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GECO – Geothermal Emission Control

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ABSTRACT

GECO (Geothermal Emission Control) is an international research project that started in 2018, funded by the EU through the H2020. The project consortium is led by Carbfix and consists of 18 partners from 9 countries across Europe. The GECO project builds upon the success of the recently developed Carbfix gas re-injection method. Applying the Carbfix method advanced considerably our ability to clean the exhaust gases emitted by geothermal power plants based on a novel water dissolution method in a dedicated scrubbing tower. The injection of the resulting gas charged waters into the subsurface disposes the captured gases within precipitated minerals that remain stable over geologic time. This method has been demonstrated to be successful and has been running at the Hellisheidi power plant in Iceland for the past six years. Through this industrial scale demonstration, this new method has been demonstrated 1) to offer considerable cost savings compared to other approaches to capture and dispose acidic carbon and sulphur bearing gases; 2) to be far more environmentally compared to other available technologies; and 3) to aid in the long-term viability of geothermal systems by enhancing the permeability of fluid injection wells. The goal of the GECO project is to adopt the Carbfix re-injection technology, together with emission gas reuse schemes, to become a standard to the geothermal power industry worldwide through the application of gas injection to five new sites across Europe. By consistently monitoring the reactions that occur in the GECO field sites, each having a distinct geology, we will be able to generalise these findings to create a tool for predicting the chemical behaviour of a large number of other systems before they are developed for geothermal energy. Such tools have the potential to decrease both the risk and the cost of future geothermal energy projects. The GECO project aims to provide a new general, efficient, cost-effective, and environmentally benign technology to clean and permanently store or reuse geothermal exhaust gases throughout Europe and the rest of the world.

1. INTRODUCTION

GECO builds upon the success of the recently completed FP7 *CARBFIX* project. This past project advanced considerably our ability to clean the exhaust gases emitted by geothermal power plants based on a novel water dissolution method in a dedicated scrubbing tower. The injection of the resulting gas charged waters into the subsurface disposes the captured gases within precipitated minerals that remain stable over geologic time. This method has been demonstrated to be successful and has been running at the Hellisheidi power plant in Iceland for the past three years. Through this industrial scale demonstration, this new method has been demonstrated 1) to offer considerable cost savings compared to other approaches to capture and dispose acidic carbon and sulphur bearing gases; 2) to be far more environmentally compared to other available technologies; and 3) to aid in the long-term viability of geothermal systems by enhancing the permeability of fluid injection wells.

The goal of this *GECO* Innovation Action is to adopt this approach, together with emission gas reuse schemes, to become a standard to the geothermal power industry worldwide through its application to three new sites across Europe. Moreover, the detailed monitoring and chemical modelling of this injection has provided novel insights into the reactions that occur in the subsurface in response to flowing fluids in geothermal systems. By consistently monitoring the reactions that occur in the five GECO field sites, each having a distinct geology, we will be able to generalise these findings to create a tool for predicting the chemical behaviour of a large number of other systems before they are developed for geothermal energy. Such tools have the potential to decrease both the risk and the cost of future geothermal energy projects. This proposal describes in detail how we will build on the success of our past breakthroughs providing a new general, efficient, cost-effective, and environmentally benign technology to clean and permanently store or reuse geothermal exhaust gases throughout Europe and the rest of the world.

Here, we briefly describe the GECO project that was started in 2018 and will run until 2022.

2. CONCEPT AND APPROACH

The *GECO* approach is built upon that of the original Carbfix project (Matter et al., 2016). The Carbfix approach is to accelerate the mineralization of injected acid gases into subsurface basaltic reservoirs. Carbon mineralization is the safest way of storing carbon-dioxide in the subsurface (Benson et al., 2005). The original Carbfix project injected 175 tons of pure CO_2 into subsurface porous basalts from January to March 2012, then 73 tons of a gas mixture from the Hellisheidi power plant consisting of 75 mol% CO_2, 24 mol% H_2S and 1 mol% H_2 from June to August 2012 (Snæbjörnsdóttir et al., 2017). In each case, the gases were dissolved into the formation water during their injection (Sigfússon et al, 2015). A combination of chemical and tracer analyses, geochemical calculations, and physical evidence demonstrated that the injected CO_2 and H_2S was fixed as minerals, notably calcite and iron sulfide minerals within two years of injection at 20-50°C (Snæbjörnsdóttir et al., 2017). The original CarbFix approach was to co-inject water and soluble gas into the subsurface. Gas was released as fine bubbles into the water at depth, which completely dissolved into the water before it entered the porous aquifer rocks. In June 2014 an upscaling at Hellisheidi was put into operation.

To reduce costs and to streamline the original Carbfix approach, CO_2 and H_2S dominated gas mixture was and continues to be directly captured from the power plant exhaust gas stream by its dissolution into pure water in a scrubbing tower (Aradóttir et al., 2015). In total, 30 to 36 kg/s of pure water was sprayed into the top of the scrubbing tower, operated at an absolute pressure of 5 bars-a at 20°C. This water interacted with the exhaust gas stream dissolving the water-soluble gases. The non-dissolved gases were vented into the atmosphere. Since then, the activites have been scaled up and currently 12,000 ton/year CO_2 are re-injected and 7,000 ton/year H_2S are injected.

A major advantage of this combined gas capture and storage approach is its cost and safety relative to conventional technologies. The capture does not involve the separation of a pure and dry CO_2 phase; it captures all water-soluble gases in a single step by its dissolution into water, which is then directly injected into the subsurface at 9 bars absolute pressure. As a result, only water and electricity are needed for capture. The overall ″on site cost″ of this gas mixture capture, transport and storage at the Hellisheidi site is US $24.8/ton.

3. APPLYING THE CARBFIX METHOD BEYOND ICELAND

The overall goal of *GECO* is to generalize the successful, low-cost, environmentally benign technology as a general method applicable to cleaning and carbonizing exhaust from the geothermal industry throughout the world. The key to generalizing this technology is to apply and optimize the Carbfix approach at other sites. To date, we have shown that the dissolution of toxic gases and CO_2 into water coupled to their mineralization in the subsurface is safe and efficient at Hellisheidi. It seems reasonable to assume the same approach will be readily adapted to other geothermal sites for a number of reasons:

- Geothermal systems currently exploited for electrical power are generally well developed with injection and production wells.
- Emissions from geothermal power plants tend to be concentrated in water soluble toxic gases and CO_2 making these efficiently captured in water-based scrubbing towers
- These systems generally have a large availability of water for the dissolution NCG.
- Geothermal systems tend to be comprised of reactive rocks that could be readily mineralized.
- Effluent water is already being injected into many of these systems to dispose this water and to promote fluid flow.

Moreover, the injection of acid charged water into the subsurface will tend to dissolve the host rock in the vicinity of the injection well leading to the increased permeability of wells.

After the previous successful results in the Carbfix project (Matter et al., 2016), the logical next step was to:

- demonstrate gas purification and reinjection technologies reaching TRL 7 at distinct geothermal power plants located in different geological settings
- to combine this approach with waste gas reuse technologies to further improve its economic viability and the competitiveness of the geothermal energy sector
- to use the lessons learned from these sites to generalize these methods so that they can be adapted to different industrial sites throughout Europe and worldwide

In order to actively take these next steps, the original Carbfix consortium joined forces with two geothermal power stations located in Italy and Turkey and an experimental field site in Germany (fig.Figure 3-1). The Italian site is a high temperature geothermal system situated in gneiss. The Turkey site is a high temperature field situated in volcano-clastic sedimentary pile. The Germany site is a low temperature system situated in sedimentary rocks.

Figure 3-1: Location of GECO demonstration sites and project partners.

3.1. Iceland – Hellisheidi and Nesjavellir Geothermal Power Plant and the Hveragerði injection test site.

Location: SW-Iceland

Plant Capacity:
Hellisheidi: 303MWe + 133MWth,
Nesjavellir: 120MWe+400MWth

Reservoir depth: 700 – 2500m

Reservoir temperature: 270-300°C

Rock type: Fractured basalt

Hellisheidi and Nesjavellir power plants are located on the southern and western parts of the Hengill volcanic system. Both are co-generative, flash-unit power plants producing both electricity and hot water from a high temperature basaltic reservoir. Nesjavellir and Hellisheidi were commissioned in 1990 and 2006. Since 2007, OR has been developing new solutions in reducing gas emissions at Hellisheidi through the Carbfix project. Pilot scale capture and injection commenced in 2011 and industrial scale capture has been built up in stages since 2014. Capture of CO_2 and H_2S is carried out via a scrubbing unit that only uses water and electricity. Captured gases are injected dissolved in water back into the geothermal reservoir where monitoring has demonstrated their fate to be rapid mineralisation. Currently about 1/3rd of CO_2 and 3/4th of H_2S are captured in this process at Hellisheidi. No capture and injection is taking place at Nesjavellir yet. GECO aims to improve efficiency of pre-existing gas capture and injection infrastructure at Hellisheidi, turn captured CO_2 into value stream at Hellisheidi, and commence pilot scale capture and injection at Nesjavellir. In addition, zero emission well testing equipment which was originally to be tested at Castelnouvo will be demonstrated near Hveragerdi, a town with decates long history of geothermal utilization.

3.2. Italy – Castelnuovo

Location: Tuscany (Italy)

Plant Capacity: 5MWe

Reservoir depth: 2500 - 3500m

Reservoir temperature: 280°C

Rock type: Gneiss

Graziella Green Power (GGP) and Storengy (STY) are developing a deep high temperature geothermal gneissic reservoir in Tuscany on the Castelnuovo Pilot lease. The project aims at exploiting a deep seated (> 3000 m) resource for power generation without rejecting into atmosphere any of the NGCs (Non-Condensable Gases). This is a demonstration project and a test case for all other projects of both industrial partners where NCGs production is an issue. Castelnuovo Pilot Project includes the drilling of 3 wells (2 production and 1 reinjection) and realizing a 5 MWe power plant. The power plant design includes an ORC (Organic Rankine Cycle) which allows to keep the geothermal fluid in a closed loop and separate the NCGs from condensed steam (liquid phase) available for reinjection. The geothermal fluid will be handled in a closed loop system, with 2 producers and one injector for a Zero Emission power plant. The geothermal fluid will heat up an ORC power plant of 5 MW capacity. Within the GECO project, geological characterization and modelling activities will be carried out as a part of comprehensive feasibility study but demonstration will not occur before the end of the project.

3.3. Turkey – Kızıldere geothermal field

Location: Kızıldere (Turkey)

The Kızıldere geothermal field is Turkey's first and high-potential geothermal field explored for energy generation. It is a high temperature metamorphic reservoir situated in the Denizli Province, southwestern Turkey. It is a complex of 3 power plants, Kızıldere-I, -II and -III. Zorlu Energy got the concession rights

Plant Capacity:
Phase I: 15MWe
Phase II: 80MWe
Phase III: 165MWe

Reservoir depth: 2000 - 3500m

Reservoir temperature: 220 - 245°C

Rock type: Marble

of Kızıldere field in 2008. Kızıldere-I is the first Geothermal Power Plant (GPP) of Turkey commissioned in 1984 with 15 MWe capacity and still operating. By taking into account reservoir feasibility studies, Zorlu constructed and commissioned its second plant Kızıldere-II with 80 MWe capacity in August 2013. The 165 MWe Kızıldere-III GPP is completely operational since March 2018. Nearly 1/3rd of the discharged NCG from Kızıldere-II is sent to a CO_2 facility operated by Linde Gas. Linde Gas processes the CO_2 for commercial activities. Through the GECO project, Zorlu Energy aims to reduce the CO_2 emissions for more green geothermal power production while maintaining the sustainability of the reservoir

3.4. Germany – Bochum MULE

Location: Bochum, Northrhine-Westfalie (Germany)

Plant Capacity: Underground laboratory, Test site

Reservoir depth: ~500m

Reservoir temperature: 25°C

Rock type: Sandstone

The Ruhr Metropolitain Underground Laboratories (MULE) at Bochum is a large-scale facility for technology development for the changes of energy systems in urban areas. MULE has a 50 km^2 geothermal mining permission with a test site right in the center of one of the largest European urban areas. The test plant shall study the effects of the injection of hydrothermal fluids enriched with CO2 into a low temperature sedimentary reservoir. It will consist of a dual flow and injection system (400 l/Min) with a closed flow-loop reactor and two 500 m wells. Emissions are controlled by an array of monitoring wells for induced chemical, hydraulic, thermal/fibre optic, seismic effects. Using MULE as GECO demo site, the Bochum Geothermal Centre is aiming at studying the effect of CO_2 injection on the sandstone formation for further injection experiments.

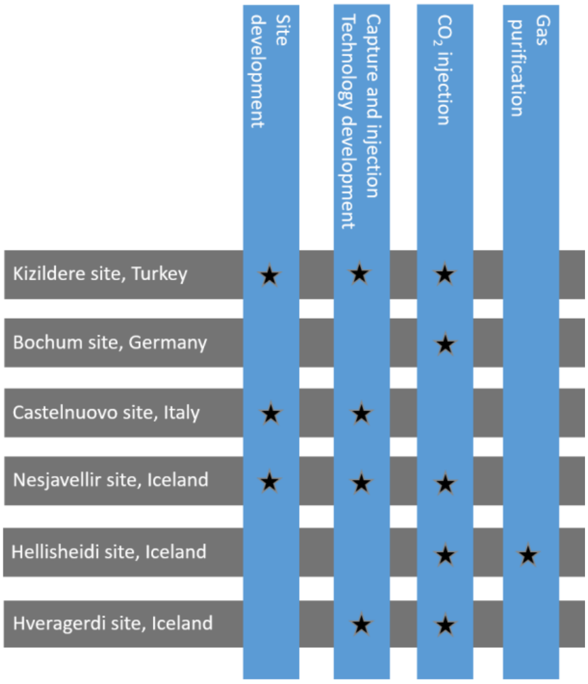

Figure 3-2: The procedures carried out at each test site within the frame of the GECO project

4. GOAL

The overall GECO objective is to generate viable, safe, and cost-efficient technologies for cleaning geothermal power plant exhaust gases that can be applied throughout Europe, and the World. To achieve this overall objective, the GECO project defined the following eight goals:

1) To lower emissions from geothermal power generation by capturing them for either reuse or storage
2) To turn captured emissions into commercial products, allowing for cost reductions through increased revenues
3) To demonstrate cost competitiveness of developed gas capture and injection methods through a comprehensive economic analysis of gas capture, injection and monitoring at each field site
4) The site-specific characterisation and modelling of geology, geochemistry and infrastructure for the optimisation of the injection experiments at five distinct geothermal systems located throughout Europe
5) To quantify the rate and extend of subsurface reactions occurring in response to induced fluid flow during and after the injection of fluids into the subsurface.

6) To integrate new technology, such as detecting CO2 fluxes via remote sensing, in-situ laser isotope analyser and corrosion monitoring system, for improved monitoring of the injections leading to decreased risks associated to leakages etc. for safer injection procedures.
7) To generate an improved understanding of the response of subsurface rocks to induced fluid flow in the subsurface.
8) The help train next generation of scientists and engineers in the current best practice work-flow for lowering emissions from deep geothermal operations and thereby moving the GECO technology into the future.

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REFERENCES

Benson, S.M.,et al., 2005. Underground Geological Storage, IPCC Special Report on Carbon Dioxide Capture and Storage, Chapter 5. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.; Gislason, S.R., Oelkers, E.H., 2014. Carbon Storage in Basalt. Science 344, 373-374.

Matter, J.M., Stute, M., Snæbjörnsdóttir, S.Ó., Oelkers, E.H., Gislason, S.R., Aradóttir, E.S., Sigfússon., B., Gunnarsson., I., Sigurdardottir., H., Gunnlaugsson, E., Axelsson, G., Alfredsson, H.A., Wolff-Boenisch, D., Mesfin, K., Fernandez de la Reguera Taya, Hall J., Dideriksen, K., Broecker, W.S. Rapid carbon mineralization for permanent and safe disposal of anthropogenic carbon dioxide emissions. Science 352, 1312-1314 (2016).

Sigfusson, B., et al. 2015. Solving the carbon-dioxide buoyancy challenge: the design and field testing of a dissolved CO_2 injection system. Int. J. Greenh. Gas Control 37, 213−219.

Snæbjörnsdóttir, S. Ó., et al. 2107. The chemistry and saturation states of subsurface fluids during the in situ mineralization of CO_2 and H_2S at the CarbFix site in SW-Iceland. Int. J. of Greenh. Gas Cont. 58. 87−102.

Pool, M., et al. 2013. Dynamics and design of systems for geological storage of dissolved CO_2. Advances in Water Resources 62, 533-542.