



## **ANNUAL REPORT 2010**

### **CarbFix project**

Project ID: 09-02-001

Coordinator: Sigurður Reynir Gíslason, University of Iceland

Start date: January/2010

Duration: 3 years

Partners: Orkuveita Reykjavíkur

## 1 Introduction

- The CarbFix project involves a combined program, consisting of a CO<sub>2</sub> injection pilot test, laboratory based experiments and numerical modelling, where the focus is on accelerating the trapping of CO<sub>2</sub> in mineral form in basaltic rocks. In 2010 we have worked according to a monitoring and accounting program, which consists of a surface, subsurface and atmospheric component. Development of a three dimensional reactive transport model that simulates hydrology and mineral alteration associated with the CO<sub>2</sub> injection has been ongoing by one PhD student at OR. Furthermore we have prepared work on laboratory experiments by one PhD student at UI for the purpose of determining the feasibility of using seawater instead of freshwater for mineral carbon storage. Since late November 2010 the CarbFix project has been up and running, water has been constantly injected into the injection well, however without CO<sub>2</sub> gas. Startup of CarbFix needs the CO<sub>2</sub> gas produced in the pilot gas separation plant at Hellisheidi power plant. The pilot plant has been facing several incidences causing delay of CO<sub>2</sub> delivery to CarbFix in 2010. This report describes how the CarbFix pilot program has advanced during the year 2010. When this text is written (early March 2011) the CO<sub>2</sub> injection will start 15 March and scientists from Columbia University will arrive to Iceland to assist the Icelandic group.

## 2 Project Status, Results and Next Steps

**WP-1: CO<sub>2</sub> charged seawater-basalt experiments:** University of Iceland (UI) hired a PhD student June 1st 2010 to carry out the WP-1. The student's name is Kiflom Mesfin. This was 3 months earlier than anticipated at the time of the signing of the grant agreement in March, see paragraph 4 below. June, July and August was mostly devoted to train the student in CO<sub>2</sub> charged pressurized seawater-basalt experiments and training in monitoring CO<sub>2</sub> charged borehole fluids. In the fall Kiflom conducted some seawater experiments as reported in the abstract from a poster presented for him at an international conference in Oman in January 2011. Since December 2010 Kiflom has been involved with developing a sampling device to collect fluids from high pressurised CO<sub>2</sub> fluid. This device, "the bailer", will be used to sample the injection fluids at the CarbFix site at Hellisheidi.

**WP-2: Monitoring and analysis:** All year 2010 work has been ongoing according to WP-2 on behalf of Orkuveita Reykjavíkur (OR):

Surface Monitoring involves CO<sub>2</sub> flux measurements (closed chamber method), sampling of injected gases from the power plant in the pilot gas separation plant and pressure and temperature logging at the well heads.

- In March and April CO<sub>2</sub> flux measurements were carried out at 165 fixed sites on the platform for the injection well HN-2 and the observation wells HN-4 and HK-34, in the Holocene lava and along the old Hellisheidi road and the Threngsli road. All background CO<sub>2</sub> flux measurements are finalised.
- In spring 2010 OR finalised the construction of a pilot gas separation plant where CO<sub>2</sub> is captured, and where CO<sub>2</sub> and H<sub>2</sub>S from the Hellisheidi power plant are separated in a

distillation column. In July the pilot plant started operation along with a planned three week testing phase prior to delivery of gas to CarbFix. Experiments with the distillation column commenced and liquid gas was produced. However, after a short period of experiments a device that condenses H<sub>2</sub>S broke down. In August, September and October there were delays of shipping of device for the pilot gas separation plant, more components and small equipments broke down almost every day. Therefore time plan of delivery of CO<sub>2</sub> for CarbFix and injection of the gas needed constant revision. In late October samples consisting of 80% clean CO<sub>2</sub> for the CarbFix project had been produced and analyzed. However, reinitiation of the gas separation plant did not go according to plan.

- All year pressure and temperature logging at the well heads has been ongoing. An accurate log is maintained on the fluids pumped out of two observation wells next to the injection well. Sampling and analysis of tracers has been ongoing in those wells to further characterize the groundwater reservoir.

Subsurface Monitoring involves monitoring the transport and reactivity of the dissolved CO<sub>2</sub> and how much CO<sub>2</sub> is stored in its various forms. In spring 2010 sampling infrastructure were already installed in the monitoring wells and non-reactive and reactive tracers have been shipped to Iceland. Systematic collection and analysis of groundwater from 9 monitoring wells at the site and in the target reservoir has been ongoing in 2010. These data provide comprehensive information on the chemistry of the ground waters in the area.

In late November and start of December two scientists from Columbia University arrived for test running the CarbFix system with the Icelandic group. The group managed to take the last background water samples from the CarbFix wells, go through the sampling equipments and sample collection procedures, conduct a gas tracer injection experiment with N<sub>2</sub> gas flow (as CO<sub>2</sub> gas was not jet available), go through the <sup>14</sup>C tracer filling procedure and other issues. Different questions and issues were raised as was expected. This visit from Columbia University stressed the importance of being able to find solutions from different angles as a group. Since the visit the CarbFix project has been up and running, water has been constantly injected into the injection well, however without CO<sub>2</sub> gas. Startup of CarbFix needs the CO<sub>2</sub> gas produced in the gas separation plant as mentioned above. The plant has been facing several incidences causing delay of CO<sub>2</sub> delivery to CarbFix for 6 months as this text is written in early March 2011). The time schedule for CO<sub>2</sub> injection has therefore been heavily impacted. This is the key risk the project has been facing in the last part of 2010, an inherited uncertainty that innovative research projects often contain.

Atmospheric Monitoring. A weather station is operating at the injection site for continuous monitoring of atmospheric CO<sub>2</sub>. The station further keeps track of all key injection parameters regarding the “bookkeeping” of the injection and provides information online, available to all collaborators in the project. Background atmospheric CO<sub>2</sub> data has been collected since October 2009. The results show that only diurnal CO<sub>2</sub> changes have been detected and dispersed CO<sub>2</sub> from the Hellisheidi power plant has not been observed. It is therefore

anticipated that concentrations exceeding ~40 ppmv above mean CO<sub>2</sub> values will be indicative of CO<sub>2</sub> leak from the injection zone. These possible abnormal CO<sub>2</sub> concentration values may be inspected in conjunction with wind speed and wind direction to estimate the probability of leaks from the subsurface.

**WP-3: Geochemical and hydrological modelling:** In 2010 development of a three dimensional reactive transport model that simulates hydrology and mineral alteration associated with the CO<sub>2</sub> injection has been ongoing at OR by the PhD student Edda Sif Pind Aradottir. TOUGH2, iTOUGH2 and TOUGHREACT are used in the model development.

The mineral reactions database in TOUGHREACT has been revised and extended, providing an internally consistent database suitable for mineral reactions of interest for this study. Hydrological parameters of the model were calibrated using iTOUGH2 to simulate field observations such as well drawdown, flow rates and tracer breakthrough curves. Modeling results indicate groundwater velocity in the reservoir to be significantly lower than expected. The slow groundwater velocity will necessitate increasing groundwater flow by producing downstream wells at low rates after CO<sub>2</sub> injection has started. The main objective of this potential production will be to pull highly concentrated carbonated water away from the immediate surroundings of the injection well to prevent clogging. Managing plans for the potential production need, however, to be carefully designed to minimize the amount of CO<sub>2</sub> that will be pumped out of downstream wells. The three dimensional CarbFix numerical model has proven to be a valuable tool in simulating different injection and pumping schemes by showing what effect different pumping scenarios have in transport and distribution of injected CO<sub>2</sub>.

Reactive chemistry has been coupled to the model and TOUGHREACT is used for reactive transport simulations. Preliminary results confirm dissolution of primary basaltic minerals as well as carbonate precipitation. Secondary mineral abundance is highly dependent on temperature, pCO<sub>2</sub> and flow rate. Ongoing work includes validation of revised thermodynamic and kinetic databases, and simulations of the CarbFix CO<sub>2</sub> injection at Hellisheidi.

**Next steps:** Injection of CO<sub>2</sub> in March 2011 together with necessary monitoring, analysis and modelling with the assistance from scientists at Columbia University, see paragraph 4 below..

The main thrust of the PhD student Kiflom Mesfin work during the first half of 2011 will be sampling the high-pressure fluids at the CarbFix site. The seawater experiments will be run parallel with this task.

Next steps for the PhD student Edda Sif Pind Aradottir work in 2011 involves using the CarbFix numerical model to answer key questions concerning the CarbFix project, i.e. how much CO<sub>2</sub> can be mineralized after injection, and how long time the mineralization does take.

In December 2010 OR started preparing a patent application on CarbFix for EPO and an US-provisional application. An application will be delivered in late March.

### 3 Publications and Presentations 2010

#### Talks given at international workshops and conferences:

- The PhD student Edda Sif Pind Aradóttir presented the CarbFix model at a GEORG workshop on Geothermal Reservoir Research in March 2010.
- Hólmfríður Sigurðardóttir, gave a talk on the CarbFix project at the World Geothermal Congress in Bali Indonesia in April 25-30.
- Bergur Sigfússon gave an invited presentation on the CarbFix project at a workshop on Carbonate Reactivities /Industrial and Academic Applications in Copenhagen, Denmark in May 9-12.
- Sigurdur Reynir Gíslason gave an invited presentation on water – rock - CO<sub>2</sub> interactions at the workshop Carbonate Reactivities /Industrial and Academic Applications in Copenhagen, Denmark in May 9-12.
- Sigurdur Reynir Gíslason gave a talk on mineral sequestration of CO<sub>2</sub> in basalt in the CarbFix project At the Goldschmidt Conference, Tennessee, USA in June.

#### Posters:

- Edda S.P. Aradóttir, Eric Sonnenthal, Grímur Björnsson and Hannes Jónsson (2010). Reactive transport models for mineral CO<sub>2</sub> storage in basaltic rocks. The 2010 AGU Fall meeting 13–17 December, California, USA.
- Hólmfríður Sigurðardóttir, B. Sigfússon, E.S.P. Aradóttir, E. Gunnlaugsson, S.R. Gíslason, H.A. Alfredsson, W.S. Broecker, J.M. Matter, M. Stute and E.H. Oelkers (2010). The CarbFix Pilot Project in Iceland. CO<sub>2</sub> capture and mineral storage in basaltic rocks. The 2010 AGU Fall meeting 13–17 December, California, USA.

#### Papers in International Journals:

- Edda Sif Pind Aradóttir. A manuscript focusing on the CarbFix conceptual model is currently in review in an International Journal.
- Edda Sif Pind Aradóttir. Two manuscripts are currently in preparation, one focusing on the thermodynamic and kinetic databases of the CarbFix numerical model but the other one on the hydrological part of the model.
- Elisabet Ragnheidardóttir, Hólmfríður Sigurðardóttir, Helga Kristjansdóttir, William Harvey (2011). Opportunities and challenges for CarbFix: An evaluation of capacities and costs for the pilot scale mineralization sequestration project at Hellisheidi, Iceland and beyond. International Journal of Greenhouse Gas Control. In Press.
- Sigurdur Reynir Gíslason, Domenik Wolff-Boenisch, Andri Stefansson, Eric H. Oelkers, Einar Gunnlaugsson, Hólmfríður Sigurðardóttir, Bergur Sigfússon, Wallace S. Broecker, Juerg M. Matter, Martin Stute, Gudni Axelsson, Thrainn Fridriksson (2010). Mineral

sequestration of carbon dioxide in basalt: A pre-injection overview of the CarbFix project. *International Journal of Greenhouse Gas Control* 4, 537–545.

Extended abstracts and chapters in books:

- Holmfrídur Sigurðardóttir, Sigurður R. Gíslason, Wallace S. Broecker, Eric H. Oelkers and Einar Gunnlaugsson (2010). The CO<sub>2</sub> Fixation into Basalt at Hellisheidi Geothermal Power Plant, Iceland. *Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April*, pp. 1-4.
- D. Wolff-Boenisch, S.R. Gíslason, S. Wenau (2010). Effect of seawater and its components on the dissolution of peridotite under CO<sub>2</sub> pressure. *Proceedings of the 13th International Conference on Water-Rock Interaction, Guanajuato, Mexico, August 16th - 20th 2010*, p. 899-902. Taylor & Francis Group, London.
- Oelkers E. H. and Gíslason S.R. (2010). Water-CO<sub>2</sub>-rock interaction during carbon sequestration. In: *Ion partitioning in ambient-temperature aqueous systems* (M. Prieto & H. Stoll, eds.) *EMU Notes in Mineralogy, Vol. 10* (2010), Chapter 9, 325–344, European Mineralogical Union, Vienna.

Reports:

- Edda Sif Pind Aradóttir (2010). CarbFix reservoir model – hydrological parameters and pumping schemes for experimental CO<sub>2</sub> injection. OR report no: 2010-03

## 4 Schedule Changes

Below is a description on incidences that have caused schedule changes:

- As discussed in ANNEX I in the grant agreement, it was discovered in the beginning of March that the gas from the condensers in the Hellisheidi power plant contained air. After thorough examination necessary amendments were dealt with. Since then the project has been facing further incidences, mainly due to operation difficulties in the gas separation plant. This had caused delay in delivery of CO<sub>2</sub> gas to CarbFix and injection of CO<sub>2</sub>. In the Status Report delivered to GEORG in September the plan was to start injecting in late October. When this text is written the CO<sub>2</sub> injection will start 15 March and our collaborators from Columbia University will arrive to Iceland 13 March to assist the Icelandic group.
- UI was able to hire a PhD student for the WP-1, three months earlier than anticipated at the time of the signing of the grant agreement in March 2010. Because of the delay of delivery of CO<sub>2</sub> to CarbFix discussed above, Kiflom Mesfin has taken over some of the field sampling duties during the year 2011. He will run the laboratory sweater experiments in parallel with the field sampling.

## 5 Financing

In 2010, UI has spent around 2.080 thousand ISK in salaries and related cost for the PhD student working on WP-1, around 44.5 million ISK in other tasks in the CarbFix-project, so in total UI's contribution has been around 46.6 million ISK.

In 2010, OR has spent around 19 million ISK on monitoring, analysing and modelling in WP-2 and WP-3. OR has spent around 18 million ISK in other tasks in the CarbFix-project, in total OR's contribution has been around 37 million ISK.

In 2010, GEORG's contribution to CarbFix has been 6 million ISK.

The contribution of OR, UI and GEORG in year 2010 can be seen in the table below.

Consortium: OR, UI	Name of Project: CarbFix	Amounts in ISK '000		
		Contribution January-December 2010		
Subtask		OR	UI	GEORG
WP-1: CO2 charged seawater-basalt experiments			2.080	2.250
WP-2: Monitoring and analysis		8.320		2.813
WP-3: Geochemical and hydrological modelling		11.000		937
	Total	19.320	2.080	6.000
Other tasks not contributed by GEORG		17.630	44.530	
	<b>Total</b>	<b>36.950</b>	<b>46.610</b>	<b>6.000</b>