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The GECO project: Lowering the emissions from the Hellisheidi and Nesjavellir Power Plants via NCG capture, utilization, and storage

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ABSTRACT

Innovative non-condensable gas (NCG) capture and storage technology has been developed and proved successfully at an industrial scale at the Hellisheidi power plant in SW-Iceland as a part of the Carbfix project. Most of the NCG is dissolved in water in a dedicated absorption column and the resulting gas/water mixture re-injected into the subsurface, resulting in significant reduction of both CO_2 and H_2S emissions. The injected gases react with the basaltic bedrock and form stable minerals for permanent storage. GECO (Geothermal Emission Control) is an international research project that started in 2018, funded by the EU through the H2020 research and innovation programme. The main aim of the project is to lower emissions from geothermal power generation by capturing them for either reuse or storage, and implement lessons learned at the Carbfix site in Hellisheidi, Iceland at five new sites in; Turkey, Italy, Germany, Nesjavellir and Hveragerdi, Iceland. This paper reports on the main activities taking place within the GECO project at the Hellisheidi and Nesjavellir sites in Iceland, where 1) a second stage CO_2 purification will be demonstrated at the Hellisheidi geothermal plant; and 2) the Carbfix technology will be optimized further by building a new demonstration plant at the Nesjavellir power plant, where the gases will be diverted into an absorption column at elevated pressure to increase capture efficiency and at the same time reduce the water demand of the technology.

1. INTRODUCTION

Geothermal energy is regarded as both clean and sustainable energy source. Emissions of carbon dioxide (CO_2) and hydrogen sulphide (H_2S) are, however, an inevitable part of geothermal utilization, but these non-condensable gases (NCG) are present in the geothermal steam, along with geothermal gases such as nitrogen, hydrogen and other gases in lower concentrations. Both CO_2 and H2S have environmental impact; CO_2 is the most abundant greenhouse gas and contributes largely to global warming, and H_2S has a local environmental effect due to its corrosive nature, odour, and toxicity.

At Hellisheidi geothermal power plant in SW-Iceland an innovative NCG capture and storage technology has been developed and proved successful at an industrial scale as a part of the Carbfix project (e.g. Gunnarsson et al., 2018; Clark et al., 2020): Orkuveita Reykjavíkur (OR) has since 2014 worked on decreasing the emissions of the Hellisheidi plant by dissolving the NCGs in water in a dedicated adsorption column and re-injecting the gas-charged water into the basaltic bedrock. There the injected gases react with the subsurface basalts and form stable carbonate and sulphide minerals, resulting in permanent storage of both CO_2 and H_2S emissions. Currently about 12,000 tonnes/yr of CO_2 and about 6,000 tonnes/yr of H_2S are injected at the site (e.g. Sigfússon et al., 2018).

Building on the success of the Carbfix project at Hellisheidi, the GECO project was started in 2018. The aim of the project is to further develop and advance the Carbfix technology, with the aim to apply it at different geothermal sites with different geological settings, both for utilization of the geothermally derived CO_2 and for permanent storage (e.g. Sigfússon et al., this issue). This paper reports on the research and innovation activities on NCG capture, utilization, and storage in the pipeline at the Hellisheidi, and Nesjavellir geothermal fields in Iceland as a part of the GECO project, with the main focus on:

1) Development of a second stage CO_2 purification method at the Hellisheidi geothermal plant for CO_2 utilisation.
2) Development of a NCG re-injection system at the Nesjavellir site, where about ~1000 tonnes/yr of CO_2 and ~500 tonnes/yr of H_2S will be captured at the Nesjavellir Power Plant, dissolved in water and injected into the basaltic bedrock.

1.1 The GECO project

The GECO project is a four-year research project which started in 2018. The project is funded by the EU through the H2020 research and innovation programme. The project consortium is led by Carbfix and consists of 18 partners from 9 countries across Europe (Figure 1). The GECO project aims to provide a new general, efficient, cost-effective, and environmentally benign technology to clean and permanently store or reuse geothermally derived CO_2, and other environmentally important gases, throughout Europe and the rest of the world. This goal will be reached by further developing the Carbfix NGC capture and storage technologies, with the additional option to purify CO_2 for utilization, providing a pathway for cost reductions through increased revenues (Sigfússon *et al.*, *this issue*).

The Carbfix technology will be adopted and applied at different field sites in four countries in Europe; these field sites are in Kizildere in Turkey, Bochum in Germany, Castelnuovo in Italy, and in Hellisheidi and Nesjavellir in Iceland. Furthermore, access has been granted to a third field site in Hveragerdi, Iceland for testing of novel capture and injection equipment which will be developed further for a new power plant that will be built at Castelnuovo in Italy. The activities that are planned at each field site within the GECO project and the locations of the sites and partners are shown in Figure 1.

Figure 1: The locations of the GECO partners and field sites and the procedures to be carried out at each field site within the frame of the GECO project.

The conditions are very variable between the different sites, including both geological conditions and NCG content of the geothermal fluids, resulting in different approaches to the technologies to be demonstrated. Consistent monitoring of the NCG capture and reservoir the response and reactions that occur during NCG injection at the different GECO field sites will help enabling the generalization of the findings. This will provide tools for better predicting the chemical behaviour of a number of other systems, both in terms of NCG capture and injection, which could result in decreased environmental impact of other geothermal energy projects worldwide.

Here we report on the NCG capture, utilization and storage that will take place at the Nesjavellir and Hellisheidi field sites in SW-Iceland.

1.2 The Hellisheidi and Nesjavellir geothermal fields

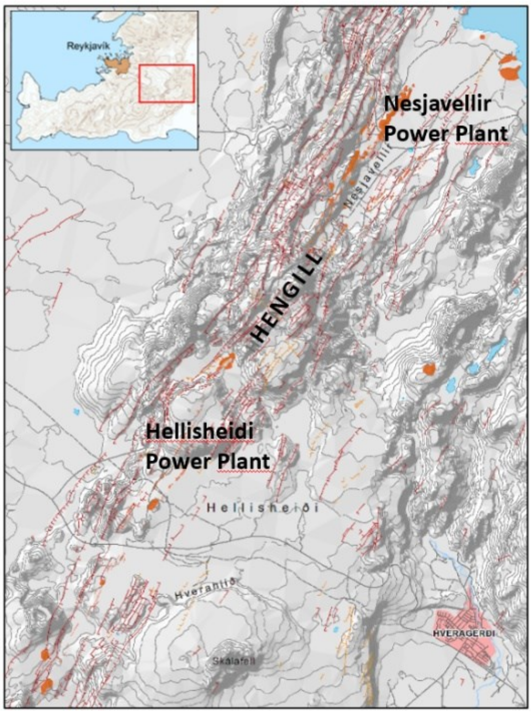

Figure 2: The Hengill volcanic system, and the Hellisheidi and Nesjavellir geothermal fields, SW-Iceland.

The Hellisheidi and Nesjavellir geothermal fields are located within the Hengill volcanic system in SW-Iceland (Figure2). The geothermal fields in the Hengill system are among the largest and most intensively studied geothermal areas in Iceland (e.g. Franzson *et al*., 2005; 2010. Helgadóttir *et al*., 2010; 2015). and are utilised for production of electricity and hot water for the district heating system of the capital Reykjavík at the Hellisheidi and Nesjavellir Power plants.

The Hellisheidi geothermal field is located in the S-part of the Hengill system, about 30 km SE of the capital Reykjavik. The Hellisheidi Power Plant was commissioned in 2006. It is a combined heat and power plant, with the capacity of production of 303 MWe and 200 MWth, which can be further expanded with increased demand. Currently, about 37,000 tonnes/yr of CO_2 and about 9,000 tonnes/yr of H_2S are produced out of the geothermal reservoir in connection with the geothermal production, of which about 1/3rd of the otherwise emitted CO_2 and about 3/4th of the H_2S are currently dissolved in water and injected back into the basaltic subsurface where they react with the subsurface rocks and mineralize for save and long-term storage (Sigfusson et al., 2018).

The Nesjavellir geothermal power plant was commissioned in 1990, with an initial phase of development of 100 MW thermal power plant, which expanded to a current capacity of 120 MWe and 300 MWth. Currently, about 15,000 tonnes of CO_2 and about 8,000 tonnes of H_2S are produced out of the geothermal reservoir annually. Building on the experience of successfully injecting CO_2 and H_2S since 2014 at the Hellisheidi power plant, the same methodology at elevated pressure will be implemented in the Nesjavellir field by 2021, increasing the efficiency of the NCG capture method.

2. LOWERING THE EMISSIONS FROM THE HELLISHEIDI AND NESJAVELLIR POWER PLANTS

The focus of this contribution will be, as previously mentioned, to describe the preparation, design and implementation steps needed for commissioning of selected NCG purification unit at the Hellisheidi power plant, and NCG capture and injection system at the Nesjavellir geothermal field in SW-Iceland.

2.1 A SECOND STAGE GAS PURIFICATION AT THE HELLISHEIDI GEOTHERMAL PLANT

The focus of the GECO project at the Hellisheidi site involves developing methods for a second stage cleaning of the gas stream for commercial utilization of CO_2. The ongoing NCG capture at Hellisheidi power plant involves capturing a mixture of CO_2 and H_2S through water dissolution. Currently, the NCG are captured in an absorption column at 6 bar-a. There, approximately 90% of the H_2S in the inlet stream is captured and about 50% of the CO_2. The plans for the GECO project in Hellisheidi is to apply a second stage cleaning by modifying a commercially available burn and scrub method to make the geothermal gas stream suitable for utilization. The modification includes using condensate from the Hellisheidi power plant to supply H_2S free CO_2 gas with some N_2 to suitable third parties without using imported chemicals.

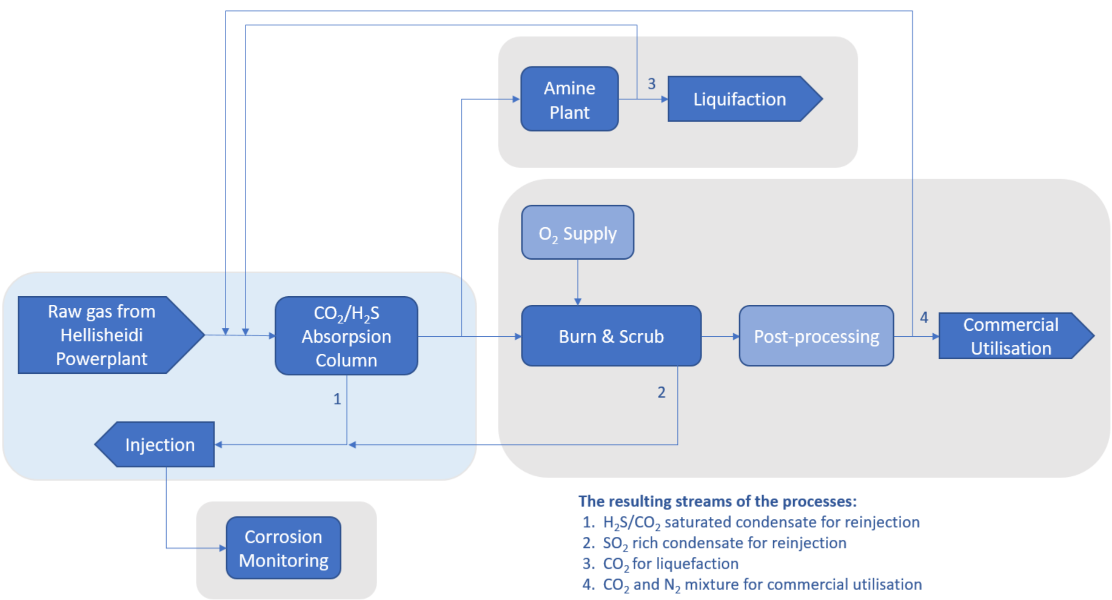

Figure 3: Hellisheidi gas purification process overview block diagram

The second stage cleaning involves blowing the vented gas mixture with excess air into an incinerator, where oxidation of H_2S into sulfur dioxide (SO_2) will occur. Due to the high solubility of SO_2 in water, the gas stream will be diverted into an absorption column where the SO_2 is scrubbed from the inlet gas stream.

The prerequisite to this overall supply chain to work is that the calorific content of the gas is sufficient and relatively constant during the process. The burn process needs to be sufficiently complete, so the resulting gas stream has no H_2S, therefore enabling successful SO_2 removal with low condensate usage. Then, the final step of CO_2 recovery becomes a less challenging task and H_2S free gas streams can be guaranteed to third parties.

When using atmospheric air for the burning process, the fraction of N_2 in the produced stream is high. Two post processing methods are being evaluated to concentrate the CO_2 stream: 1) separating the CO_2 from the stream with membranes; 2) by using hot potassium carbonate process.

In addition to the second stage purification, as described above, a gas purification system based on an amine/low temperature hybrid concept will be developed and demonstrated at the Hellisheidi site in connection with the GECO project. The aim is to be able to separate and purify CO_2 from the geothermal non-condensable for further utilization.

The first stage is an amine chemical absorption process to selectively remove H_2S from the gas stream. The CO_2-rich gas from the amine absorber requires a complete dehydration before going through a CO_2 condensation unit, where the main portion of CO_2 is separated from the other components in the gas such as H_2, N_2 and CH_4. Subsequently, the dry gas is compressed to ~60 bar and cooled to a separation temperature of ~-55°C. The fraction of CO_2 condensed depends on the inlet CO_2 concentration, the pressure and the separation temperature.

2.2 PILOT CAPTURE AND INJECTION OF CO_2 AND H_2S AT THE NESJAVELLIR GEOTHERMAL FIELD

Building on the experience of successfully capturing and injecting CO_2 and H_2S at the Hellisheidi power plant since 2014, the same methodology is planned to be implemented in the Nesjavellir field in 2021 (Figure 4). Currently, about 15,000 tonnes of CO_2 and about 8,000 tonnes of H_2S are produced out of the geothermal reservoir annually during the production of 120 MWe and 300 MWth at the Nesjavellir Power Plant. The plans within the GECO project involve a demonstration of capture and injection of ~1000 tonnes CO_2/yr and about ~600 tonnes of H_2S/yr.

Compared to Hellisheiði plant, the design of the Nesjavellir capture plant required a thorough review of potential compressors and other equipment due to different operating conditions. The process design includes the retrofitting of the gland steam system of the turbines to separate the gland steam from the geothermal gases and therefore reducing the indrawn atmospheric air affecting the gas composition. A special caution needs to be taken due to higher concentration of H_2 and H_2S compared to the gas stream in Hellisheidi which increases the risk of self-ignition within the gas system.

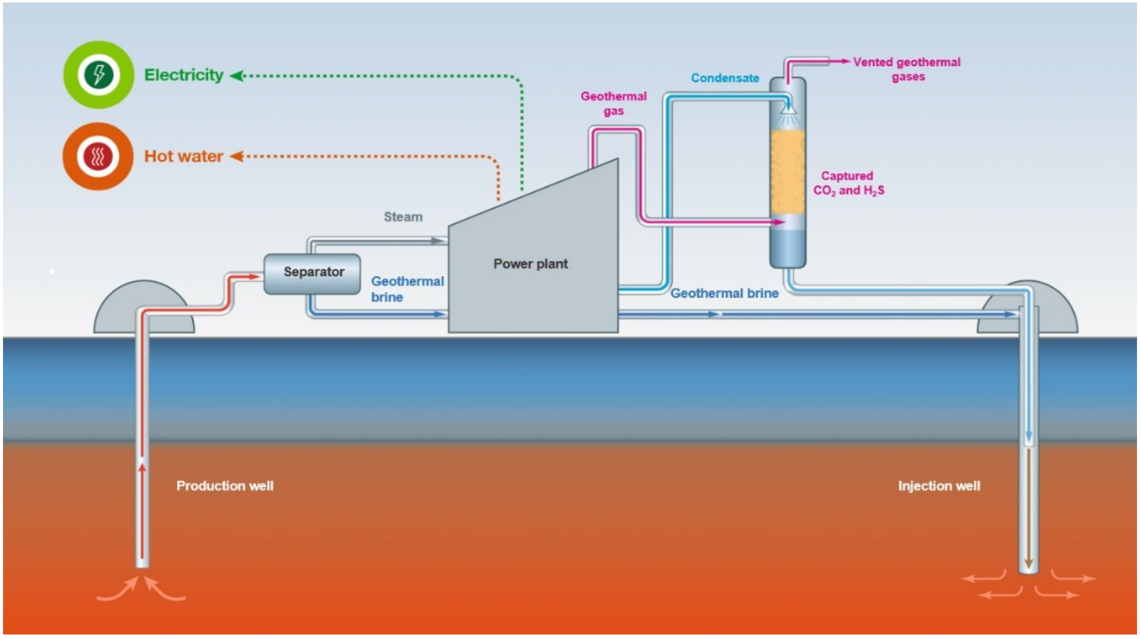

Figure 4: Overview of the geothermal production and the proposed gas capture at Nesjavellir geothermal plant. The non-condensable gases CO_2 and H_2S are dissolved in an absorption column using condensate from the turbines.

A designated NCG absorption column will be built at the site, where the mixture of CO_2 and H_2S will be captured through water dissolution. The plans aim to increase the absorption pressure from the 6 bar-a, as operated at the Hellisheidi site, up to ~10-11 bar-a. This results in increased NCG capture efficiency and reduced water demand for a fixed feed gas composition (Figure 5). Simulations indicate a capture efficiency of the demonstration system of about 95% for CO_2 and about 99% H_2S capture efficiency in the demonstration plant as compared to Hellisheiði plant where the capture efficiency is approximately 50% and 95% for CO_2 and H_2S respectively.

The dissolved NCG stream will be diverted to injection well NJ-18 in the northern part of the Nesjavellir field, where it will be injected. The well is 2136 m deep with temperatures up to 250°C, and is cased off at about 950 m. It is anticipated that the injected fluid will enter the storage formation at depths between 950-2136 m, with the main feed-zones located at 1610 m and 1703 m depth. The fluid will then react with the basaltic formation rocks for safe and permanent storage of the injected NCG. A more detailed description of the preparations for the NCG injection is provided by Snæbjörnsdóttir *et al.* (*this issue*).

Some of the challenges to be addressed for the design of the injection system include the evaluation of: 1) the resistance of the installed casings of the injection well to the acidic gas-charged fluid; 2) the depth of injection within the injection well to ensure dissolution of the gases (CO_2 and H_2S) during and after injection; 3) the measures to be taken to prevent degassing of the fluid due to any kinds of operation problems.

The construction of the injection system will start early 2021, with the aim to start injection by the end of the year.

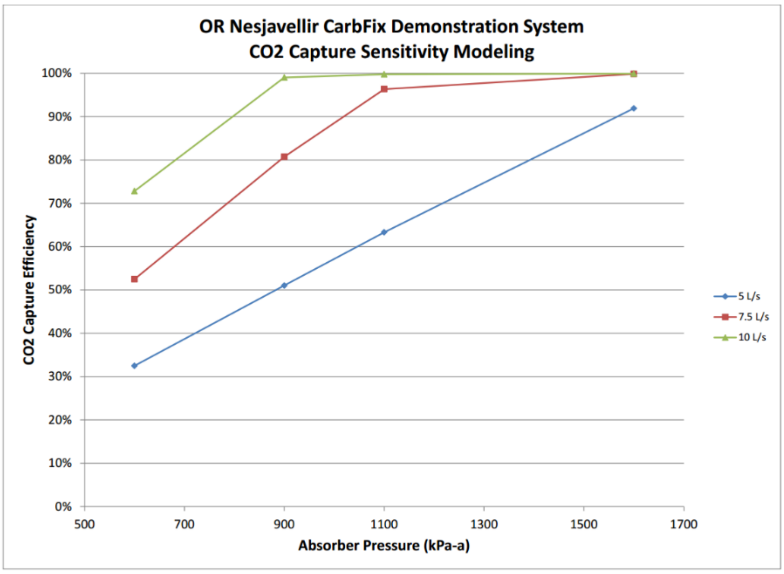

Figure 5: CO_2 capture efficiency vs. absorber pressure. At 5 l/s water flow rate the capture efficiency may be increased from 32% to 92% by elevating the absorber pressure from 6 bar-a to 16 bar-a. Similarly, in a process with ~50% capture efficiency, the water demand of the process may be reduced from 7.5 to 5 l/s by increasing the absorption pressure from 6 bar-a to 9 bar-a.

4. FINAL REMARKS AND DISCUSSION

This paper reports on the advances in the pipeline for NCG capture, utilization and storage at the Hellisheidi and Nesjavellir Power Plants in connection with the GECO project (see also Sigfússon *et al*, *this issue;* Snæbjörnsdóttir *et al*., *this issue*). This includes a second stage purification of the gas-stream in Hellisheidi for CO_2 utilization. This will be done using a modified burn and scrub method, parallel to an amine scrubbing process Furthermore, the NCG capture and storage process that has been on-going in Hellisheidi since 2014 will be replicated in the Nesjavellir geothermal field at elevated pressure, where a NCG absorption column will be designed and built for injection of ~1000 tonnes of CO_2/yr and ~600 tonnes of H_2S/yr.

The implementation of these technologies will add to the value of safe and efficient carbon capture, utilization, and storage for the geothermal sector for reduced emissions of geothermal gases. A major contributor to this reduction is the transition to less carbon-intensive and more sustainable energy systems, including more extensive utilization of geothermal energy.

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