



**HAL**  
open science

## Assessing the performance of concepts hybridizing geothermal energy and carbon capture and storage

Thomas Le Guéan, Annick Loschetter, Christophe Kervéan, Rowena Stead, Chrystel Dezayes

### ► To cite this version:

Thomas Le Guéan, Annick Loschetter, Christophe Kervéan, Rowena Stead, Chrystel Dezayes. Assessing the performance of concepts hybridizing geothermal energy and carbon capture and storage. 4th EAGE Global Energy Transition Conference and Exhibition (GET 2023), Nov 2023, Paris, France. hal-04258285

**HAL Id: hal-04258285**

**<https://brgm.hal.science/hal-04258285>**

Submitted on 25 Oct 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Assessing the performance of concepts hybridizing geothermal energy and carbon capture and storage

### Introduction

Carbon Capture and Storage (CCS) and deep geothermal energy are two types of technological solutions that use the subsurface for climate change mitigation. Many papers have been published in recent years proposing ways to combine the two in different configurations. We will call these combinations hybrid concepts (of CCS and geothermal energy). In a recent IEAGHG funded study, BRGM did a thorough review of these concepts from the literature (IEAGHG, 2023).

One question then is how to compare and evaluate these hybrid concepts in order to guide decision-making, such as what concepts deserve further investigation and what place they can take amongst decarbonisation plans. This paper presents the method we proposed for evaluating the performance of concepts hybridizing CCS and geothermal energy.

### Summary of the literature review of hybrid concepts

In the study, we considered about 150 references relevant to hybrid concepts. Overall, we identified 15 main concepts (**Figure 1**). They are grouped in three broad categories:

- Use of supercritical CO<sub>2</sub> as a heat vector for geothermal energy production – this includes CPG (CO<sub>2</sub> Plume Geothermal) (Randolph *et al.*, 2011), CO<sub>2</sub>-EGS (Enhanced Geothermal Systems), heat production from former oil and gas reservoirs, CPG-ES (Energy Storage) (Adams *et al.*, 2019), and Earth Battery (Randolf, 2018).
- Water-driven geothermal concepts with CO<sub>2</sub> injection or re-injection generally dissolved in the geothermal brine. The source of the CO<sub>2</sub> is either from an external source, e.g. CO<sub>2</sub>-Dissolved (Kervévan *et al.*, 2017) and Geothermal BECCS (Bio-Energy with CCS) (Kemper, 2015), or from the geothermal fluid e.g. CarbFix (Snæbjörnsdóttir *et al.*, 2020), CLEAG-AATG<sup>1</sup> and CO<sub>2</sub>-reinjection concepts. Of these, pilots are in preparation in France, operational in Iceland or about to start in Croatia, Italy, New Zealand and Turkey.
- Other synergetic uses – CCS with improved efficiency in the capture process by using geothermal energy, synergy through dual non-competitive use in the same reservoir, and synergetic use through pressure management.

Other concepts were considered out of the scope of the study, in particular closed-loop geothermal systems with CO<sub>2</sub> as a working fluid: in this case, the CO<sub>2</sub> is used and not stored, and thus this concept does not correspond to our definition of a hybrid system (i.e. that seeks both objectives of storing CO<sub>2</sub> and producing geothermal energy).

### Method: performance assessment of hybrid concepts

BRGM developed a performance assessment method for subsurface uses. The core principle is to be able to compute Key Performance Indicators (KPIs), and the KPI should reflect the expected overall performance. As the performance of a system is the ability to meet its objectives, by this definition, performance is multi-dimensional. For all subsurface uses, there is generally one main objective, which corresponds to the transfer (injection, storage, or extraction) of material (gas, brine, mineral, etc.). There are multiple associated objectives, and the most significant ones are generally: “do no significant harm to humans and the environment”, and “reach economic profitability”. Other objectives are defined in accordance with stakeholders’ expectations of the projects. All these objectives are represented by one or several KPIs, possibly grouped into different sub-objectives.

This method was adapted for the review of hybrid concepts. First, there is the need to account for several main objectives, i.e. the concepts should seek to store CO<sub>2</sub> and produce energy. In order to be able to compare each concept, we propose an index that combines the performance of CO<sub>2</sub> storage and geothermal energy, based on the respective expected economic value.

The other issue was the need to adopt a qualitative or semi-quantitative scoring in order to be able to assess KPIs for the concepts. The original performance assessment method mostly relies on models for computing the KPIs (Le Guenan *et al.*, 2022). In this study, there were multiple concepts to compare, where the only source of information were published papers, with heterogeneous data provided.

---

<sup>1</sup> <https://aatg.energy/>

Besides, some KPIs are quantitative by nature, e.g. quantity of energy produced, or economic KPIs. Other KPIs are more qualitative such as maturity or complexity. We thus chose to use a semi-quantitative Likert scale (from 1 to 5, 5 being best performance), and the score was based on our own assessment, considering the available information from the literature.

The main result is a table representing the KPIs assessed for each concepts (**Figure 1**).

### Overview of KPIs defined for the study

We proposed 17 KPIs grouped into seven categories.

The first category is “ambitions and replicability”, and represents the main purpose of the concepts, related to climate change mitigation. The first score is the index mentioned above. The other KPIs consider replicability potential: the idea is to differentiate concepts that have a high index, but can be implemented on few locations only (because they need very specific geological features), with concepts that have a low index but can be reproduced all over the world.

The second category is “integration, modularity & scalability” and groups three KPIs that convey the notion that better concepts can better fit in the “surface” environment (i.e. in terms of upstream and downstream requirements, and scalability).

The third category is “perception by stakeholders” and is represented by one KPI representing how well a concept could be perceived based on analogues. The fourth category is “readiness”, and is represented by one KPI as well. We did not use the Technological Readiness Level (TRL) scale as in our case, most concepts are still at the modelling stage (i.e. low TRL) and thus the comparison with this scale was not informative. Instead, we considered that the overall readiness is based on two dimensions: technical performance (does the concept produces energy / stores CO<sub>2</sub> as expected?) and safety. For each concept, we considered whether there are objective elements as proofs for both aspects. For instance, CPG is using CO<sub>2</sub> as geothermal fluid in a hydrothermal system: the ability to produce heat or electricity still needs to be demonstrated at scale, but the safety aspect is almost identical to standard CO<sub>2</sub> storage (same type of reservoir and caprock system) and thus the proof of safety is provided by existing CO<sub>2</sub> storage operations. The final score is an average of the two aspects (e.g. CPG scores 3, the median score, on readiness).

The fifth category groups four KPIs representing “Environmental risks & impacts”. For the comparison, we considered surface footprint, water consumption, leakage risk and induced seismicity risk.

The sixth category groups two KPIs for “technical complexity and scientific challenges”, as some concepts rely on a high number of wells, or on complex phenomena.

The last category is “credible path to commerciality” and is computed with two KPIs. One is about development risk (also related to technical complexity but also uncertainty and maturity), and the other about economic barriers, i.e. concepts which require high upfront investment and/or have uncertain or delayed revenues will have a lower score.

In summary, these KPIs and categories aim primarily at evaluating the ability of the concepts to contribute to climate change mitigation at scale, and to ponder this with elements of uncertainty, and technical challenges. In addition, KPIs consider the environmental, societal and economic aspects, as essential components of the overall performance of systems.

### Results

**Figure 1** shows the average score for each category of KPIs and for each concept. We do not provide a final number as it would require pondering each category with different weights and we felt it would introduce too much subjectivity.

|  | AMBITIONS & REPLICABILITY | INTEGRATION, MODULARITY & SCALABILITY | PERCEPTION BY STAKEHOLDERS | READINESS | ENVIRONMENTAL RISKS & IMPACTS | TECHNICAL COMPLEXITY AND SCIENTIFIC CHALLENGES | CREDIBLE PATH TO COMMERCIALITY |
|--|---------------------------|---------------------------------------|----------------------------|-----------|-------------------------------|--|--------------------------------|
| CO2-EGS  | 3.3                       | 3.3                                   | 2.0                        | 2.0       | 3.0                           | 1.0  | 1.5                            |
| CPG  | 4.3                       | 3.0                                   | 3.0                        | 3.0       | 3.8                           | 3.0  | 3.0                            |
| Heat mining with SC-CO2 in gas/oil reservoir           | 2.5                       | 4.0                                   | 4.0                        | 4.0       | 4.3                           | 3.0  | 4.5                            |
| CPG-ES   | 3.8                       | 2.7                                   | 3.0                        | 2.0       | 3.5                           | 2.5  | 2.0                            |
| Earth Battery - CO2-BES/TES                            | 4.5                       | 3.0                                   | 3.0                        | 2.0       | 3.5                           | 2.5  | 2.5                            |
| Carbfix*-like concept                                  | 2.5                       | 4.3                                   | 5.0                        | 5.0       | 4.3                           | 4.0  | 4.0                            |
| CO2-reinjection concept                                | 3.5                       | 3.7                                   | 4.0                        | 3.0       | 4.3                           | 3.5  | 3.0                            |
| CLEAG-like concept                                     | 3.0                       | 4.0                                   | 5.0                        | 5.0       | 4.3                           | 4.5  | 4.0                            |
| CO2-Dissolved-like concept                             | 4.0                       | 4.0                                   | 3.0                        | 4.0       | 4.3                           | 4.5  | 4.0                            |
| Geothermal BECCS                                       | 4.8                       | 4.3                                   | 3.0                        | 3.0       | 4.0                           | 3.5  | 4.0                            |
| CCS-driven concept                                     | 2.8                       | 3.7                                   | 3.0                        | 2.0       | 4.0                           | 3.5  | 2.5                            |
| CCS with geothermal energy for capture process         | 3.3                       | 3.7                                   | 3.0                        | 3.0       | 3.8                           | 3.5  | 3.5                            |
| Hybrid-energy systems                                  | 3.5                       | 4.0                                   | 3.0                        | 2.0       | 3.8                           | 3.5  | 3.0                            |
| Synergetic use through dual uses in the same reservoir | 4.0                       | 3.3                                   | 3.0                        | 3.0       | 3.8                           | 3.0  | 4.0                            |
| Synergy through pressure management                    | 4.3                       | 3.0                                   | 3.0                        | 4.0       | 4.0                           | 3.5  | 4.0                            |

Figure 1 Main criteria performance indicators for each concept and averaged Likert scale results

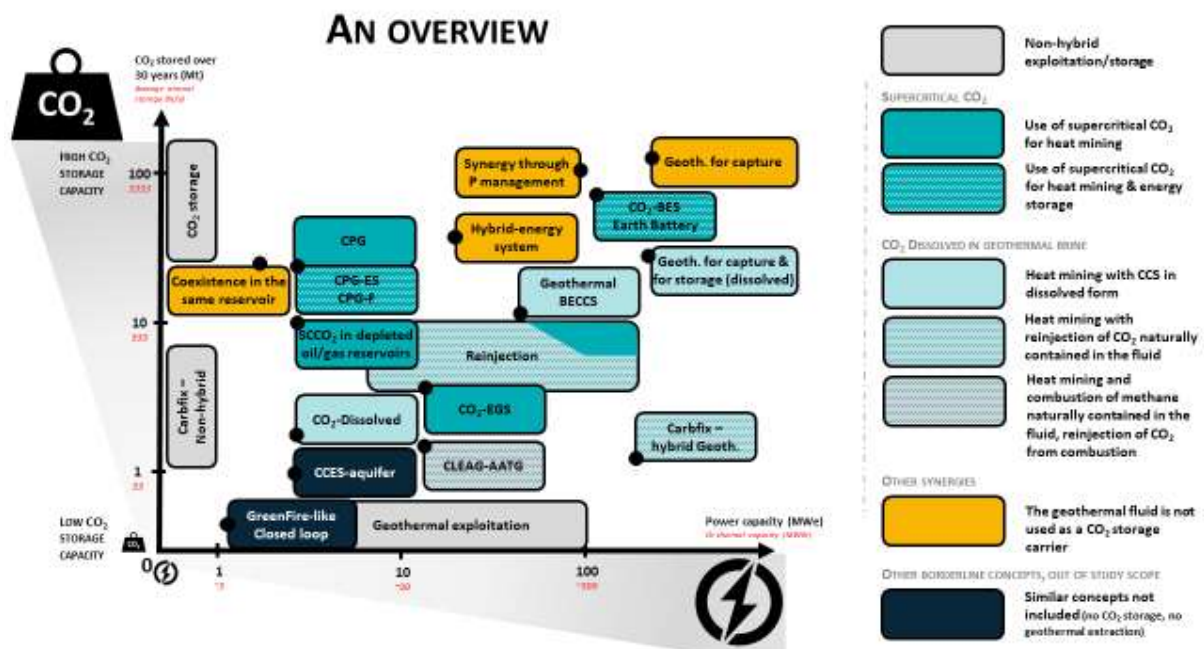


Figure 2 Comparison of CO<sub>2</sub> storage capacity vs power generation capacity for the hybrid concepts identified in this study

Figure 2 provides a graphical display of the concepts along an horizontal axis representing geothermal power capacity and a vertical axis representing CO<sub>2</sub> storage capacity. A colour code provide additional insights into the concept category (see legend).

**Conclusions**

The proposed method allows a comparison of heterogeneous concepts hybridizing CO<sub>2</sub> storage and geothermal energy. This can help to show the concepts with higher potential for deployment and to

prioritize funding. It is also a first step in order to better consider these concepts in future decarbonisation plans.

From the ranking exercise the most ambitious concepts in terms of high energy delivery and high CO<sub>2</sub> storage potential- (CO<sub>2</sub>-EGS, CPG-ES, Earth Battery, Hybrid Energy Systems) rely on high technological complexity that needs to be proven to confirm feasibility. Whereas, lower capacity systems, such as most of the water-driven geothermal concepts with CO<sub>2</sub>-(re)injection, have the advantage of using simpler and more mature technologies, making technical feasibility more likely to be achievable or already proven by existing demonstrators (CarbFix, CLEAG, CO<sub>2</sub> re-injection). These concepts, involving smaller amounts of CO<sub>2</sub>, require high level of replicability if they are going to have a measurable environmental impact on reducing CO<sub>2</sub> emissions, but are potentially easier to manage permitting and gain social acceptance.

### Acknowledgements

We are grateful to IEAGHG for proposing and funding this topic and for interesting scientific discussions and debates as part of this work. The presented method was partly developed in internal BRGM exploration projects.

### References

- Adams, B.M., Fleming, M.R., Bielicki, J.M., Hansper, J., Glos, S., Langer, M., Wechsung, M., Saar, M.O.**, 2019. Grid scale energy storage using CO<sub>2</sub> in sedimentary basins: The cost of power flexibility, in: European Geothermal Congress. pp. 1–6.
- IEAGHG**, 2023. Prospective Integration of Geothermal Energy with Carbon Capture and Storage (2023– 02). IEAGHG.
- Kemper, J.**, 2015. Biomass and carbon dioxide capture and storage: A review. International Journal of Greenhouse Gas Control, Special Issue commemorating the 10th year anniversary of the publication of the Intergovernmental Panel on Climate Change Special Report on CO<sub>2</sub> Capture and Storage 40, 401–430. <https://doi.org/10.1016/j.ijggc.2015.06.012>
- Kervéan, C., Beddelem, M.-H., Galiègue, X., Le Gallo, Y., May, F., O’Neil, K., Sterpenich, J.**, 2017. Main Results of the CO<sub>2</sub>-DISSOLVED Project: First Step toward a Future Industrial Pilot Combining Geological Storage of Dissolved CO<sub>2</sub> and Geothermal Heat Recovery. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 4086–4098. <https://doi.org/10.1016/j.egypro.2017.03.1549>
- Le Guenan, T., Loschetter, A., Mathurin, F., Branchu, F., Kervevan, C.**, 2022. Does Exploiting Synergies with Geothermal Energy Facilitate the Deployment of CO<sub>2</sub> Storage? <https://doi.org/10.2139/ssrn.4286505>
- Randolf, J.**, 2018. CO<sub>2</sub> plume geothermal (CPG) and the earth battery-innovative, dispatchable geothermal power production and geologic energy storage using non-water working fluids. TrGRC 42, 1543–1556.
- Randolph, J.B., Saar, M.O.**, 2011. Combining geothermal energy capture with geologic carbon dioxide sequestration. Geophysical Research Letters 38. <https://doi.org/10.1029/2011GL047265>
- Snæbjörnsdóttir, S.Ó., Sigfússon, B., Marieni, C., Goldberg, D., Gislason, S.R., Oelkers, E.H.**, 2020. Carbon dioxide storage through mineral carbonation. Nat Rev Earth Environ 1, 90–102. <https://doi.org/10.1038/s43017-019-0011-8>