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The CO_2 Fixation into Basalt at Hellisheidi Geothermal Power Plant, Iceland

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ABSTRACT

The reduction of anthropogenic CO_2 emissions is considered one of the main challenges of this century. Capturing CO_2 from various sources and injecting it into carefully selected deep rock formations with large potential storage capacity might help to mitigate climate change.

More than 90% of Iceland's crust is composed of basalt. Basaltic rocks are one of the most reactive rock types in the Earth's crust and contain reactive minerals and glasses with high potential for CO_2 sequestration. At Hellisheidi Geothermal Power Plant a mixture of water and steam was harnessed from 2000-3000 m deep wells. The steam contained geothermal gases, with CO_2 accounting for about 85 % of these gases. CO_2 from the geothermal plant will be dissolved in water at elevated pressures and then injected into wells with depths of 400-800 m, just outside the boundary of the geothermal system. The liquid will react with minerals such as magnesium and calcium from the basalt to form solid carbonates. This process occurs naturally in basaltic volcanoes that host geothermal systems, and the carbonates are stable for thousands of years. The proposed CarbFix pilot project aims to accelerate these natural processes.

1. INTRODUCTION

The aim of the Iceland-based CarbFix project is to develop a practical and cost effective technology for carbon mineralization in basalts. CarbFix is a combined program consisting of field-scale injection of CO_2 charged waters into basaltic rocks in Iceland, laboratory-based experiments, the study of natural CO_2 waters as a natural analogue, and geochemical modeling (see www.carbfix.com).

Mineral storage of CO_2 is a well-known natural process in basaltic volcanoes that host geothermal systems, Ármannsson et al (2007). Icelandic, American, and French scientists have established a project consortium to develop methods imitating and expediating this natural transformation of CO_2 gas, which is the prevalent contributor to global warming, Broecker (2008); Broecker and Kunzig (2008); Oelkers and Cole(2008). The CarbFix project was formally launched in September 2007, and an injection of CO_2 from the Hellisheidi geothermal plant into the basaltic bedrock is planned for the second half of 2009. A primary goal of this project is to imitate the natural storage process already observed in geothermal fields. The implications of this project in the fight against global warming may be considerable, since basaltic bedrock susceptive to CO_2 injections are widely found on the planet, as is illustrated in Figure 1, Oelkers et al (2008).

2. ACCELERATING NATURAL PROCESSES

Solidification of deep magma situated at depths of a few km in basaltic volcanoes is a natural source of CO_2 that results in a continuous flux of the gas into overlying geothermal reservoirs, Arnórsson and Gíslason (1994). Part of the CO_2 molecule reacts with divalent cations such as calcium and magnesium found in basalts and precipitate carbonate minerals, Flaaten et al (2009); Matter et al (2009). These minerals are stable for thousands of years in geothermal systems. Chemical weathering of basalts at the surface of the Earth is another example of carbon fixation in nature Gislason et al (1996); Stefánsson and Gíslason (2001). The proposed CarbFix project aims to accelerate these natural processes.

Reykjavik Energy, one of the world's leading geothermal energy companies, is the main sponsor of the CarbFix project. The company's facilities at the Hengill geothermal area in SW Iceland, where a 300 MW geothermal power plant is under construction, are an ideal site for the multinational scientific project. An aerial photograph of these facilities is displayed in Figure 2. The area has been extensively studied in connection to the construction of the Hellisheidi geothermal plant. Further, a substantial part of the needed infrastructure such as land and boreholes are already in place, thereby creating a natural laboratory suitable for this particular research Sigurdardottir (2008).

Reykjavik Energy is currently generating hot water for district-heating and electricity by tapping water and steam from the large Hengill geothermal resource. The steam from the 2000-3000 m deep wells contains geothermal gases including CO_2. As part of a field management strategy, Reykjavik Energy has interest in capturing, re-injecting and fixing this geothermal CO_2 gas, thereby optimally storing the greenhouse gas for the long term as carbonate minerals.

3. THE CO_2 INJECTION SITE AT HELLISHEIDI, ICELAND

The CarbFix injection site is situated about 3 km south of the Hellisheidi geothermal power plant. The rocks at the site are of basaltic composition, both glassy and crystalline, Alfredsson et al (2008). The geothermal power plant currently produces up to 60,000 tons of CO_2 per year that originated in the geothermal system. The geothermal steam is composed of approximately 0.5% geothermal gases, and CO_2 is the main gas. The geothermal gases will be separated in a pilot gas processing plant, which is currently under construction. The CO_2 will be fully dissolved in water during injection, resulting in a single fluid phase entering the rock. The target injection formation is located at a depth of 400-800 m. The demand for the mineral sequestration of carbon is large. It takes at least 2.4 tons of basaltic glass to fix one ton of CO_2, Oelkers et al. (2008).

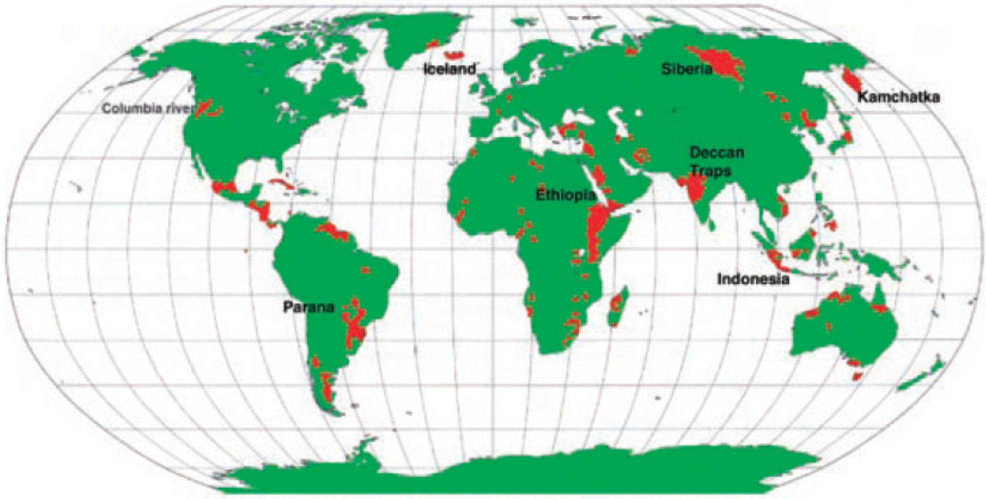

Figure 1: Locations of continental basalts that could serve as mineral carbonation sites (Oelkers et al. 2008)

4. THE STATUS OF THE CARBFIX PROJECT AT HELLISHEIDI

4.1 Background field characterization study

Prior to the planned CO_2 injection, a field characterization study has been completed including the monitoring of groundwater chemistry, soil CO_2 flux measurements, and tracer tests within the injection reservoir. They have revealed that preferential flow paths within the target reservoir exist but that most of the basaltic bedrock consists of relatively homogeneous porous media implying that the rock surface area for CO_2-water-rock interaction is large, Axelsson (2007); Khalilabad et al (2008). In addition, the tracer tests are intended to ensure that there is no loss of injected CO_2 to the surface.

4.2 Modeling

Chemical modelling scenarios are being performed along with laboratory experiments to evaluate the thermodynamics and reaction kinetics of basaltic rocks. This is to ensure that future site activities can be modelled beforehand to enable better management of CO_2 storage projects, Sigurdardottir (2008). TOUGHREACT, a numerical simulation code developed at Lawrence Berkeley National Laboratory (LBNL) in California is being used in the CarbFix project to develop reactive fluid flow models of the CO_2 mineralization is, Xu et al (2005). The code requires vast amount of thermodynamic and kinetic data. Effort has been put into developing a consistent database with up to date parameters that are suitable for conditions at Hellisheidi and basaltic systems in general. Two types of models have been constructed: a laboratory sized plug-flow model and a horizontal, two-layer field model surrounding the injection site. Both models are currently being used to simulate different scenarios that are under consideration for the CO_2 fixation, Stefansson (2008); Aradottir (2008).

4.3 Licenses

Iceland has no specified legal or regulatory frameworks for the long-term storage of CO_2. However, some relevant regulations for injecting chemicals underground do exist such as regulations concerning prevention of groundwater contamination, health and safety regulations, and planning and nature conservation acts. Environmental authorities have already granted a licence for this CO_2 injection based on a detailed monitoring plan of the injection facilities in the pilot project, the storage complex, and the surrounding environment (where appropriate). Further, the Icelandic Radiation Safety Authority has already granted permission to use 14C tracer for one year.

5 THE CO2 INJECTION PILOT STUDY IN THE SECOND HALF OF 2009

5.1 Gas treatment facility

High levels of hydrogen sulphide gas (H_2S) in Hellisheiði geothermal plant steam are a concern. A pilot gas processing plant is therefore under construction. The gases from the power plant condenser will be compressed and cooled. The CO_2 and the H_2S will be separated and the H_2S will be reinjected with brine to the deep, hot geothermal reservoir. The remaining gas, a mixture of 98% CO_2 and 2% H_2S, will then be available for the CarbFix project in 2009. This gas processing will result in a gas composition similar to what may become available elsewhere in the world in the near future, thus adding an element of global significance to the project. CO_2 gas will be transported under pressure from the gas purification plant along a 3 km plastic pipeline to the injection well.

5.2 The injection

An initial test injection of 0.05 kg/s of CO_2 dissolved in ~2 kg/s of water at 19°C is planned for the second half of 2009. This translates to 1.5 thousand tons of CO_2 per year. Several methods for mixing the carbon dioxide and water have been discussed. The mixing can be problematic as the carbon dioxide might form gas bubbles that can escape to the surface. It has been decided to inject the fluid at about 25 bar pressure to a depth of about 350 m. The fluid stream will carry CO_2 bubbles down-well to ~540 m depths ensuring total dissolution of the CO_2 before entering the aquifer.

After total dissolution of the CO_2 the fluid is a weak acid, Stefánsson (2008). As soon as the CO_2-charged waters filter through the rock and mix with the dilute aquifer water, the pH of the injected water will slowly rise, and alkalinity will increase. The concentration of the dissolved elements will increase and alteration minerals will form, resulting in the mineral fixation of carbon. The overall mineral precipitation will eventually clog up the pores in the system.

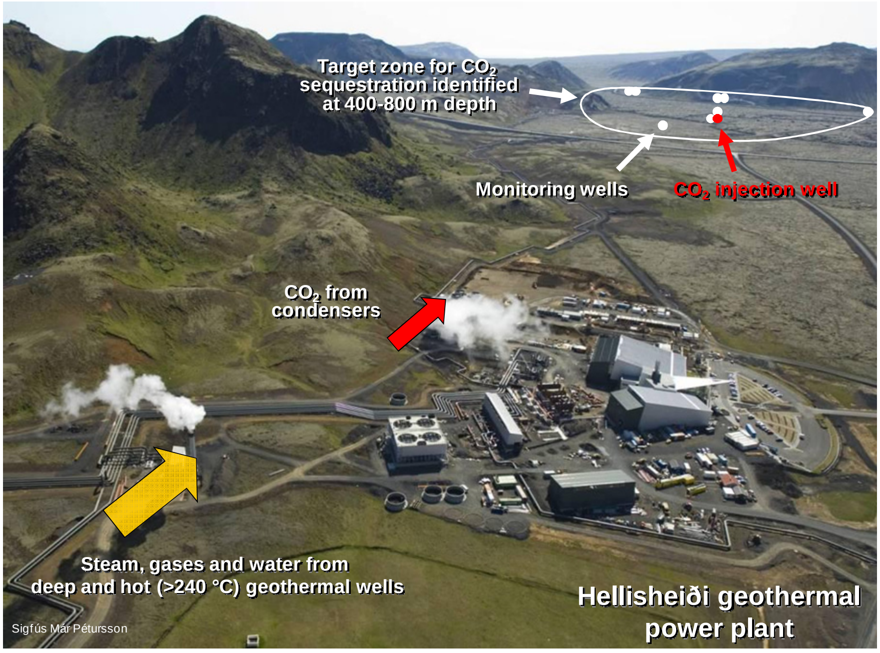

Figure 2: The Hellisheidi geothermal power plant and the injection site with the CO2 injection well and several monitoring wells.

Figure 3: The Hellisheidi area: Basaltic crystallized lava in the foreground covered with moss (Racomitrium lanuginosum) and mountains behind formed under glaciers where the material is glassy but of basaltic composition (Photo: Sigfus Mar Petursson)

5.3 Monitoring

Careful monitoring of the subsurface impact of the injected CO_2 gas is essential for the project's success and validation. Various methods are to be performed on-site, including soil CO_2 flux measurements. Assessment of CO_2 mineral sequestration will be performed with the aid of various tracers like 14C-labelled CO_2 and with solution chemistry.

6 CONCLUSION

It shall be kept in mind that the amount of pores in the basaltic rock is limited. Therefore, the results from the Hellisheidi experiment will not save the world's climate. However, the experiment has the potential to demonstrate that a “near zero CO_2 emission” geothermal power plant and even storing the main part of Iceland's CO_2 emissions in a safe way are possibilities. Should the project succeed, there is a great amount of material at Hellisheidi to fix the CO_2, as is shown in Figure 3. This technology, if proven to be successful, might be exported to other basaltic terrains on Earth.

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