CO_2 Fixation into Basalts
Hellisheiði
Iceland

Annual Status Report 2010

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HÁSKÓLI ÍSLANDS

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Prologue

CarbFix, a combined industrial-academic pilot program, was developed in order to assess the feasibility of in situ CO_2 mineral sequestration in basaltic rocks. Unique to CarbFix is its connection to the Hellisheidi geothermal power plant in SW Iceland, allowing for capture of otherwise emitted CO_2 in addition to CO_2 transport and mineral sequestration.

The overall objective of the CarbFix project is to develop and optimize a practical and cost-effective technology for mineral storage of carbon dioxide in basaltic rock, and to train young scientist to carry this knowledge into the future. The project consist of field injection of CO_2 charged water at the Hellisheidi power plant, laboratory experiments, computer modelling of fluid flow and gas-water-rock interactions, tracer tests, natural analogue and cost analysis.

The CO_2 injection site is situated about 3 km south of the Hellisheidi geothermal power plant. The power plant currently produces 40.000 tons of CO_2 per year. The CO_2 gas is a by-product of the geothermal energy production and of magmatic origin. The produced geothermal gas mainly consists of CO_2 and H_2S. The two gases will be separated in a pilot gas separation plant, and CO_2 will be transported in a pipeline to the injection site. There, CO_2 will be fully dissolved in water during injection, resulting in a single fluid phase entering the storage formation. The CO_2 charged water is reactive and will dissolve divalent cations from the rock, which will combine with the dissolved carbon to form solid carbonate minerals. The injection test is designed to inject approximately 2.000 tons of CO_2 per year, but there is the potential to upscale if mineral carbonation proves to be successful.

In 2010 the CarbFix group has been working according to a monitoring and accounting program for the field injection, which consists of a surface, subsurface and atmospheric component. In early spring 2010 the construction of the CarbFix mechanism and equipments was finalised and in March 2010 CarbFix was ready for a few weeks test-run prior to being able to start injecting CO_2. Start-up of CarbFix needs the CO_2 gas produced in the pilot gas separation plant at Hellisheidi power plant. During its testing phase the pilot gas separation plant has been facing several incidences causing delay of CO_2 delivery to CarbFix now planned in 2011. In late November and beginning of December scientists from Columbia University arrived for testing the CarbFix system with the Icelandic groups. This test was a success. Furthermore, several scientific papers and abstracts on the laboratory experiments, developments of reactive transport computer models, natural analogue studies and cost analysis studies were submitted to international journals.

This report describes how the CarbFix pilot program has advanced during the year 2010.

Participants

The CarbFix project was formally launched on September 29th 2007. It is a consortium of the following four partners who signed a partnership agreement for the purpose of setting forth objectives, plans and undertakings with respect to the CarbFix project. Below is a short description of each partner and their responsibilities.

Figure 1 – CarbFix is connected to the Hellisheidi geothermal power plant in SW Iceland. The CarbFix injection site is located in the right part of the figure. *Photo: Mats Wibe Lund.*

Orkuveita Reykjavíkur (OR)

OR operates a geothermal district-heating system, an electricity distribution network and a water distribution system, serving 67% of Iceland's population. OR is the main sponsor of the project being the owner of the Hellisheidi geothermal plant and the infrastructure used for the CarbFix pilot project at the injection site (Figure 1). OR provides the pilot gas spearation plant (source of CO_2), pipelines, injection system, injection- and monitoring wells, management and logistics, geothermal science and technology as many of OR's scientists, engineers and technicians work on this project. OR is responsible for communication with stakeholders and obtaining licences from local and environmental authorities. OR operates the Environmental and Energy Research Fund to support research, development and innovation in the field of environment and energy science. A considerable part of the annual budget has been granted to CarbFix.

Iceland Geosurvey (ISOR) is one of OR's primary consultants. ISOR maintains a database of important geologic, geophysical and geochemical data of the Hengill area. ISOR plays an important role in monitoring and verifying of the CO_2 injection and is designing and conducting a soil gas monitoring program to detect possible CO_2 leakage to the surface before, during and after the injection.

Mannvit Engineering, Iceland (Mannvit) is one of OR's primary consultants for the development of its power plants. Mannvit assists, the development, design and test of the CO_2 injection system.

Lawrence Berkeley National Laboratory USA (LBNL) is a long-term partner of OR for geothermal reservoir modelling. LBNL has adopted properties of Icelandic basalts into the reactive transport modelling code (TOUGHREACT), to predict the long-term success of CO_2 injection into basalts and to interpret field and experimental data.

The University of Iceland – Institute of Earth Sciences (IES)

IES develops and runs laboratory experiments and the plug flow reactor in collaboration with CNRS. The result of the laboratory experiments, kinetic and thermodynamic data are used for reaction and reactive transport modelling. The plug-flow reactor will be used to fine tune reactive transport models. IES in cooperation with LDEO, ISOR and OR administers the designing of the monitoring protocol and sampling equipment for the field injection at Hellisheidi. IES has a leading role in systematic collection and analysis of the groundwater in the injection and monitoring wells in cooperation with LDEO and OR.

Columbia University USA – Earth Institute - Lamont-Doherty Earth Observatory (LDEO)

LDEO has a leading role with OR and ISOR in monitoring and verifying the CO_2 injection. The work includes pre-injection characterization of the basaltic rocks and ground waters with geochemical and geophysical tools to assess the CO_2 storage capacity of the injection site, developing a monitoring program for the CO_2-water-rock interactions in situ in the subsurface and validate the hydrological modelling with tracer studies in cooperation with IES and ISOR. LDEO develops a CO_2-water mixing system in collaboration with OR and Mannvit Engineering.

The Centre National de la Recherche Scientifique, France (CNRS)

CNRS through the Laboratoire des Mécanismes et Transferts en Géologie (LMTG - UMR 5563) evaluates kinetic and thermodynamic data for basaltic rocks that will be used to further the CO_2 storage process and reactive transport models. Laboratory efforts aim at characterizing the effect of surface coatings on mineral dissolution rates and the effect of solution compositions on precipitation rates, as well as the long-term evolution and consequences of these reactions on the porosity and permeability of the basaltic rocks.

IPGP in Paris is a collaborator of CNRS and has been working on performing a geo-microbiological monitoring on the Hellisheidi pilot site.

Leadership

The Scientific Steering Committee**:**

Sigurður Reynir Gíslason (Chairman). Research Professor at the Institute of Earth Sciences, University of Iceland. sigrg@raunvis.is

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PhD Students

In 2010 eight PhD students were working on science projects, within the CarbFix project. One PhD student, Therese Flaathen, was the first one to finish in September 2009. In autumn 2010 one of the students had to quit the PhD thesis due to personal reasons.

Name	Title of Ph.D. thesis	University	Start	Finish
Alexander Gysi	CO_2-water-basalt interaction: experiments and geochemical modelling	University of Iceland	Sept 2007	Aug 2011
Diana Fernandez de la Reguera	Monitoring and verification of geologic CO_2 storage using tracer techniques	Columbia University	Sept 2008	Quit Sept 2010
Edda S. P. Aradóttir	Reactive transport approach to studying CO_2-water-basalt interaction: Modeling, designing and optimizing mineral CO_2 sequestration in basaltic rocks	University of Iceland	Jan 2007	Sept 2011
Gabriella Stockmann	Experimental determination of the effect of precipitated mineral coatings on the rates of basaltic glass and minerals; effect of bacteria on the dissolution of basaltic glass	University of Iceland	Sept 2007	Nov 2011
Helgi Arnar Alfreðsson	CO_2 sequestration in basaltic rock: Pre-injection studies of the injection field and development of a piston-type down hole sampler for CO_2 rich fluids and tracers	University of Iceland	Sept 2007	April 2012
Iwona Galeczka	Experimental studies on CO_2 sequestration in basaltic rocks with the plug flow reactor	University of Iceland	Sept 2009	Sept 2012
Snorri Guðbrandsson	Dissolution rates of crystalline basalt as a function of temperature and solution composition	University of Iceland	Sept 2007	March 2012
Kiflom Gebrehiwot Mesfin	Dissolution of basaltic glass in seawater at 100°C and 70 bars CO_2 pressure. Implications for CO_2 mineral sequestration	University of Iceland	June 2010	June 2013

Following is the main research focus of the PhD students:

Alexander Gysi: Laboratory batch experiments at pCO_2 of 0-40 bar and 40-250 °C. Analysis of secondary precipitates using x-ray diffraction (XRD), scanning electron microscope (SEM/EDS) and electron microprobe (EMPA). Geochemical modeling using PHREEQC and update of the thermodynamic dataset relevant for low temperature CO_2-water-basalt interaction.

Diana Fernandez de la Reguera: Laboratory experiments to study the dissolution of carbon dioxide (CO_2) in fresh and salt water. The objectives of these experiments were to simulate a representative scaled down version of the planned CarbFix CO_2 injection scenario, and to test different ways to maximize the percentage of dissolved CO_2. Results from these experiments were used to optimize the design of the CarbFix CO_2 injection system. The student had to quit in September 2010.

Edda S. P. Aradóttir: TOUGHREACT and iTOUGH2 are used to develop reactive transport models that simulate hydrology and mineral alteration associated with injecting dissolved CO_2 into basalts. 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 tracer tests that have been ongoing since 2007. Reactive chemistry was coupled to the model and TOUGHREACT used for reactive transport simulations, which are ongoing.

Gabriella Jarvik Stockmann: Experiments performed partly in Iceland and partly in Toulouse, France: Long-term calcite precipitation on basaltic glass and diopside crystal surfaces. Calcite coatings on different

silicates - to investigate if crystal structure plays a role in calcite precipitation. Bacteria effect on the dissolution rate of basaltic glass.

Helgi Arnar Alfreðsson: Pre-injection study of the injection site at Hellisheidi. Water sampling and analysis from the boreholes. Development of a piston-type down-hole sampler for CO_2 rich fluids and tracers.

Iwona Monika Galeczka: Crushing, sieving and cleaning basaltic material which will fill up a plug flow reactor. Assembling the plug with attached equipment and conducted mixed flow experiments in the laboratory. Iwona was also involved with Helgi, Domenik and Kiflom in testing the piston sampler.

Snorri Guðbrandsson: Continued experiments on the dissolution rates of crystalline basalt and plagioclases of variable composition, and submitted a paper to GCA on the dissolution rate of crystalline basalt. Snorri spent several months in the CNRS laboratory in Toulouse, France conducting precipitation rate experiments.

Kiflom Gebrehiwot Mesfin: Batch experiments at pCO_2 of 70,100 bar and 100°-150°C. Analyse the evolution of the solute chemistry as well as the precipitation of secondary phases using XRD (X-ray diffraction), SEM (Scanning Electron Microprobe) and EMPA (Electron Microprobe). He was involved in developing the piston sampler to be used to monitor the high pressure solution at Hellisheidi.

MSc Students

Friday 20th January, Elísabet Vilborg Ragnheiðardóttir defended her MSc thesis. The MSc is a joint degree between the University of Iceland and Reykjavik University.

Name	Title of MSc thesis	University Programme	Start	Finish
Elísabet Vilborg Ragnheiðardóttir	Costs, Profitability and Potential Gains of the CarbFix Program	Reykjavik Energy Graduate School of Sustainable Systems	Jan 2009	Jan 2010

Following is the main research focus of the MSc student:

Elísabet Vilborg Ragnheiðardóttir: Review the costs associated with the CarbFix pilot CO_2 injection program and identify avenues for improvement. The CarbFix costs are reviewed both for the current pilot project, as well as for two larger scenarios involving greater sequestration at the Hellisheidi geothermal power plant in SW Iceland and a hypothetical pulverized coal plant.

Related projects

CO_2-charged seawaters-basalt experiments. Domenik Wolff-Boenisch, Project Director for the University of Iceland´s contribution to CarbFix has been working on buffer capacities of seawater solutions equilibrated with different partial pressure of CO_2 are presented, under open and closed conditions.

Name	Title of Project	University	Start	Finish
Domenik Wolff-Boenisch	On the buffer capacity of CO_2-charged waters used for mineral sequestration	University of Iceland	Jan 2010	Dec 2010

Successful mineral trapping of carbon dioxide faces the challenge of effectively titrating a CO_2-charged acidic injection solution to pH conditions favourable to carbonate precipitation -using the rock as primary alkalinity source. To illustrate the magnitude of this task work has been done on buffer capacities of seawater solutions equilibrated with different partial pressure of CO_2 are presented, under open and closed conditions.

Impact of CO_2 injection on deep biota. Since 2008 a group of French scientist at IPGP, Paris has been working on performing a geo-microbiological monitoring on the Hellisheidi pilot site.

Name	Title of Project	Organisation	Start
Bénédicte Menez	CO_2FIX (French ANR project - LMTG Toulouse, IPGP Paris, Géosciences Montpellier, ICMCB Bordeaux)	IPGP, Paris, France	October 2008

The Status of the CarbFix Project 2010

The CarbFix Field Site

The Hellisheidi geothermal power plant is the source of the CO_2. The plant produces electricity and thermal energy by harnessing geothermal steam. The produced steam contains geothermal gases, mainly CO_2 and H_2S. The targeted field site for the injection of CO_2-charged water is close (3 km distance) to the Hellisheidi geothermal plant in SW Iceland (Figure 2). The well field had already been developed by Reykjavík Energy to serve as a deep reinjection system for separated water from Hellisheidi geothermal power plant, currently generating 213 MW_e and 133 MW_{th}. The power plant annually produces some 40,000 tons CO_2 of volcanic origin as a by-product of the geothermal energy production.

The Hellisheidi natural laboratory comprises ideal conditions for studying the long-term effect of mineral CO_2 sequestration in basaltic rocks. Connection to the power plant provides access to a concentrated source of CO_2. Additionally, field data, such as calcite rich cap rocks overlying the high-temperature reservoir, suggest that mineral CO_2 sequestration already plays an important role in the evolution of the Hellisheidi geothermal system. Injecting and precipitating CO_2 into nearby formations with the objective of imitating and accelerating this natural CO_2 sequestration process should therefore be considered as an environmentally benign process.

The CO_2 gas. In spring 2010 the construction of the pilot gas separation station was finalised at the Hellisheidi geothermal power plant. The pilot station separates CO_2 from the geothermal gas coming from the condensers of the power plant by sequential extraction. First, a scrubber washes CO_2 and H_2S out from less soluble gas species (H_2, N_2, Ar and CH_4). A deaerator then removes CO_2 and H_2S from the washing water, followed by separation of CO_2 and H_2S in a distillation column. The H_2S will be re-injected with brine to the deep geothermal reservoir and the CO_2 will be available for the CarbFix project.

In early March it was discovered that the gas from the condensers in the Hellisheidi power plant contained air. After thorough examination necessary amendments were dealt with. This incidence did however cause delays in the time schedule and it was not possible to start the pilot gas spearation plant until after the power plant stop in late June.

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_2S broke down. In August, September and October there were delays of shipping of device for the pilot plant, more components and small equipments broke down almost every day. Therefore, the time plan of delivery of CO_2 for CarbFix and injection of the gas needed constant revision. In late October samples consisting of 80% clean CO_2 for the CarbFix project had been produced and analyzed. However, reinitiation of the gas separation plant did not go according to plan and delivery of CO_2 to CarbFix is planned in 2011.

In the pilot study, approximately 5% of the total geothermal gas coming from the power station will be separated in the pilot station. Thus, about 2,200 tons CO_2 are to be captured and made available for CarbFix on an annual basis.

The CarbFix wells. After its capture, CO_2 will be transported in a 3 km pipeline to the pilot injection site as pressurized gas. There, CO_2 will be injected at depth into well HN-2 (Figure 2). Co-injected water will divert injected CO_2 further downward, resulting in a single fluid phase entering the sequestration formation. Wells HN-4, HK-34, HK-31 and HK-26 are deep monitoring wells and wells HK-12, HK-25, HK-7 and HK-13 are shallow monitoring wells. Long-term CO_2 pilot injection is scheduled to start in the first half of 2011. Environmental authorities in Iceland have granted licenses for the injection. The injection well (1.997 m) was drilled in 2005, the four shallow monitoring wells were drilled in the period 2001-2005 and their depth is 80-140 m. The five deep monitoring wells were drilled in the period 2004-2008 and they are 800-1.300 m deep.

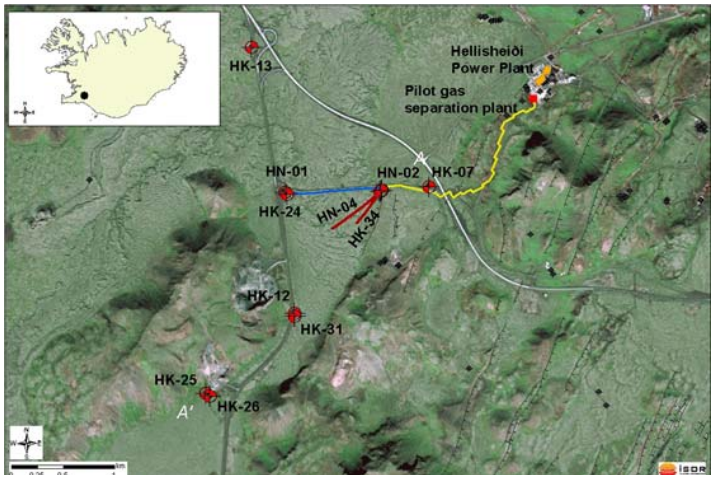

Figure 2 –Aerial map of the CarbFix pilot injection site at Hellisheidi, SW Iceland. Fresh groundwater, used for dissolving CO_2, is pumped from well HN-01 and transported to well HN-02 in a pipeline (blue line). CO_2 captured at the pilot gas separation plant is transported in a pipeline (yellow line) to well HN-02 where it is injected along with water from HN-01. Deviation of wells HN-04 and HK-34 is depicted by red lines. Combed lines represent faults. *Figure: ISOR.*

Resource Characterisation

Prior to the planned CO_2 injection in 2011, a background field characterization study at the injection site and in the target reservoir has been ongoing since 2006. Different monitoring methods in the project have already proven their value and will be continued after CO_2 injection.

Tracer tests have been launched in 2007(using sodium fluorescein) and 2008 (using sulfur hexafluoride (SF_6) and sodium fluorescein) in collaboration with scientists at LDEO and ISOR to understand and characterise the regional groundwater flow and to estimate the volume of the reservoir available for CO_2 injection. In addition the tracer tests are intended to ensure that there is no loss of injected CO_2 to the surface, see more information in the Annual Status Report 2008 and 2009 at the CarbFix website: www.carbfix.com.

All year 2010, samples were taken from wells HN-4 and HK-34 once a week and the rest of the wells once a month. In early January it was not possible to take samples from the deep wells HN-4 and HK-34 due to construction on the site and heavy frost. In August no samples were taken due to a motor failure in the fixed submersible pump. The pump needed to be lifted to the surface. In February it was not possible to take samples from the shallow wells HK-13, HK-7, and HK-25 due to heavy frost. This was also the case in October as a trailer for the portable pump was under construction. The SF_6 samples were shipped to LDEO for analysis and the sodium fluorescein samples were analysed at ISOR.

The chemistry of the ground waters. Since July 2008 the chemistry of the ground water at the injection site has been studied regularly. IES with the aid of OR have taken down hole samples from the CarbFix wells every second month. Temperature, pH, alkalinity, conductivity, major and trace elements, dissolved organic carbon, nutrients, ^{18}O, ^{13}C, δD and ^{34}S isotopes have been measured and analysed by IES.

Construction of the Injection System

In January the construction was in its last phase and test runs of certain equipment were to start and engineers, technicians and scientists at OR, Mannvit and Verkis held two construction meetings. A final meeting for construction appraisal was held at the CarbFix site January 29th (Figure 3). March 2nd a coffee party was held to celebrate the end of construction and the CarbFix was ready to few weeks test run prior to being able to start injecting CO_2.

Figure 3 – A final meeting for construction appraisal was held at the CarbFix site in late January. *Photo:Hólmfríður Sigurðardóttir*

Testing of the Injection System

In January 2010 testing of equipment started and was conducted with periods during February. Early March 2010 it was discovered the gas lead into the pilot gas separation plant contained high percentage of air. This was very serious indeed as the risk of explosion might increase as well as this might also have an impact on the gas content delivered to the CarbFix project. Necessary amendments were made but this incidence delayed the time schedule in the CarbFix project for several months.

Figure 4 – J. Matter and M. Stute from Columbia University and B. Sigfússon from Orkuveita Reykjavíkur. *Photo: S.R. Gíslason*

In July the pilot plant started operation along with a planned three week testing phase prior to delivery of gas to CarbFix. After a short period of experiments the group experienced a continuous period until October with devices breaking down. Therefore time plan of delivery of CO_2 for CarbFix and injection of the gas needed constant revision.

In late November and start of December two scientists from Columbia University arrived for testing the CarbFix system with the Icelandic groups. The groups conducted a gas tracer injection experiment with N_2 gas flow (as CO_2 gas was not jet available). 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 (Figure 4).

Since the visit in November the CarbFix project has been up and running, water has been constantly injected into the injection well, however without CO_2 gas. Startup of CarbFix needs the CO_2 gas produced in the gas separation plant as mentioned above. The injection is now planned in 2011.

Risk Assessment and amendments: In 2010 several meetings were held assessing the risk of the CarbFix project and implementing necessary amendments.

Licenses and Consultation

The Environmental Agency has given a positive statement for the CO_2 injection and the use of the tracers, trifluormethylsulphur pentafluoride (SF_5CF_3), amidorhodamine G dye and radiocarbon ^{14}C. The Municipality of Olfus has granted an operation license for the CO_2 injection.

Modelling

In 2010 chemical modelling scenarios are being performed by the Institute of Earth Sciences in Iceland and the Centre National de la Recherche Scientifique, France, by lab experiments and numerical modelling.

In 2010 development of a three dimensional reactive transport model that simulates hydrology and mineral alteration associated with the CO_2 injection has been ongoing at OR. 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_2 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_2 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_2.

Fluid-rock reactions has been coupled to the hydrology model using TOUGHREACT. Preliminary results confirm dissolution of primary basaltic minerals as well as carbonate precipitation. Secondary mineral abundance is highly dependent on temperature, pCO_2 and flow rate. Ongoing work includes validation of revised thermodynamic and kinetic databases, and simulations of the CarbFix CO_2 injection at Hellisheidi.

Monitoring

In 2010 a monitoring and accounting plan has been developed, which integrates surface, subsurface and atmospheric monitoring.

Figure 5 – CO_2 flux measurements. *Photo: Þráinn Friðriksson*

Surface Monitoring involves CO_2 flux measurements, closed chamber method, (Figure 5), sampling of injected gases from the power plant and pressure and temperature logging at the well heads. In March and April CO_2 flux measurements were carried out by ISOR 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_2 flux measurements are finalised.
All year pressure and temperature logging has been ongoing in the monitoring wells. Sampling and analysis of tracers has been ongoing in those wells to further characterize the groundwater reservoir.

Subsurface Monitoring and Sampling Infrastructure involves monitoring the transport and reactivity of the dissolved CO_2 and how much CO_2 is stored in its various forms. In spring 2010 sampling infrastructure were already installed in the monitoring wells (fixed submersible pumps that allow sampling of groundwater at reservoir conditions) and non-reactive and reactive tracers had been shipped to Iceland. Construction of a piston-bailer that will be used to retrieve samples from the injection well HN-2 was developed as well as the design of a sampling line. In late November and start of December two scientists from Columbia University arrived for testing the CarbFix system with the Icelandic group as mentioned above. The group managed to take the last background water samples from the CarbFix wells before CO_2 injection, verifying the sampling equipments and sample collection procedures and go through the ^{14}C tracer filling procedure and other issues.

Atmospheric Monitoring. Since August 2009 OR has operated a weather station at the injection site for continuous monitoring of atmospheric CO_2 data. 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. The results show that only diurnal CO_2 changes have been detected and

dispersed CO_2 from the Hellisheidi power plant has not been observed. It is therefore anticipated that concentrations exceeding ~40 ppmv above mean CO_2 values will be indicative of CO_2 leak from the injection zone. These possible abnormal CO_2 concentration values may be inspected in conjunction with wind speed and wind direction to estimate the probability of leaks from the subsurface.

Plug Flow Reactor

IES in collaboration with OR and CNRS finished designing and constructing a 2,5 m long laboratory plug flow reactor that will be filled with basaltic material. In 2010, IES worked on testing the plug to assure proper working of all items. The start of the experiment is now scheduled in 2011. Reactive transport models will be implemented to model the replacement reactions within the plug.

Patent

In December OR started preparing a patent application on CarbFix for EPO and an US-provisional application.

Webpage

From the beginning, the CarbFix group has stressed the importance of sharing the generated knowledge with the scientific/engineering community as well as with the public. Annual reports, which include a description of project progress, new developments, and budget information, are available on the project website (www.carbfix.com).

Meetings

The Scientific Steering Committee and the Management Team held the following joint meetings in 2010:

- Conference Call**:** January 25th, February 1st, 15th and 23th, March 9th and 26th, April 12th and 19th, May 3th and 17th, June 2nd and 28th, July 13th, August 18th, September 28th, October 15th and 28th, November 12th and 18th , December 16th.
- Physical Meetings: November 29th and December 2nd.

Engineers, technicians and scientists at OR, Mannvit and Verkis held Construction Meetings on the following dates in 2010:

- Construction Meetings: January 12th and 25th.
- Construction appraisal at the CarbFix site: January 29th.

Scientists, engineers and technicians at OR held test meetings on the following dates in 2010:

- Test &Test Run Meetings on CarbFix: February, 2nd, 9th, 16th and 23nd, March 2nd and 26th, April 27th, May 4th, 11th, 18th and 25th, June 1st, 8th, 15th, 22nd and 29th, August 11th, 18th, 25th and 31st, September 7th, 15th, 21st and 28th, October 5th, 13th, 29th and 27th.
- Joint Meetings on Test Running and Safety Issues on CarbFix, SulFix and Gas Separation Plant: November 3rd, 10th and 17th, December 8th, 15th and 22nd.
- Joint Meetings on Risk Assessment on CarbFix, SulFix and Gas Separation Plant: March 5th, April 20th, May 6th and 25th, June 26th, July 1st, August 5th and 16th.

Scientists at OR and ISOR held a meeting on tracers, sampling, analysing and cost in 2010: March 3rd.

Funds

Since 2006 the CarbFix project has been financed only by its partners through various funding agencies. In 2010 the project has been seeking additional funding from different sources. In March a grant was received from GEORG (Geothermal Research Group – see details at www.georg.hi.is) amounting USD 70.000 per year for two years and USD 30.000 for one year. In April an application was submitted to the U.S. Department of Energy (DOE) and grant was received from DOE amounting USD 1.015.180 for three years. In January an application was submitted to the Global CCS Institute in Australia but did not receive funding. An application submitted in December 2009 to the EU-7th framework programme on research and development: Marie Curie Initial Training Networks (ITN) Call: FP7-PEOPLE- 2010-ITN did not receive funding. In November an application was submitted to the European Union 7th framework programme on energy, Call FP7-ENERGY-2011-1, Stage 1 requesting funding of EUR 1.400.000 to the CarbFix project. Results regarding outcome of this applications are expected by spring 2011.

Financial Status and Outcome 2010

The four participants in the CarbFix project have been performing preliminary studies in the field since 2006. Orkuveita Reykjavíkur finalised constructing the injection facilities and started testing them in 2010.

When the CarbFix project was formally launched in September 2007, the initial total budget for the project was estimated to be EUR 7.333.262 over a period of three years (Table 1). The real total expenses for all participants according to exchange rate 2007 are EUR 6.622.059. For further detail on estimated and real segmentation between participants see Table 1. The referent exchange rate 2007 was 90,0 ISK/EUR and 0,7 USD/EUR. Since September 2007 the exchange rate of the Icelandic króna (ISK) has significantly weakened compared to the euro. For further detail of exchange rates see Note 1 and 2 on page 15.

The CO_2 injection was planned in the fall 2008 but has been delayed until 2011 due to more time consuming design of the injection facilities than initially expected and delay in delivery of CO_2 from the pilot gas separation plant at Hellisheidi. The following abbreviations are used in Table 1 and Index I:

- OR: Orkuveita Reykjavíkur
- IES: The University of Iceland – Institute of Earth Sciences
- LDEO: Columbia University USA – Earth Institute - Lamont-Doherty Earth Observatory
- CNRS: The Centre National de la Recherche Scientifique, France
- CBI: Central Bank of Iceland

Table 1. Initial estimated CarbFix budget in 2007 and expenses according to exchange rate 2007*

Estimated CarbFix Budget 2007 (EUR):	2006	2007	2008	2009	2010	Total
OR		1.725.987	772.675	806.308		**3.304.970**
IES		742.634	727.270	773.888		**2.243.792**
LDEO		384.484	396.020	317.470		**1.097.974**
CNRS		301.800	192.462	197.264		**691.526**
Total		**3.154.905**	**2.088.427**	**2.094.930**		**7.338.262**
Expenses according to exchange rate 2007:	**2006**	**2007**	**2008**	**2009**	**2010**	**Total**
OR	70.282	229.400	559.106	1.162.031	476.379	**2.497.198**
IES	99.348	335.697	701.637	857.037	746.084	**2.739.802**
LDEO	60.322	48.114	133.851	220.364	245.442	**708.092**
CNRS	17.640	58.064	136.643	297.499	181.625	**691.470**
Total	**247.592**	**671.275**	**1.531.236**	**2.536.930**	**1.649.530**	**6.636.562**

* The referent exchange rate 2007 was 90,0 ISK/EUR and 0,7 USD/EUR.

In Index I (see next page) the financial outcome of year 2010 (in addition to 2006, 2007, 2008 and 2009) is presented as well as the estimated forecast for 2011. Note that the figures are presented according to exchange rate each year, not according to exchange rate 2007. This explains the difference between figures in Table 1 and Index I. As shown in Index I it was decided to present profit or loss for each year. Instead of moving it to a specific Balance sheet for each year the profit/loss is moved to a so-called "Balance" that shows how the profit or loss moves between years. As mentioned above the CO_2 injection has been delayed until 2011. Therefore the estimated cost of design and construction is credited in 2009 and execution of the injection and monitoring will be credited in 2011.

Orkuveita Reykjavíkur does not credit the CarbFix project accessibility of land and wells at the Hellisheidi field site. The estimated cost of drilling all nine CarbFix wells is EUR 6.000.000. In 2009 OR sponsored the International Conference on Carbon Capture and Storage held at the Hellisheidi Geothermal Power Plant. OR has constructed a pilot gas separation plant that separates H_2S and CO_2 from other geothermal gases. This pilot plant is a separate project from CarbFix, but means the CO_2 will be available for the CarbFix project. For information the estimated cost of the pilot gas separation plant is EUR 2.500.000.

Despite the difficult financial situation in Iceland since fall 2008 the Board of Directors at OR has supported the CarbFix project. It is a joint benefit for both OR and the CarbFix-project to grant the project this interest.

Index I – Financial Information

CarbFix - Budget according to actual exchange rate each year (EUR)

	2006 EUR	2007 EUR	2008 EUR	2009 EUR	2010 EUR	2011 EUR	NOTES
Contribution							
Estimated Contribution from OR	72.109	228.311	1.252.041	405.170	585.832	314.743	1,3,5,15
Estimated Contribution from IES	87.131	523.333	374.031	238.410	354.257	160.244	1,4,5,18
Real Contribution from LDEO	52.979	48.114	137.100	214.481	227.682	253.571	2,17
Real Contribution from CNRS	17.640	58.064	136.643	297.499	181.625	133.901	
Total Contribution	**229.859**	**857.821**	**1.899.815**	**1.155.559**	**1.349.397**	**862.459**	
Expences							
Salaries and Wages - OR	45.848	114.048	106.685	169.320	168.552	121.805	6
Salaries and Wages - IES	49.075	163.180	181.838	208.632	224.396	124.189	
Salaries and Wages - LDEO	28.988	37.582	76.097	121.808	110.851	116.585	7
Salaries and Wages - CNRS	11.400	41.279	96.375	152.281	106.365	67.607	
Total Salaries/Wages	**135.311**	**356.089**	**460.995**	**652.041**	**610.164**	**430.186**	
Travel Cost - International - OR	0	9.835	1.535	0	2.212	0	
Travel Cost - International/Domestic - IES	16.961	34.930	32.698	38.380	42.487	0	
Travel Cost - International - LDEO	8.130	2.298	9.909	12.500	7.928	22.748	
Travel Cost - International/Domestic - CNRS	2.500	5.020	9.870	30.200	10.400	10.200	
Total Travel Cost - International	**27.591**	**52.083**	**54.013**	**81.080**	**63.027**	**32.948**	
Operational and Equipment Cost - OR	26.261	97.776	266.288	425.401	58.111	154.853	8
Operational and Equipment Cost - IES	20.010	82.961	195.014	87.367	52.909	0	9
Operational and Equipment Cost - LDEO	12.489	1.958	33.211	52.791	40.506	28.140	9
Operational and Equipment Cost - CNRS	500	1.100	5.300	60.375	31.500	31.500	9
Total Operational and Equipment Cost	**59.261**	**183.794**	**499.813**	**625.934**	**183.026**	**214.494**	
Website and conference-OR	0	7.741	3.626	11.538	1.018	1.889	10
Website and conference-IES	0	0	0	38.720	112	0	18
Total Website and Conference - RE and IES	**0**	**7.741**	**3.626**	**50.258**	**1.130**	**1.889**	
Indirect cost recovery-OR					34.497	47.211	11
Indirect cost recovery-IES	15.884	54.626	64.980	74.038	69.458	36.055	12
Indirect cost recovery - LDEO	3.371	6.276	17.883	27.382	68.398	86.099	13
Indirect cost recovery - CNRS	3.240	10.665	25.098	54.643	33.360	24.594	14
Other Operational Cost	**22.495**	**71.566**	**107.960**	**156.062**	**205.712**	**193.959**	
Total Operational Cost-OR	72.109	229.400	378.134	606.259	264.390	325.759	1,16
Total Operational Cost-IES	101.930	335.697	474.530	447.137	389.362	160.244	1,17
Total Operational Cost-LDEO	52.979	48.114	137.100	214.481	227.682	253.571	2,17
Total Operational Cost-CNRS	17.640	58.064	136.643	297.499	181.625	133.901	
Total Operational Cost	**244.658**	**671.275**	**1.126.407**	**1.565.375**	**1.063.059**	**873.476**	
Profit/Loss							
Profit (loss)-OR	0	-1.090	873.907	-201.090	321.443	0	
Profit (loss)-IES	-14.799	187.636	-100.499	-208.727	-34.993	0	
Profit (loss)-LDEO	0	0	0	0	0	0	
Profit (loss)-CNRS	0	0	0	0	0	0	
Total Profit (Loss)	**-14.799**	**186.546**	**773.408**	**-409.816**	**286.449**	**0**	
Balance							
Balance from previous year- OR		0	-1.090	872.817	671.727	993.170	15, 19
Balance from previous year - IES		-14.799	172.837	72.338	-136.389	-171.382	
Balance from previous year- LDEO		0	0	0	0	0	
Balance from previous year- CNRS		0	0	0	0	0	
Total Balance from Previous Year		**-14.799**	**171.747**	**945.155**	**535.339**	**821.788**	

OR = Orkuveita Reykjavíkur (Reykjavik Energy)
IES = University of Iceland - Institute of Earth Sciences
LDEO = Columbia University - Lamont Doherty Earth Observatory
CNRS = Centre National de la Rescherche Scientifique

Notes

Note							
1	Average Exchange Rate 2006	87,72	ISK/EUR	Average Exchange Rate Jan-June 2008	110,12	ISK/EUR	CBI*
	Average exchange rate 2007	87,60	ISK/EUR	Average Exchange Rate July-Sept 2008	125,59	ISK/EUR	CBI
				Average Exchange Rate Oct-Dec 2008	163,51	ISK/EUR	CBI
	Average Exchange Rate Jan-Mar 2009	153,17	ISK/EUR	Average Exchange Rate Jan-Mar 2010	176,17	ISK/EUR	CBI
	Average Exchange Rate Apr-June 2009	172,37	ISK/EUR	Average Exchange Rate Apr-June 2010	163,66	ISK/EUR	CBI
	Average Exchange Rate July-Sept 2009	180,73	ISK/EUR	Average Exchange Rate July-Sept 2010	154,79	ISK/EUR	CBI
	Average Exchange Rate Oct-Dec 2009	183,75	ISK/EUR	Average Exchange Rate Oct-Dec 2010	154,03	ISK/EUR	CBI
	Average Exchange Rate Jan-Mar 2011	158,86	ISK/EUR				CBI
2	Average Exchange Rate 2006	0,7970	USD/EUR				
	Average Exchange Rate 2007	0,7308	USD/EUR				
	Average Exchange Rate 2008	0,6834	USD/EUR				
	Average Exchange Rate 2009	0,7192	USD/EUR				
	Average Exchange Rate 2010	0,7546	USD/EUR				
	Average Exchange Rate Jan-Mar 2011	0,7439	USD/EUR				

3 Estimated number 2010 published in Annual Status Report 2009 calculated with actual exchange rate 2010.

4 In year 2007, 2008 and 2009 Orkuveita Reykjavíkur granted IES a substantial support through the Environment and Energy Research Fund and the Division of Innovation and Development. The proportion of this funding in IES's contribution to the CarbFix project was 57-67%. In 2007 and 2008 IES was granted a support from Hitaveita Suðurnesja and Norðurál The proportion of EU funds in the contribution from IES was 7% in 2006, 5% in 2007, 13% in 2008 and 2009 and 60% in 2010

5 In year 2010 OR and IES recieved a grant from GEORG (The Geothermal Research Group - www.georg.hi.is))

6 Salaries: Project Manager, Research Scientists, Engineers, Technicians and Lawyer

7 Includes salary and wages for personnel and fringe benefits. 30.8% in 2006-2009 and 28.5% in 2010-2011

8 Includes filed supply: Setup in boreholes, downhole pumps, containers, dieselmotors, connection to electricity grid, oil and electricity on site, equipment for sampling, heavy machinery, ISOR fieldwork and analysis and OR's cost of designing, constructing and maintaining the injection setup

9 Laboratory and filed supply and analyses

10 Cost of the CarbFix website and management meetings. Cost of the International Conference on Carbon Capture and Storage held at the Hellisheidi Geothermal Power Plant in September 2009

11 2010 and 2011 OR counts in overhead cost (15%)

12 IES verhead cost (22,5%)

13 2010 and 2011 the ICR is significantly increased because of a federal (U.S. Department of Energy) grant for the CarbFix project. Columbia/EI charges 61% overhead for a federal grant and Lamont charges 54%.

14 CNRS overhead cost (22,5%)

15 The CO2 injection was planned in the fall 2008 but was delayed until 2011. Therefore the estimated cost of design and construction is credited in 2009 and 2010 and execution of the injection and monitoring is credited in 2010 and 2011

16 OR contributed less to CarbFix in 2010 than estimated due to delay of injection and monitoring, see note no 17

17 IES and LDEO contributed more to CarbFix in 2010 than estimated

18 IES cost of International Conference on Carbon Capture and Storage held at Hellisheidi September 2009

19 When examining this surplus it should be kept in mind that OR does not credit the CarbFix project accessibility of land and wells at the CarbFix injection site. OR did not credit the CarbFix project the cost of drilling a new monitoring well, HK-34, at the CO2 injection site in 2008. (Cost of drilling a well like the injection well is ~ EUR 2 million and drilling a monitoring well is ~ EUR 0.3 million. The estimated cost of drilling all wells in the CarbFix project is ~EUR 6 million). OR sponsored the International Conference on Carbon Capture and Storage held at the Geothermal Hellisheidi Power Plant in 2009

* CBI= Central Bank of Iceland

Summary

In early spring 2010 the construction of the CarbFix mechanism was finalised and in March CarbFix was ready to a few weeks test-run prior to being able to start injecting CO_2. However, due to air in the gas from the Hellisheidi power plant to the pilot gas separation plant and due to the power plant stop in late June the pilot plant didn't started operation until July. After a short period of experiments a device that condenses H_2S broke down. In August, September and October there were delays of shipping of device for the pilot plant, more components and small equipments broke down almost every day. Therefore time plan of delivery of CO_2 for CarbFix and injection of the gas needed constant revision. In late November and start of December scientists from Columbia University arrived for testing the CarbFix system with the Icelandic groups. This visit stressed the importance of finding solutions from different angles as a group. Since late November 2010 the CarbFix project has been up and running, water has been constantly injected into the injection well, however without CO_2 gas. Start-up of CarbFix is planned in 2011.

All year 2010 the CarbFix project continued addressing background fluid chemistries at the injection site and characterizing the target reservoir for the planned CO_2 injection. Numerous groundwater samples have been collected by the Institute of Earth Sciences, Orkuveita Reykjavíkur and French collaborators at the injection site. The samples have been analysed at the Iceland Geosurvey, Institute of Earth Sciences in Iceland, Columbia University in New York and in various laboratories in France.

A monitoring and accounting plan has been developed by the CarbFix group, which integrates surface, subsurface and atmospheric monitoring. All year 2010 Orkuveita Reykjavíkur has been operating a weather station at the injection site for continuous monitoring of atmospheric CO_2 and to track all key parameters for the injection. The station provides information online, available to all collaborators in the project. Different monitoring methods in the project have proven their value and will be continued after CO_2 injection.

Environmental authorities and the Municipality Ölfus have granted licenses for the CO_2 injection and the tracers, based on a detailed monitoring plan of the injection facilities in the pilot project.

Chemical modelling scenarios are being performed by the Institute of Earth Sciences in Iceland and the Centre National de la Recherche Scientifique in France, by lab experiments and numerical modelling. At Orkuveita Reykjavíkur development of a three dimensional reactive transport model that simulates hydrology and mineral alteration associated with the CO_2 injection has been ongoing. Reactive chemistry has been coupled to the model and TOUGHREACT is used for reactive transport simulations. Ongoing work includes validation of revised thermodynamic and kinetic databases, and simulations of the CarbFix CO_2 injection at Hellisheidi.

In 2010 Institute of Earth Sciences in collaboration with the Centre National de la Recherche Scientifique, started testing a 2,5 m long laboratory plug flow reactor that is filled with basaltic material. The experiments with the plug are scheduled in 2011. Institute of Earth Sciences finished constructing a bailer that will be used to retrieve samples at reservoir conditions, several laboratory experiments were successful and the results submitted to international journals.

Eight PhD students were working on science projects, closely linked to the CarbFix project. One MSc student defended the thesis in late January 2010.

From the start, the CarbFix group has stressed the importance of sharing the generated knowledge with the scientific/engineering community as well as with the public. Annual reports are available on the project website www.carbfix.com. As CarbFix develops new technologies for enhanced in situ mineral carbonation, some specific parts of these technologies may be an intellectual property of the stakeholders of the project. In December 2010 Orkuveita Reykjavíkur started preparing a patent application on CarbFix for EPO and an US-provisional application.

In 2010 the project received grants from GEORG (Geothermal Research Group – see details at www.georg.hi.is) and the U.S. Department of Energy (DOE).

Appendix I – List of Selected Publications and Presentations 2010

Columbia University USA – Earth Institute - Lamont-Doherty Earth Observatory (LDEO)

2010

Name	Talk	Poster	Abstract	Paper/Report	Radio/TV interview
W.S. Broecker*					
J. M. Matter	7	1	1	1	1
M. Stute*					
D.Fernandez de la Reguera			1		
Summary	**7**	**1**	**2**	**1**	**1**

* See J.M. Matter and D. Fernandez de la Reguera

Papers in International Journals:

J.M. Matter, Broecker, W., Gislason, S. R., Gunnlaugsson, E., Oelkers, E., Stute, M., Sigurdardóttir, H., Stefansson, A., Wolff-Boenisch, D., Axelsson, G., Sigfússon, B. The CarbFix Pilot Project – storing carbon dioxide in basalt. Energy Procedia (2010), in press. (CFA[1]).

Conference Abstracts:

Fernandez de la Reguera, D., M. Stute, and J. M. Matter (2010). Laboratory experiments on CO_2 dissolution in water for carbon sequestration. Abstract GC31C-0899 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec. (CFA[1]).

Matter, J. M., Broecker, W., Gislason, S. R., Gunnlaugsson, E., Oelkers, E., Stute, M., Sigurdardóttir, H., Stefansson, A., Wolff-Boenisch, D., Axelsson, G., Sigfússon, B. (2010). The CarbFix Pilot Project – Storing Carbon Dioxide in Basalt. Abstract presented at 2010 International Conference on Greenhouse Gas Technologies, Amsterdam, The Netherlands, 19-23 Sept. (CFA[1]).

Invited Talks at international workshops and Conferences (all this presentations included the CarbFix Project):

J.M. Matter, 2010. "Permanent geologic storage of carbon dioxide in basaltic rocks", Presentation to ENEL, New York, Feb 11, 2010.

J.M. Matter, 2010. "Permanent storage of carbon dioxide in geological reservoirs by mineral carbonation" Department of Geosciences Seminar, Rice University, March 17, 2010.

J.M. Matter, 2010. "Integrated CCS Project Developments", Wye Workshop on Strategic Initiatives for CCS Deployment, U.S. Department of Energy, May 4-6.

J.M. Matter, 2010. "The CarbFix Project – Storing Carbon Dioxide in Basalt", Presentation at 2010 International Conference on Greenhouse Gas Technologies, Amsterdam, The Netherlands, 19-23 Sept 2010.

J.M. Matter, 2010. "Ongoing Research on Carbon Dioxide Research at Columbia University – The CarbFix Project" Seminar Talk at Department of Mechanical and Process Engineering, ETH Zuerich, Oct 22, 2010.

J.M. Matter, 2010. "Permanent Storage of Carbon Dioxide in Geological Reservoirs by Mineral Carbonation", Seminar Talk at Department of Environmental Engineering, EPFL, Lausanne, Switzerland, October 26, 2010.

J.M. Matter, 2010. "Radiocarbon as a reactive tracer for tracking permanent CO_2 storage in basaltic rocks" U.S. Department of Energy Project Kickoff Meeting, Nov 23, 2011.

Poster Presentation:

J.M. Matter, 2010. "Laboratory experiments on CO_2 dissolution in water for carbon sequestration" AGU Fall Meeting, San Francisco, Dec 13-17, 2010.

Radio/TV interviews:

J.M. Matter, 2010. Interview with Janet Fang for Nature News, Jul 27, 2010.

[1] Counted by the First Author

The Centre National de la Recherche Scientifique, France (CNRS)

2010

Name	Talk	Poster	Abstract	Paper/Report/Book	Radio/TV interview
E.H. Oelkers				1	
Summary				**1**	

Chapters in books:
Oelkers E. H. and Gislason S.R. (2010). Water-CO_2-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. (CFA[1]).

Orkuveita Reykjavíkur (OR)

2010

Name	Talk	Poster	Abstract	Paper/Report	Radio/TV interview
E. Gunnlaugsson	2				
B. Sigfússon	2				
H. Sigurðardóttir	12	1	1		
Summary	**16**	**1**	**1**		

Conference Abstracts:

H. Sigurdardottir, S. R. Gislason, W. S. Broecker, E. H. Oelkers, and E. Gunnlaugsson (2010). The CO_2 Fixation into Basalt at Hellisheidi Geothermal Power Plant, Iceland. In Proceedings, World Geothermal Congress, Bali, Indonesia, 25-29 April, 2010. (CFA[1]).

Invited Talks at international workshops and Conferences:

Bergur Sigfússon, 2010. "Some problems and solutions associated with high temperature geothermal utilization". Workshop on Carbonate Reactivities /Industrial and Academic Applications in Copenhagen, Denmark in May 9-12.

Hólmfríður Sigurðardóttir, 2010. "The CO_2 Fixation into Basalt at Hellisheidi Geothermal Power Plant, Iceland." World Geothermal Congress in Bali Indonesia in April 25-30.

List of selected talks on the CarbFix project 2010:

Einar Gunnlaugsson. The President of the Maldives, 12 March.

E. Gunnlaugsson. Visit from the Roskilde High school in Denmark, 23 March.

Bergur Sigfússon. CarbFix Seminar, 24 February.

Holmfridur Sigurdardottir. Framadagar 10 February.

H. Sigurdardottir. CarbFix Seminar, 24 February.

H. Sigurdardottir. DGA Dalkia France. 4 March.

H. Sigurdardottir. EU Sustainable Energy Week, Iceland, 25 March.

H. Sigurdardottir. Visit form the Environmental Protection College Slovenia, 1 July.

H. Sigurdardottir. Columbia University graduate student tour of the Hellisheidi Plant and CarbFix Project, 20 August.

H. Sigurdardottir. Representative from the European FP7 – Energy, 15 September.

H. Sigurdardottir. The Minister of Energy in India, 27 September.

H. Sigurdardottir. The Municipality Ölfus, 19 October.

H. Sigurdardottir. Commercial counsellour of the Embassy of Hungary in Oslo, 1 December.

H. Sigurdardottir. Open House at Reykjavik Energy, 4 December.

Poster Presentation:
Holmfridur Sigurðardóttir, B. Sigfússon, E.S.P. Aradóttir, E. Gunnlaugsson, S.R. Gíslason, H.A. Alfreðsson, W.S. Broecker, J.M. Matter, M. Stute and E.H. Oelkers (2010). The CarbFix Pilot Project in Iceland. CO_2 capture and mineral storage in basaltic rocks. The 2010 AGU Fall meeting 13–17 December, California, USA. (CFA[1]).

[1] Counted by the First Author

The University of Iceland – Institute of Earth Sciences (IES)

2010

Name	Talk	Poster	Abstract	Paper/Report	Radio/TV interview
S.R. Gislason	5			1	
D. Wolf-Boenisch	1	2	1	1	
H.A. Alfredsson	1	3	2	2	
E.S.P. Aradóttir*	1	2		1	
I. Galeczka	2	2	1		
S. Gudbrandsson	2	2	2	1	
A. P. Gysi				2	
G.J. Stockmann	1	3	3	1	
A. Stefansson**					
Summary	**13**	**14**	**9**	**9**	

*Orkuveita Reykjavíkur and PhD student at the University of Iceland – Department of Chemistry

** See A.P. Gysi

Papers in International Journals:

Helgi A. Alfredsson, D. W. Boenisch and A. Stefánsson, 2010. CO_2 sequestration in basaltic rocks in Iceland: Development of a piston-type downhole sampler for CO_2 rich fluids and tracers. Energy Procedia (In press). (CFA[1]).

Sigurdur R. Gislason, Domenik Wolff-Boenisch, Andri Stefansson, Eric H. Oelkers, Einar Gunnlaugsson , Hólmfridur Sigurdardottir, Bergur Sigfusson, 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. (CFA[1]).

Snorri Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., An experimental studyof crystalline basalt dissolution from $2 \leq pH \leq 11$ and temperatures from 5 to 75° C. Submitted to Geochimica Cosmochimica Acta 2nd of December 2010. (CFA[1]).

Alex P. Gysi and Stefansson A, 2010. CO_2-water-basalt interaction I. Low temperature experiments and implications for CO_2 sequestration into basalts. Article submitted to Geochimica et Cosmochimica Acta. (CFA[1]).

A. P. Gysi and Stefansson A, 2010 CO_2-water-basalt interaction II. Numerical simulation of low temperature CO_2 sequestration into basalts. Article submitted to Geochimica et Cosmochimica Acta. (CFA[1]).

Gabrielle J. Stockmann, D. Wolff-Boenisch, S. R. Gíslason & E. H. Oelkers, 2010. Do carbonate precipitates affect dissolution kinetics? 1: Basaltic glass. Article submitted to Chemical Geology in October 2010. (CFA[1]).

Domenik Wolff-Boenisch (2010) On the buffer capacity of CO_2-charged seawater used for carbonation and subsequent mineral sequestration. Energy Procedia, in press. (CFA[1]).

Conference Abstracts:

Helgi A. Alfredsson, D. W. Boenisch and A. Stefánsson, 2010. CO_2 sequestration in basaltic rocks in Iceland: Development of a piston-type downhole sampler for CO_2-rich fluids and tracers. The Greenhouse Gas Control Technologies conference, Amsterdam, Netherlands, August 2010. (CFA[1]).

H. A. Alfredsson, and Gislason S. R., 2010. CarbFix – CO_2 sequestration in basaltic rocks: Chemistry of the rocks and ground waters at the injection site, Hellisheidi, SW-Iceland The European Geothermal PhD Day at GFZ – Potsdam, Germany, 12th February 2010. (CFA[1]).

Iwona Galeczka, Wolff-Boenisch D. & Gislason S. 2010. Modeling CO_2 sequestration in basaltic rocks with a plug flow reactor" Symposium on Current Research in Engineering and Natural Sciences at University of Iceland. (CFA[1]).

Snorri Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., Determination of crystalline basalt dissolution rates as a function of temperature and solution composition. Delta-Min meeting, Seefeld, Austria, 28th of February to 5th of March 2010. (CFA[1]).

[1] Counted by the First Author

S. Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., Dissolution rates of crystalline basalt at pH 2 - 11 and 5-75 °C. Delta-Min meeting, Santorini, Greece, 3-8th October 2010. (CFA[1]).

Gabrielle J. Stockmann, L. S. Shirokova, O. S. Pokrovsky, E. H. Oelkers & P. Benezeth, 2010. Does the presence of bacteria affect basaltic glass dissolution rates? 1: Dead Pseudomonas reactants. EGU General Assembly 2010 in Vienna. (CFA[1]).

G. J. Stockmann, L. S. Shirokova, O. S. Pokrovsky, P. Benezeth & E. H. Oelkers, 2010. Does the presence of bacteria affect basaltic glass dissolution rates? 2: Live Pseudomonas reactants. The Goldschmidt 2010 conference in USA. (CFA[1]).

G. J. Stockmann, L. S. Shirokova, O. S. Pokrovsky, P. Benezeth & E. H. Oelkers, 2010. Does the presence of bacteria (Pseudomonas reactants) affect basaltic glass dissolution rates? Implications for CO_2 injection in Iceland. The Natural Science Symposium 2010 at the University of Iceland. (CFA[1]).

D. Wolff-Boenisch, S. R. Gislason, S. Wenau (2010). Effect of seawater and its components on the dissolution of peridotite under CO_2 pressure. Proceedings of the 13th International Conference on Water-Rock Interaction, Guanajuato, Mexico, August 2010, p. 899-902. Taylor & Francis Group, London. (CFA[1]).

Invited Talks at international workshops and Conferences:

H.A. Alfredsson, and Gislason S. R., 2010. CarbFix – CO_2 sequestration in basaltic rocks: Chemistry of the rocks and ground waters at the injection site, Hellisheidi, SW-Iceland The European Geothermal PhD Day at GFZ – Potsdam, Germany, 12th February 2010. (CFA[1]).

Edda Sif Pind Aradottir 2010. Coupling reactive transport to reservoir modeling. GEORG workshop on Geothermal Reservoir Research in 4 March.

Iwona Galeczka, Wolff-Boenisch D, Gislason S., Sigfuson B. and Stefanson A. 2010. Experimental studies on CO_2 sequestration in basaltic rocks with the plug flow reactor" Delta-Min meeting, Seefeld. (CFA[1]).

I. Galeczka, Wolff-Boenisch D, Gislason S. 2010. Experimental studies on CO_2 sequestration in basaltic rocks with the plug flow reactor" – October 2010. Mid-term Delta-Min meeting, Santorini. (CFA[1]).

Sigurdur Reynir Gíslason, 2010. Water – rock - CO_2 interactions. Workshop Carbonate Reactivities /Industrial and Academic Applications in Copenhagen, Denmark in May 9-12.

S. R. Gislason, D. Wolff-Boenisch, A. Stefansson, H. Alfredsson, E.H. Oelkers, E. Gunnlaugsson, H. Sigurdardottir, B. Sigfusson, E.S.P. Aradottir, W.S. Broecker, J.M. Matter, M. Stute and G. Axelsson. Mineral seqestration of CO_2 in basalt: The CarbFix project. Invited talk at the Goldschmidt Conference, Tennessee, USA June. (CFA[1]).

Snorri Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., Dissolution rates of crystalline basalt at pH 2-11 and 5-75 °C. Tthe European Geothermal PhD Day, Potsdam, Germany, 12 February. (CFA[1]).

S. Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., Dissolution rates of crystalline basalt at pH 2 - 11 and 5 °C to 75 °C. Delta-Min meeting, Santorini, Greece, 3-8th October 2010. (CFA[1]).

Gabrielle J. Stockmann, 2010. The CarbFix project in Iceland. The 2nd year geology students at the University of Gothenburg, Sweden.

Domenik Wolff-Boenisch, Wenau, S., and Gislason, S. (2010) Effect of seawater and its components on the dissolution of peridotite under CO_2 pressure. 13th International Conference on Water-Rock Interaction, Guanajuato, Mexico, August 16th – 20th 2010. (CFA[1]).

List of selected talks on the CarbFix project 2010:

Sigurdur .R. Gíslason. The carbon cycle and the CarbFix project. Föstudagsseminar Nordvol, Askja 22 January.

S.R. Gíslason. Áhrif manna á kolefnishringrás Jarðar. Hið íslenska náttúrufræðifélag, 22 February.

S.R Gíslason. CarbFix verkefnið. Ráðstefnu Umhverfis- og orkurannsóknasjóðs OR. Orkuveitu Reykjavíkur 14 May.

Poster Presentation:

Helgi A. Alfredsson, D. W. Boenisch and A. Stefánsson, 2010. CO_2 sequestration in basaltic rocks in Iceland: Development of a piston-type downhole sampler for CO_2 rich fluids and tracers. The R-VON symposium 2010, University of Iceland. (CFA[1]).

[1] Counted by the First Author

H. A. Alfredsson, D. W. Boenisch and A. Stefánsson, 2010. CO_2 sequestration in basaltic rocks in Iceland: Development of a piston-type downhole sampler for CO_2-rich fluids and tracers The Greenhouse Gas Control Technologies conference, Amsterdam, Netherlands, August 2010. (CFA[1]).

H. A. Alfreðsson, S. R. Gíslason, D. W. Boenisch and A. Stefánsson, 2010. CO_2 sequestration in basaltic rocks: Pre-injection studies of the injection field and Development of a piston-type downhole sampler for CO_2 rich fluids and tracers. The Mir and Mingro meeting in Cophenhagen, May 2010. (CFA[1]).

Edda S.P. Aradóttir. Reactive transport models for mineral CO_2 storage in basaltic rocks. Poster at at R-VoN 2010 – A Symposium on Current Research in Engineering and Natural Sciences at the University of Iceland. 8-9 October 2010.

E.S.P. Aradóttir, E. Sonnenthal, G. Björnsson and H. Jónsson (2010). Reactive transport models for mineral CO_2 storage in basaltic rocks. The 2010 AGU Fall meeting 13–17 December, California, USA. (CFA[1]).

Iwona Galeczka, Wolff-Boenisch D. and Gislason S. 2010. Modeling CO_2 sequestration in basaltic rocks with a plug flow reactor" – October 2010. Mid-term Delta-Min meeting, Santorini. (CFA[1]).

I. Galeczka, Wolff-Boenisch D. & Gislason S. 2010. Modeling CO_2 sequestration in basaltic rocks with a plug flow reactor". Oct. A Symposium on Current Research in Engineering and Natural Sciences at University of Iceland, (CFA[1]).

Snorri Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., Dissolution rates of crystalline basalt at pH 2-11 and 5-75 °C. The European Geothermal PhD Day, Potsdam, Germany, 12 February. (CFA[1]).

S. Gudbrandsson, Wolff-Boenisch, Gislason, S.R. and Oelkers, E.H., Dissolution rates of crystalline basalt at pH 2 - 11 and 5 °C to 75 °C. Delta-Min meeting, Santorini, Greece, 3-8th October 2010. (CFA[1]).

Gabrielle J. Stockmann, L. S. Shirokova, O. S. Pokrovsky, E. H. Oelkers & P. Benezeth, 2010. Does the presence of bacteria affect basaltic glass dissolution rates? 1: Dead Pseudomonas reactants. EGU General Assembly 2010 in Vienna. (CFA[1]).

G. J. Stockmann, L. S. Shirokova, O. S. Pokrovsky, P. Benezeth & E. H. Oelkers, 2010. Does the presence of bacteria affect basaltic glass dissolution rates? 2: Live Pseudomonas reactants. The Goldschmidt conference in USA. (CFA[1]).

G. J. Stockmann, L. S. Shirokova, O. S. Pokrovsky, P. Benezeth & E. H. Oelkers, 2010. Does the presence of bacteria (Pseudomonas reactants) affect basaltic glass dissolution rates? Implications for CO_2 injection in Iceland. The Natural Science Symposium 2010 at the University of Iceland. (CFA[1]).

Domenik Wolff-Boenisch, Wenau, S., and Gislason, S.R. (2010) Mineral sequestration of carbon dioxide in peridotitic and basaltic rocks using seawater for carbonation. European Geoscience Union, General Assembly 2010, Vienna, Austria, May 2nd – May 7th 2010. (CFA[1]).

D. Wolff-Boenisch (2010) On the buffer capacity of CO_2-charged seawater used for carbonation and subsequent mineral sequestration. 10th International Conference on Greenhouse Gas Technologies, Amsterdam, Netherlands, September 19-23.

Reports:

Helgi A. Alfredsson, 2010. CarbFix – Monitoring descriptions. CarbFix report 2010.

Edda Sif Pind Aradóttir (2010). CarbFix reservoir model – hydrological parameters and pumping schemes for experimental CO_2 injection. OR report no: 2010-03.

Reykjavik Energy Graduate School of Sustainable Systems (REYST)

2010

Name	Talk	Poster	Abstract	Paper/Report	Radio/TV interview
E. V. Ragnheidardottir				1	
Summary				**1**	

Publications:

Elísabet. V. Ragnheidardottir, H. Sigurdardottir, H. Kristjansdottir, and W. Harvey (2010). Opportunities and challenges for CarbFix: An evaluation of capacities and costs for the pilot scale mineralization sequestration project at Hellisheidi, Iceland and beyond. Int. J. Greenhouse Gas Control. Article in press, (CFA[1]).

[1] Counted by the First Author