D9.5 ROADMAP FOR THE DEPLOYMENT OF GEOTHERMAL EMISSIONS CONTROL SYSTEMS

Funded by the Horizon 2020 Framework Programme of the European Union

Project acronym:	**GECO**		
Project title:	Geothermal Emission Control		
Activity:	LC-SC3-RES-13-2018		
Call:	H2020-LC-SC3-2018-RES-SingleStage		
Funding Scheme:	IA	**Grant Agreement No:**	818169-GECO
Project dates:	01/10/2018 – 30/09/2022	**Duration in months:**	48
WP9	**GECO results exploitation and environmental assessment**		

D9.5: Roadmap for the deployment of geothermal emissions control systems

Due date:	31/03/2023	
Actual Submission Date:	15/05/2023	
Lead Beneficiary:	GEORG-Rannsóknarklasi í jarðhita (GEORG) Phone: (+354) 618 3541 Email: hpi@georg.cluster.is	
Main authors/contributors:	Amel Barich (AB), Sigurður Tómas Björnvinsson (STB), Björn Þór Guðmundsson (BTG), Bergur Sigfusson (BS), Serhat Akin (SA), Felix Jagert (FJ), Lorena Freire (LF), Damien Wiedman (DW), Maria Dolores Mainar Toledo (MDMT), Giampaolo Manfrida (GM), Fausto Batini (FB), Héctor Leiva (HL)	
Dissemination Level[1]:	PU	
Nature:	Report	
Status of this version:		**Draft under Development**
		For Review by Coordinator
	X	**Submitted**
Version:	01	

REVISION HISTORY

Version	Date	Main Authors/Contributors	Description of changes
01	09.05.2023	Amel Barich (GEORG)	N/A (First version)
02	10.05.2023	Amel Barich (GEORG)	Editing
03	15.05.2023	Amel Barich (GEORG)	Editing/Reviewing

[1] Dissemination level security:

PU – Public (e.g. on website, for publication etc.) / **PP** – Restricted to other programme participants (incl. Commission services) /

RE – Restricted to a group specified by the consortium (incl. Commission services) / **CO** – confidential, only for members of the consortium (incl. Commission services)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 818169-GECO. This publication reflects the views only of the author(s), and the Commission cannot be held responsible for any use which may be made of the information contained therein.

SUMMARY

The GECO roadmap outlines the strategic steps for the deployment of GECO Systems in the deep geothermal sector. By addressing emissions challenges associated with geothermal power generation, GECO aims to promote sustainable energy production and contribute to global climate change mitigation efforts. This roadmap builds upon the progress made in market analysis, collaboration, and regulatory engagement, and outlines the next crucial stages for scaling up deployment, customization, and knowledge transfer. By following this roadmap, GECO will continue to advance its mission of reducing greenhouse gas emissions from geothermal plants and establishing itself as a leading provider of emissions control technology in the deep geothermal sector.

CONTENTS

SUMMARY ... *4*

1. INTRODUCTION ... *6*

2. CURRENT STATE OF GEOTHERMAL EMISSIONS ... *6*

3. TECHNOLOGIES FOR EMISSION CONTROL ... *7*

4. GEOTHERMAL EMISSSION CONTROL: THE GECO CONCEPT ... *8*

5. EXPERIENCES FROM THE DEMO-SITES ... *9*

5.1 CHALLENGES AND OPPORTUNITIES ... 9

5.1.1 GECO Roadmap Questionnaire: ... *9*

5.2 HELLISHEIÐI AND NESJAVELLIR - ICELAND: ... 11

5.3 KIZILDERE - TURKEY: ... 12

5.4 BOCHUM MULE - GERMANY: ... 13

5.5 CASTELNUOVO - ITALY: ... 14

6. ROADMAP FOR IMPLEMENTATION ... *14*

7. CONCLUSIONS ... *17*

1. INTRODUCTION

The deployment of effective renewable electricity generation technologies is essential for Europe at present. The EU commitment to reduce greenhouse gas emissions by at least 80% by 2050 requires the refinement and commercialisation of proven carbon capture and storage approaches in addition to increased market uptake of the renewables. The GECO project addresses challenges on demonstrating cost-effective technologies to limit emissions of geothermal plants either by re-injection or turning them into commercial products. The gas capture and injection technologies developed by former projects involving GECO partners will be implemented not only in a fractured basaltic reservoir but moved forward in the project´s four field sites in fractured gneiss, metamorphic and sedimentary reservoirs. This document lays out the roadmap for geothermal emission control technologies It is therefore anticipated that a roadmap for feasible injection of geothermal gases (and CO2 from other sources) based on field demonstrations in different locations will be made available to stakeholders, being either plant operators or policy makers.

2. CURRENT STATE OF GEOTHERMAL EMISSIONS

Geothermal energy is a renewable energy source used for heating or power production, and its utilization may cause greenhouse gas (GHG) emissions, although they are relatively small compared to traditional base load thermal energy power generation facilities. However, as the geothermal sector expands, more geothermal resources with relatively high GHG concentrations in the reservoir fluid are being exploited, raising concerns about GHG emissions.

There is limited understanding of GHG emissions from geothermal power production, and there are still uncertainties surrounding the trends in emissions over a plant's lifetime and how geothermal power production may affect natural GHG emissions through the Earth's surface. The national regulatory frameworks for carbon emissions from geothermal power production also vary from country to country.

GHGs are naturally present in all geothermal fluids, and the dominant NCG in geothermal fluids is carbon dioxide (CO_2), typically constituting more than 95% of the total NCG content. The other relevant GHG in geothermal fluids is methane (CH_4), whose concentration is generally a few hundredths to a few tenths of a percent by mass but can in rare cases make up more than 1.5% of the total gas. However, most available data on GHG emissions from geothermal power plants refers to CO_2 only.

The GECO project is using deep geothermal resources to generate power, which is already cost-competitive with the electricity generation costs outlined in the SET Plan targets. The production sites in Iceland, Italy, and Turkey have costs lower than 0.077 €/kWh. However, the costs are expected to increase due to the emission treatment required to handle CO_2, H_2S, and other harmful gases. Therefore, it is crucial for the geothermal industry to demonstrate ways to significantly reduce or eliminate these emissions. The GECO project aims to do this economically and in an environmentally friendly manner by implementing novel gas capture methods coupled with storage or reuse. The SET Plan targets for deep geothermal energy include improving the overall conversion efficiency of geothermal installations by 10% in 2030 and 20% in 2050, as well as reducing production costs to below 10 €ct/kWhel for electricity and 5 €ct/kWhth for heat by 2025.

3. TECHNOLOGIES FOR EMISSION CONTROL

The GECO project is based on the CarbFix approach, which aims to accelerate the mineralization of acid gases injected into subsurface basaltic reservoirs. This method is considered to be the safest way to store carbon dioxide in the subsurface. The original CarbFix project injected pure CO2 and a gas mixture containing CO_2, H_2S, and H_2 into subsurface porous basalts in 2012. The gases were dissolved into the formation water during their injection and fixed as minerals, such as calcite and iron sulfide minerals, within two years.

The original CarbFix approach co-injected 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.

The CarbFix approach was subsequently scaled up to capture and store all the acid gases emitted from the Hellisheidi power plant. This geothermal power plant emits 50,000 tons of a geothermal gas mixture annually, consisting of mainly CO_2 and H_2S. To reduce costs and streamline the approach, the CO_2 and H_2S gas mixture is directly captured from the power plant exhaust gas stream by dissolving it into pure water in a scrubbing tower. This method has been successful and environmentally benign, and the goal of GECO is to generalize this 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 geothermal sites, which should be feasible for several reasons. Geothermal systems currently exploited for electrical power are generally well-developed with injection and production wells, and emissions from geothermal power plants tend to be concentrated in water-soluble toxic gases and CO_2, which can be efficiently captured in water-based scrubbing towers. These systems generally have a large availability of water for the dissolution of non-condensable gases. Geothermal systems also 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 of 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.

4. GEOTHERMAL EMISSSION CONTROL: THE GECO CONCEPT

Carbfix 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 Hellisheiði 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 four 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.

GOAL 1

To lower emissions from geothermal power generation by capturing them for either reuse or storage. This will be done 1) by further optimizing gas capture and injection infrastructure at Hellisheiði and thereby further lowering emissions; 2) by implementing lessons learned at Hellisheiði at 3 other field site demonstrations across Europe and 3) by combining the success of the CarbFix approach with corresponding gas re-use approaches.

GOAL 2

To turn captured emissions into commercial products, allowing for cost reductions through increased revenues. By producing pure enough gas streams for utilisation processes, products like hydrogen gas and pure CO_2 can be used as an added value to help offset the costs of cleaning exhaust gases. In Hellisheiði, captured and purified CO_2 will e.g. be supplied to algae production facilities.

GOAL 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. Added value/revenues of utilizing captured streams will further be analysed where applicable. Conversion of H_2S to SO_2 will cause HSE risks due to pH modification of brines within power plants to be decreased by regulating pH with SO_2 instead of H_2S.

GOAL 4

The site-specific characterisation and modelling of geology, geochemistry and infrastructure for the optimisation of the injection experiments at four distinct geothermal systems located throughout Europe. By applying our approach successfully at 4 diverse locations we will aid in the public acceptance of geothermal energy throughout the continent.

GOAL 5

To quantify the rate and extent of subsurface reactions occurring in response to induced fluid flow during and after the injection of fluids into the subsurface. We will quantify these through a comprehensive modelling program, and using tracers and geochemical data, to gain better understanding of these processes.

GOAL 6

To integrate new technology, such as detecting CO_2 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. Such demonstrated technology has the potential to be transferred to a large number of other sub-surface applications.

GOAL 7

To generate an improved understanding of the response of subsurface rocks to induced fluid flow in the subsurface. Notably by combining the results of a consistent chemical monitoring, and modelling program on a diverse set of geothermal systems we will generate computational tools to predict the behaviour of other systems.

GOAL 8

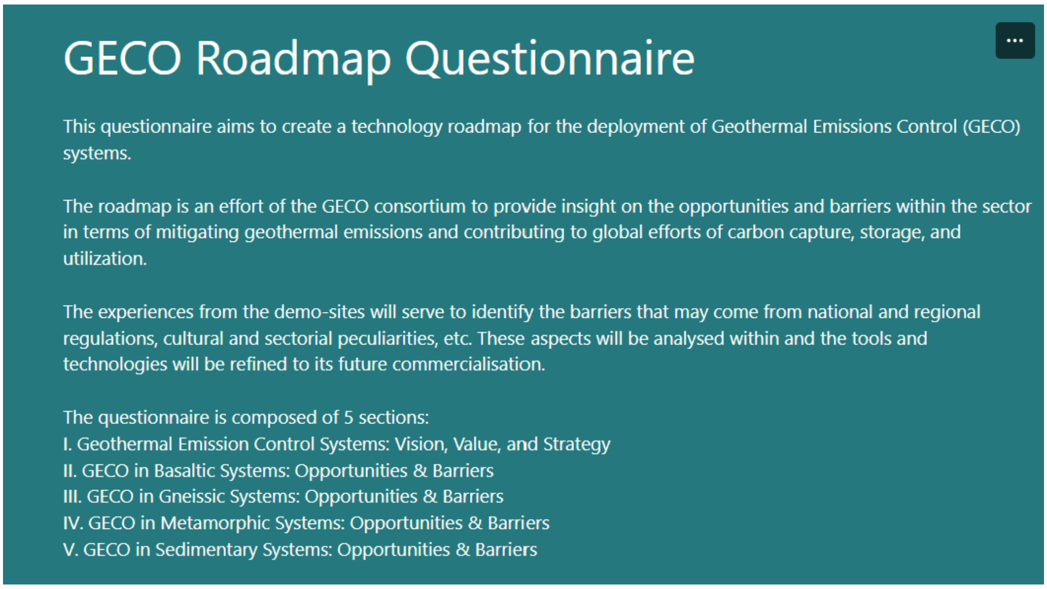
To help train next generation of scientist and engineers in the current best practice work-flow for lowering emissions from deep geothermal operations and thereby moving the GECO technology into the future. This will be done through both the integration of early career scientists into parts of the GECO program through suite of outreach activities.

5. EXPERIENCES FROM THE DEMO-SITES

5.1 Challenges and Opportunities

5.1.1 GECO Roadmap Questionnaire:

The questionnaire used in the GECO project aimed to assess the opportunities and barriers for GECO Systems in four geological settings: basaltic, gneissic, metamorphic, and sedimentary. The questionnaire consisted of 19 questions that covered topics such as the value of GECO systems, potential customers and use cases, technical and regulatory barriers, and cultural and sectorial peculiarities that may hinder deployment. Specific questions were asked for each geological setting, such as the opportunities for GECO in that setting, technical barriers, and any regulatory or cultural challenges that the project may have faced. The questionnaire aimed to provide insights into how GECO systems can serve the geothermal community and how it can thrive beyond the lifetime of the GECO Project.



GECO Roadmap Questionnaire

This questionnaire aims to create a technology roadmap for the deployment of Geothermal Emissions Control (GECO) systems.

The roadmap is an effort of the GECO consortium to provide insight on the opportunities and barriers within the sector in terms of mitigating geothermal emissions and contributing to global efforts of carbon capture, storage, and utilization.

The experiences from the demo-sites will serve to identify the barriers that may come from national and regional regulations, cultural and sectorial peculiarities, etc. These aspects will be analysed within and the tools and technologies will be refined to its future commercialisation.

The questionnaire is composed of 5 sections:
I. Geothermal Emission Control Systems: Vision, Value, and Strategy
II. GECO in Basaltic Systems: Opportunities & Barriers
III. GECO in Gneissic Systems: Opportunities & Barriers
IV. GECO in Metamorphic Systems: Opportunities & Barriers
V. GECO in Sedimentary Systems: Opportunities & Barriers

Feedback from part of consortium shows that the GECO project is serving the geothermal community by implementing innovative processes and technology that will reduce gas emissions from geothermal power plants. This will enhance their environmental sustainability and increase social acceptance. The GECO systems offer unique and unprecedented value to the market, with innovative solutions that accelerate the deployment of new geothermal projects, creating new jobs and delivering social and economic benefits.

The total reinjection of non-condensable gases is a first-of-its-kind application in the geothermal energy sector worldwide. The main customers of GECO technology will be services companies, power plant manufacturers, and geothermal operators. To thrive beyond the lifetime of the GECO project, the establishment of a consulting company involving GECO consortium partners is recommended to leverage the developed know-how globally. There is no information about the most promising use cases and solutions of the GECO project, and the expected competition is unknown.

5.2 Hellisheiði and Nesjavellir - Iceland:

The answers provided in the GECO roadmap questionnaire indicate several opportunities and technical barriers for GECO systems in basaltic geothermal fields. The best opportunity for GECO in these systems is the potential for CO2 storage due to the presence of olivines. The corrosion/scaling monitoring system developed by the project can also be implemented in any type of demosite suffering from corrosion processes. The Laser Isotope Ratio Analyzer (LIRA) developed by the project has the potential to unlock novel applications for understanding sub-surface processes, but technical barriers include instrument maturity, geochemical scientific understanding, and modeling.

However, several technical barriers exist for GECO systems in basaltic geothermal fields. The limited porosity of these reservoirs can cause clogging with intensive CO_2 storage, drastically reducing reservoir permeability. Other barriers include the cost of the system, strong safety guidelines in installation plants, and the lack of trained staff in the field of corrosion. It is suggested that training courses and dissemination in conferences, industrial workshops, and specific trade fairs are necessary to address these barriers.

There were no reported incidents of the project experiencing barriers due to national or regional regulations. However, there may be cultural and/or sectorial peculiarities that could hinder the deployment of GECO. In the context of LIRA, the novelty of the technology may be a hindrance, as its potential value is not yet fully understood, and only R&D active geothermal industrial players are interested. Additionally, geothermal energy in Iceland may not be viewed as a sustainable renewable energy source, as it is often compared unfavorably to the availability of hydroelectricity.

5.3 Kizildere - Turkey:

There are several opportunities for GECO systems in metamorphic reservoirs, such as the utilization of non-condensable gas (NCG) injection as an artificial lifting methodology and the reduction of the carbon footprint through a closed-loop NCG injection cycle. Additionally, CO_2 reinjection into the reservoir can help to maintain pressure levels and limit resource decay over time. However, the composition of NCG presents a significant technical barrier to the selection of injection equipment, and the limited amount of CO2 that can be injected in the liquid phase requires large pressure vessels for mixing, which can be a safety issue limiting capacity. The project did not experience any significant barriers due to regulations, and there are no cultural or sectorial peculiarities that may hinder the deployment of GECO technologies in the region.

5.4 Bochum MULE - Germany:

The sedimentary reservoir system in Bochum, Germany offers potential opportunities for GECO technology. Sandstone reservoirs that previously held oil and gas may be repurposed for carbon capture and storage. Additionally, the corrosion and scaling monitoring systems developed in this demo site can be implemented in any other site experiencing similar corrosion issues. GECO technology may also offer a feasible method for extensive carbon capture and storage with mineralization. However, technical barriers exist such as the on-site mineralogy not being as effective for mineral carbonation as the olivine found at the Carbfix site. Furthermore, the cost of the system, safety guidelines, and lack of trained staff in the field of corrosion pose implementation challenges. Regulations also exist, such as the German Coal Dioxide Storage Act, which could prevent scientific and industrial CO_2 storage, although it may only refer to liquid CO_2 and not mineral carbonation. The German population is also generally critical about the implementation of CO_2 sequestration, which may hinder the deployment of GECO technology. Overall, while opportunities exist in sedimentary reservoir systems for GECO technology, technical barriers, regulations, and cultural concerns must be addressed for successful implementation.

5.5 Castelnuovo - Italy:

In terms of technical barriers, the GECO project faced challenges related to the incomplete demonstration of two-phase reinjection and the need for complex and expensive solutions to prevent corrosion when reinjecting geothermal fluids with high non-condensable gas content in steam-dominated systems in gneissic geothermal fields.

Regarding regulations, the project did not encounter any barriers on a national or regional level. However, the tests were proposed in Hveragerði, Iceland, because it was impossible to perform them within the existing regulations in Italy for projects like Castelnuovo at the current stage of development.

In terms of cultural and sectorial peculiarities, the resistance to changing operating methods in steam-dominant systems led to the belief that gas rejection was not technically feasible. Additionally, the dominance of current technology (dry steam or flash plants) made it difficult to compete with closed-loop operation proposals.

6. ROADMAP FOR IMPLEMENTATION

The GECO systems offers promising opportunities for geothermal energy and carbon capture and storage in various geological contexts. To implement the GECO systems effectively, several steps need to be taken, including:

1. **Market Analysis:** Continue conducting a comprehensive market analysis to identify potential opportunities and barriers for GECO Systems in different regions and geological settings. Use the insights gained to refine target markets and prioritize deployment efforts.

2. **Collaboration and Partnerships:** Build on existing collaborations and partnerships with geothermal industry stakeholders, including power plant operators, geothermal developers, and government agencies. Strengthen these relationships and explore new partnerships to promote the adoption of GECO technology.

3. **Regulatory Engagement:** Continue engaging with national and regional regulatory bodies to ensure compliance with environmental regulations and facilitate the integration of GECO systems into existing geothermal infrastructure. Address any remaining regulatory barriers and advocate for supportive policies.

4. **Scaling Up:** Based on the successful implementation of pilot projects, scale up deployment efforts in geological settings where GECO has demonstrated its effectiveness. Increase the number of installations and expand the geographical reach to capture a larger market share.

5. **Customization and Adaptation:** Customize GECO systems further to suit the specific geological characteristics of each target region. Continuously improve the technology to optimize performance and emissions reduction in different geological settings.

6. **Knowledge Transfer and Capacity Building:** Continue organizing workshops, training programs, and technical exchanges to facilitate knowledge transfer and capacity building. Empower local communities, engineers, and stakeholders with the necessary skills and expertise to implement and maintain GECO systems effectively.

7. **Monitoring and Evaluation:** Implement a robust monitoring and evaluation framework to assess the performance and impact of GECO systems in terms of emissions reduction and energy efficiency. Continuously gather data and feedback to improve the technology and enhance its value proposition.


ROADMAP OF
GEOTHERMAL EMISSION CONTROL SYSTEMS
DEPLOYMENT IN THE DEEP GEOTHERMAL SECTOR
1
MARKET ANALYSIS
• Continue conducting a comprehensive market analysis for GECO Systems application in different regions and geological settings.
2
COLLABORATION AND PARTNERSHIPS
• Build on existing collaborations and partnerships with geothermal industry stakeholders.
3
REGULATORY ENGAGEMENT
• Ensure compliance with environmental regulations and facilitate the integration of GECO systems into existing geothermal infrastructure.
4
SCALING UP
• Increase the number of installations and expand the geographical reach to capture a larger market share.
5
CUSTOMIZATION AND ADAPTATION
• Customize GECO systems further to suit the specific geological characteristics of each target region and specific power plants type and infrastructure.
6
KNOWLEDGE TRANSFER AND CAPACITY BUILDING
• Facilitate knowledge transfer and capacity building.
• Workforce training
• Social Engagement to accelerate deployment
7
MONITORING AND EVALUATION
• Implement a robust monitoring and evaluation framework to assess the performance and impact of GECO solutions in terms of emissions reduction and energy efficiency.
#GECOh2020

Overall, the successful implementation of the GECO systems requires a coordinated effort involving various stakeholders, including the geothermal industry, regulatory authorities, and the local communities. With the development of effective solutions to overcome technical barriers and regulatory issues, and the promotion of awareness and training, the GECO systems can be implemented effectively to support sustainable geothermal energy production and carbon capture and storage.

7. CONCLUSIONS

In conclusion, the GECO roadmap presents a comprehensive plan for the deployment and implementation of the GECO systems in geothermal and CCS applications. The roadmap identifies the main technical opportunities and barriers associated with the deployment of the GECO systems in different reservoir types, including basaltic, metamorphic, and sedimentary systems. Through the demonstration of the GECO systems in real-world scenarios, the roadmap aims to establish a scalable and economically feasible solution for mitigating CO_2 emissions in the geothermal sector.

The GECO roadmap highlights the importance of collaborative efforts between industry, academia, and government to overcome the technical and regulatory barriers associated with the deployment of the GECO systems. It emphasizes the need for increased funding for research and development to advance the GECO technology and ensure its commercial viability. Additionally, the roadmap recognizes the significance of public acceptance and engagement in the deployment of the GECO systems.

Overall, the GECO roadmap presents a practical approach for the deployment of the GECO systems, which has the potential to revolutionize the geothermal and CCS industries. The roadmap's implementation is expected to contribute to the global efforts to reduce carbon emissions and mitigate climate change.