CO_2 escape risks, and the potential for more rapid mineralization.

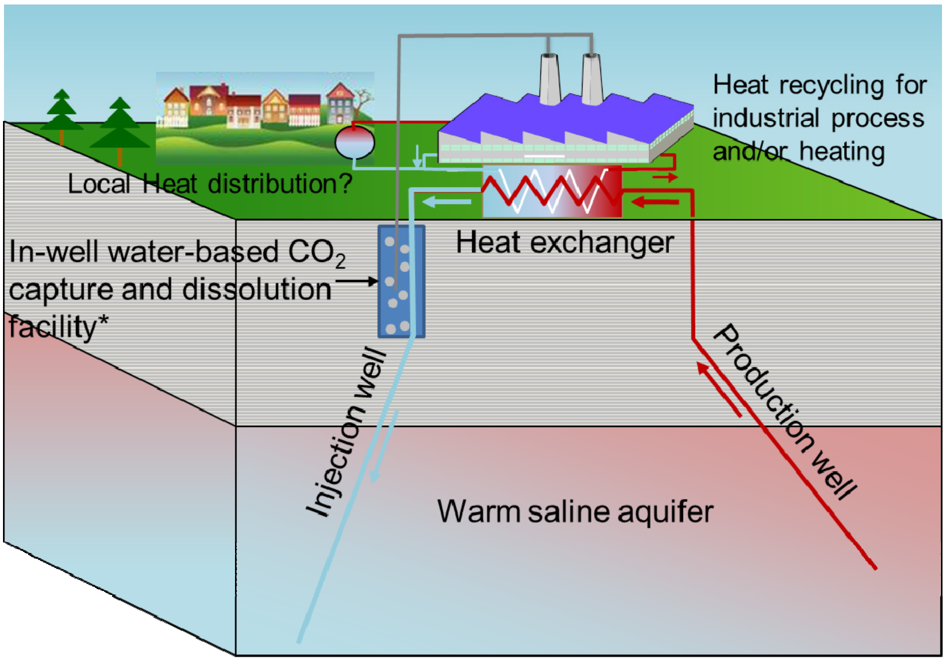

Figure 1 *Schematic representation of the innovative CCS concept proposed in the CO_2-DISSOLVED project.*

Initial modeling indicates that the proposed injection of the CO_2-rich cooled brine strengthens the density contrast such that the injected water will naturally sink toward the deepest layers of the aquifer and migrate along the bottom of the formation with low to no tendency to escape in upward joints, faults, or other avenues. We propose that this may result in significant increases in storage safety with eventual decreases in monitoring and containment requirements. Further we propose that the injection of dissolved CO_2 will reduce brine displacement risks and will move the process more quickly toward mineralization.

Finally, this project adds the potential for energy and/or revenue generation through geothermal heat recovery. This constitutes an interesting way of valorization of the injection operations, demonstrating that an actual synergy between CO_2 storage and geothermal activities may exist.

In terms of limitations, it is expected that the solubility of the CO_2 in the brine will be a limiting factor to the amount of CO_2 that can be injected given time and aquifer flow rate variables. Targeted rates in industrial projects typically relying on the standard supercritical CO_2 injection generally range between 1 to 5 Mt/yr/well. In contrast, based on typical production flow rates (100-350 m^3/h) and an average CO_2 solubility of 1 mol/kg of water, one might theoretically expect CO_2 injection rates varying from 10 to 100 kt/yr/doublet in low energy geothermal doublets of the Paris basin. Consequently in this region, this approach would require tens of injecting and producing wells to reach the rates of the supercritical approach. Though this possibility is envisaged in some theoretical research studies in the US (e.g. Burton, 2008), its practical applicability in the context of densely populated area as encountered in known geothermal and industrial basins of Western Europe (France, Germany) may be a limitation.

Consequently, and as another contributing novel factor, this proposal targets low to medium range CO_2-emitters (ca. 10-100 kt/yr), that could be compatible with a single doublet installation. Unlike the standard approach which focuses on very large regional emitters, the proposed CO_2-DISSOLVED concept opens new potential opportunities for local storage solutions dedicated to low emitters such as food, paper, or glass industry, building materials makers, etc. Since it is intended to be a local solution, the costs related to CO_2 transport would then be dramatically reduced, provided that the local underground geology is favorable. In addition, the heat recovered could benefit directly to the industrial emitters for their own heating and/or process needs and possibly for heating other collective buildings at the vicinity of the storage facility.

One of the technological issues to address for this concept to be applicable relies basically on our capacity to propose an efficient CO_2 dissolution system. On this key aspect, CO_2 DISSOLVED brings another novelty by proposing to assess the feasibility of integrating an exclusive capture and dissolution technology, property of Pi-Innovation (American partner in our project), as part of an integrated CO_2 capture, storage, and geothermal heating system. The Pi-Innovation patented invention offers a two-fold deep-well technology allowing us to process both water-based CO_2 capture and dissolution in brine before injection.

Though being mainly a feasibility study relying on engineering methodologies, the achievement of this project will also have to rely on ambitious research work in order to address the following points:

- Standard monitoring and risk analysis approaches need be revisited as a function of the new features and constraints of the CO_2-DISSOLVED approach. Innovative geochemical (based on the inevitable continuous injection of atmospheric CFC and/or SF6 gases within the CO_2 laden brine), and geophysical (using metallic casing of boreholes to inject current and record EM field in surface) monitoring solutions are intended to be evaluated and tested, both on-field and in-lab. A new risk analysis methodology will be specifically designed and applied in accordance with the modeled and observed properties of the whole system.

- The potential acidified brine reactivity will now be delivered out of the injection well, unlike the supercritical approach where the acid front followed the extension of the CO_2 plume. Specific work, focusing on the near-well areas and relying on both new experimental and modeling approaches will be carried out in this project. A new dedicated experimental facility (MIRAGES-2, which actually mimics an injection well at the centimeter scale) will be specifically designed for experiments involving injection of dissolved CO_2.

- The association of CCS to geothermal heat production, applied locally to small CO_2-emitters, makes partly obsolete previous conceptual economic models of CCS. New models will then have to be developed and validated. They will be fed by parameters arising from the results of the project and will be applied to two selected test-cases (one in France, one in Germany).

Conclusion and perspectives

The CO_2-DISSOLVED project potentially opens a new route toward an actual synergy between CCS and geothermal energy exploitation, which is clearly a key question of the moment both at European and international levels. The expected results will permit to have at our disposal a complete portfolio of innovative technologies associated with adapted experimental, numerical, and theoretical tools, so that in case of positive conclusions on the feasibility of this concept, promising industrial pilot applications could be envisaged on the short term by the end of this 36-month project.

Acknowledgements

The authors would like to thank the ANR for funding this project in the framework of the 2012 SEED program. We are also grateful to several contributors: B. Bourgeois, C. Castillo, C. Fléhoc, J.-F. Girard, L. de Lary de Latour, H. Pauwels, P. Wawrzyniak (BRGM); M. H. Beddelem, C. Cotiche (CFG Services); J. Pironon, A. Randi (GéoRessources, Université de Lorraine); G. Munier (Geogreen), M. Fodha (LEO, Université d'Orléans); A. Laude (REGARDS, Université de Reims), G. Blount (Pi-Innovation); S. Knopf (BGR).

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