



**CO<sub>2</sub> Fixation into Basalts  
Hellisheiði  
Iceland**

**Annual Status Report 2009  
Hólmfríður Sigurðardóttir**

---

## Contents

<b>Prologue .....</b>	<b>3</b>
<b>Participants .....</b>	<b>4</b>
Orkuveita Reykjavíkur (OR) .....	4
The University of Iceland – Institute of Earth Sciences (IES) .....	5
Columbia University USA – Earth Institute - Lamont-Doherty Earth Observatory (LDEO) .....	5
The Centre National de la Recherche Scientifique, France (CNRS) .....	5
Leadership .....	5
PhD Students .....	6
MSc Students .....	7
<b>The Status of the CarbFix Project 2009 .....</b>	<b>8</b>
The CarbFix Field Site .....	8
Resource Characterisation .....	8
Design and Construction of the Injection System .....	9
Licenses and Constultation .....	10
Modeling .....	11
Monitoring .....	11
Plug Flow Reactor .....	12
Webpage .....	12
International Conference .....	12
Meetings .....	12
Funding .....	12
<b>Financial Status and Outcome 2009 .....</b>	<b>13</b>
Index I – Financial Information .....	14
Notes .....	15
<b>Summary .....</b>	<b>16</b>
<b>Appendix I – List of Selected Publications and Presentations 2009 .....</b>	<b>17</b>
Columbia University USA – Earth Institute - Lamont-Doherty Earth Observatory (LDEO) .....	17
The Centre National de la Recherche Scientifique, France (CNRS) .....	17
Orkuveita Reykjavíkur (OR) .....	18
The University of Iceland – Institute of Earth Sciences (IES) .....	19
Reykjavik Energy Graduate School of Sustainable Systems (REYST) .....	21
<b>Appendix II – CarbFix in the Media 2009 .....</b>	<b>22</b>

## Prologue

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<sub>2</sub> charged water at the Hellisheidi power plant in SW Iceland, laboratory experiments, computer modelling of fluid flow and gas-water-rock interactions, tracer tests, natural analogue- and cost analysis.

The CO<sub>2</sub> injection site is situated about 3 km south of the Hellisheidi geothermal power plant. The power plant currently produces 60,000 tons of CO<sub>2</sub> per year. The CO<sub>2</sub> gas is a by-product of the geothermal energy production and of magmatic origin. The produced geothermal gas mainly consists of CO<sub>2</sub> and H<sub>2</sub>S. The two gases will be separated in a pilot gas treatment plant, and CO<sub>2</sub> will be transported in a pipeline to the injection site. There, CO<sub>2</sub> will be fully dissolved in water during injection, resulting in a single fluid phase entering the storage formation. The CO<sub>2</sub> 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 2000 tons of CO<sub>2</sub> per year, but there is the potential to upscale if mineral carbonation proves to be successful.

This report describes how the CarbFix pilot program advanced during the year 2009.

## Participants

The CarbFix project was formally launched on September 29<sup>th</sup> 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 (Figure 1). Below is a short description of each partner and their responsibilities.



Figure 1 – Members of the CarbFix scientific steering committee together with the President of Iceland at Hellisheiði Geothermal Power Plant in September 2009. From the left: Dr Einar Gunnlaugsson, Dr Sigurdur R. Gislason, President of Iceland Mr Olafur Ragnar Grimsson, Dr Wally Broecker and Dr Eric Oelkers. *Photo: Sigfús Már Pétursson.*

### 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 Hellisheiði geothermal plant and the infrastructure used for the CarbFix pilot project. OR provides the pilot gas treatment plant (source of CO<sub>2</sub>), 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 the CO<sub>2</sub> studies.

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<sub>2</sub> injection and is designing and conducting a soil gas monitoring program to detect possible CO<sub>2</sub> 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, among other things, the development, design and test of the CO<sub>2</sub> 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<sub>2</sub> 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. IES has a leading role in systematic collection and analysis of the groundwater in the injection wells as well as in the 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<sub>2</sub> injection. The work includes pre-injection characterization of the basaltic rocks and ground waters with geochemical and geophysical tools to assess the CO<sub>2</sub> storage capacity of the injection site, developing a monitoring program for the CO<sub>2</sub>-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<sub>2</sub>-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<sub>2</sub> 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.

#### **Leadership**

##### The Scientific Steering Committee:

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

Wallace S. Broecker. Newberry Professor of Earth & Environmental Sciences, Lamont-Doherty Earth Observatory of Columbia University, USA. broecker@ldeo.columbia.edu

Eric H. Oelkers. Research Director - Chemistry and Earth Science, CNRS UMR 5563/Université Paul Sabatier, France. oelkers@lmtg.obs-mip.fr

Einar Gunnlaugsson. Research Director - Chemistry and Earth Science, Orkuveita Reykjavíkur, Iceland. einar.gunnlaugsson@or.is

##### The Management Team:

Jakob Sigurður Friðriksson (Chairman). Director of Production and Sales, Orkuveita Reykjavíkur, Iceland. jakob.fridriksson@or.is

Juerg M. Matter. Doherty Associate Research Scientist. Lamont-Doherty Earth Observatory of Columbia University, USA. jmatter@ldeo.columbia.edu

Andri Stefánsson. Associated Professor at the Institute of Earth Sciences, University of Iceland. as@hi.is

##### Project Manager:

Hólmfríður Sigurðardóttir. Head of Innovation and Development, Orkuveita Reykjavíkur, Iceland. holmfridur.sigurdardottir@or.is

## PhD Students

In 2009 eight PhD students were working on science projects, closely linked to the CarbFix project. Thursday 3<sup>rd</sup> of September, Therese Kaarbø Flaathen defended her PhD thesis. The PhD is a joint degree between the University of Iceland and University III – Paul Sabatier, Toulouse, France.

Name	Title of Ph.D. thesis	University	Start	Finish
Alexander Gysi	CO <sub>2</sub> -water-basalt: experiments and geochemical modelling	University of Iceland	Sept 2007	Dec 2010
Diana Fernandez de la Reguera	Monitoring and verification of geologic CO <sub>2</sub> storage using tracer techniques	Columbia University	Sept 2008	2013
Edda Sif Aradóttir	Computational study of chemical changes in Icelandic geothermal areas: Coupling chemical reactions into reservoir models.	University of Iceland	Jan 2007	2010
Gabriella Stockmann	Experimental determination of the effect of precipitated mineral coatings on the rates of basaltic mineral and glass dissolution rates	University of Iceland	Sept 2007	Dec 2010
Helgi Arnar Alfreðsson	Characterization of the rocks and fluids, before and after CO <sub>2</sub> injection, at the Hellisheidi Iceland site, SW-Iceland	University of Iceland	Sept 2007	Sept 2011
Iwona Galeczka	Experimental studies on the sequestration of CO <sub>2</sub> in basaltic rocks. Change in chemistry and mineralogy of solutions under pCO <sub>2</sub> pressure percolating through a vertical column (plug) filled with basalt particles	University of Iceland	Sept 2009	Sept 2012
Snorri Guðbrandsson	Dissolution rates of crystalline basalt as a function of temperature, pressure and solution composition	University of Iceland	Sept 2007	Dec 2011
Therese Kaarbo Flaathen	Water-rock interaction during CO <sub>2</sub> sequestration in basalt	The Centre National de la Recherche Scientifique, France and University of Iceland	Sept 2006	Sept 2009

Following is the main research focus of the PhD students in 2009:

Alexander Gysi: Laboratory batch experiments at pCO<sub>2</sub> of 0-32 bar and 22-250 °C. Analysis of secondary precipitates using x-ray diffraction (XRD), scanning electron microscope (SEM/EDS) and electron microprobe (EMPA). Geochemical modelling using PHREEQC and update of the thermodynamic dataset relevant for low temperature CO<sub>2</sub>-water-basalt interaction.

Diana Fernandez de la Reguera: Laboratory experiments to study the dissolution of carbon dioxide (CO<sub>2</sub>) in fresh and salt water. The objectives of these experiments were to simulate a representative scaled down version of the planned CarbFix CO<sub>2</sub> injection scenario, and to test different ways to maximize the percentage of dissolved CO<sub>2</sub>. Results from these experiments were used to optimize the design of the CarbFix CO<sub>2</sub> injection system.

Edda Sif Aradóttir: Hydrological parameters of a three dimensional field model covering all wells in the CarbFix reservoir have been calibrated using data from tracer tests that have been ongoing in Hellisheidi since 2007. Current work involves updating the hydrological model to a reactive transport model by adding reactive chemistry to the CarbFix reservoir model.

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, Hellisheidi, SW-Iceland. Water sampling and analysis from the boreholes. Development of a piston-type down hole sampler for CO<sub>2</sub> rich fluids and tracers.

Iwona Monika Galeczka: Crushing, sieving and cleaning basaltic material which will fill up the plug flow reactor. Assembling the plug with attached equipment.

Snorri Guðbrandsson: Continued experiments on the dissolution rates of crystalline basalt. Four months visit to the NanoGeo Science Center at Copenhagen University.

### **MSc Students**

In 2009 one MSc student was working on a science project linked to the CarbFix project.

<b>Name</b>	<b>Title of MSc thesis</b>	<b>University</b>	<b>Start</b>	<b>Finish</b>
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 in 2009:

Elísabet Vilborg Ragnheiðardóttir: Review the costs associated with the CarbFix pilot CO<sub>2</sub> 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.



## The Status of the CarbFix Project 2009

### The CarbFix Field Site

The Hellisheidi geothermal power plant is the source of the CO<sub>2</sub>. The plant produces electricity and thermal energy by harnessing geothermal steam. The produced steam contains geothermal gases, mainly CO<sub>2</sub> and H<sub>2</sub>S. The targeted field site for the injection of CO<sub>2</sub>-charged water is close (3 km distance) to the Hellisheidi geothermal plant in SW Iceland. In December 2009, the pilot gas treatment plant, pipelines, injection and monitoring wells have been installed and test runs of certain equipment have started.

The CO<sub>2</sub> gas. The CO<sub>2</sub> will be captured in a pilot gas treatment plant where CO<sub>2</sub> and H<sub>2</sub>S will be separated in a distillation column. The process starts with a removal of Non-Condensable Gas, containing CO<sub>2</sub>, H<sub>2</sub>S, H<sub>2</sub>, and other gases, from the condenser at Hellisheidi geothermal plant. The gases will be compressed and cooled. A hydrogen component will be separated from the gas mixture by diffusion of H<sub>2</sub> through membranes and/or absorption of H<sub>2</sub>S and CO<sub>2</sub> into water in a scrubber, allowing H<sub>2</sub> to be released. The stream, comprised primarily of H<sub>2</sub>S and CO<sub>2</sub>, is then directed to the distillation column, where these components are separated. The H<sub>2</sub>S will be re-injected with brine to the deep geothermal reservoir and the CO<sub>2</sub> will be available for the CarbFix project which will be injected in 2010.

The CarbFix wells. The CO<sub>2</sub> will be dissolved in water from well HN-1 and injected into well HN-2 (Figure 2). 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.

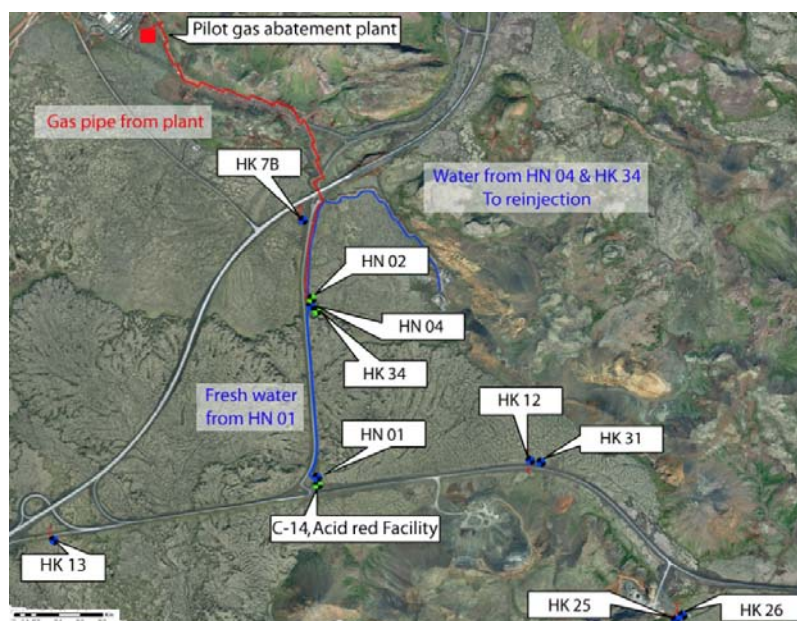


Figure 2 – The CarbFix field site. The CO<sub>2</sub> will be dissolved in water from well HN-1 and injected into well HN-2. Wells HN-4, HK-34, HK-31 and HK-26 are deep monitoring wells and wells HK-12, HK-25, HK-7 and HK-13 are shallow monitoring wells.

Map: Skúli Arnlaugsson

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.

### Resource Characterisation

Prior to the planned CO<sub>2</sub> injection in 2010, 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<sub>2</sub> injection. Tracer tests have been launched in 2007 and 2008 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<sub>2</sub> injection. In addition the tracer tests are intended to ensure that there is no loss of injected CO<sub>2</sub> to the surface, see more information in the Annual Status Report 2008 at the CarbFix website: [www.carbfix.com](http://www.carbfix.com).

A large-scale tracer test (natural gradient test), using sulfur hexafluoride (SF<sub>6</sub>) and sodium fluorescein, was launched in 2006 and is still running. All year 2009, samples were taken from wells HN-4 and HK-34 once a week and the rest of the wells once a month. In January to early March, in late April and late June it was not possible to take samples from the shallow wells HK-13, HK-7, and HK-25 due to heavy frost and a breakdown of the portable pump. The well HK-13 needed to be “cased” by a plastic pipe. The SF<sub>6</sub> 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 (Figure 3). Temperature, pH, alkalinity, conductivity, major and trace elements, dissolved organic carbon, nutrients, <sup>18</sup>O, <sup>13</sup>C, δD and <sup>34</sup>S isotopes have been measured and analysed by IES.



Figure 3 – Sampling from CarbFix monitoring wells *Photo: Helgi A. Alfreðsson and Eydís S. Eiríksdóttir*

Temperature log and spinner measurements in well HN-2 and well HN-4. In 2008 spinner logging in the wells did not give accurate quantitative results. After thorough examination of a temperature log measured after 6.5 months of continuous injection in well HN-2 and pumping from well HN-4 by ISOR, the logging was considered accurate enough to define the depth of the CO<sub>2</sub>/water injection pipe in well HN-2. In late November a down hole camera was used to scan the injection well HN-2 and observation well HN-4. The scanning confirmed ISOR’s estimation of the main feed-zones in these wells.

CO<sub>2</sub> dissolution lab experiment. In March and May LDEO design and executed a representative scaled down version of the planned CO<sub>2</sub> injection scenario at Hellisheidi. Results from these experiments were used to optimize the design of the CarbFix CO<sub>2</sub> injection system.

Pumping test from the injection well HN-2. In May a short pumping test was performed at the injection well HN-2. This test confirmed the relatively slow groundwater flow rate at the injection site. In early June a decision was taken on pumping the observation wells HN-4 and HK-34 after CO<sub>2</sub> injection to drive the flow of CO<sub>2</sub> rich water through the bedrock. This requires a disposal of tracer rich fluid from well HN-4 and well HK-34 in well HN-3 near Gráuhnúkar (east of the injection site). This decision along with adjustments at well HN-1 increased the time and cost of design, equipment and construction.

## **Design and Construction of the Injection System**

### Design

During the past 3 years several designs for the injection setup have been proposed. In January 2009 it was announced that ten times less CO<sub>2</sub> gas would be available for the CarbFix project than had been anticipated.

This new strategy required changes in design of the injection system. Consequently a frequent consultation was held between OR, Mannvit, LDEO and IES on design, the project diagram and process description.

In early April a decision was made on the set-up for the CO<sub>2</sub> injection in the injection well HN-2 based on OR's and Mannvit's design and model calculations, LDEO's CO<sub>2</sub> dissolution lab experiment and ISOR's temperature log. This was followed by OR's Purchase Council agreement on the estimated cost for equipment and construction of the injection system. In late April decisions on type, flow and logging of tracers were taken. Following, the design was continued, viable offers for equipment sought out and shipped to Iceland. In early June a decision was taken on pumping the observation wells HN-4 and HK-34 after CO<sub>2</sub> injection. The changes of assumptions did impact the time and cost of design, equipment and construction.

From January to September OR, Mannvit and EIS held meetings prior to telephone conferences with scientists from LDEO and CNRS. At the telephone conferences key issues were discussed and decisions were taken. Following, OR's and Mannvit's engineers and scientists put forward updated proposals for the CarbFix group to decide upon. From May to September OR's and Mannvit's engineers and scientists held weekly meetings and after several inspections of scientists at LDEO the project diagram and process description were finalised.

### Construction

In July CarbFix signed a construction contract with OR's Construction Department following the approval of estimated cost of construction and equipment by OR's Purchase Council. A start meeting for construction was held in mid July. In September to October the 3 km long CO<sub>2</sub> pipeline from the pilot gas treatment plant to the injection site was installed. In October a 1 km long subsurface water pipeline was installed as well as necessary fibre optic cables, data loggers and other sensors and valves. In August to November facilities for tracers and necessary sampling equipment were installed. In November and December the down hole pumps were installed in the observation wells HN-4 and HK-34, and pipes were installed in the injection well HN-2 in December (Figure 4).



Figure 4 – Installation of downhole pumps in monitoring wells in November 2009. Photo: Þorsteinn G. Kristmundsson

In late December the construction was in its last phase and test runs of certain equipment were to start. From August to December engineers, technicians and scientists at OR, Mannvit and Verkis held construction meetings every second week.

### **Licenses and Consultation**

Environmental authorities have granted licenses for the CO<sub>2</sub> injection and the tracers based on a detailed monitoring plan of the injection facilities in the pilot project. On January 30<sup>th</sup> the Icelandic Radiation Protection Institute granted a license with conditions for the import and use of radiocarbon <sup>14</sup>C and on May 11<sup>th</sup> the Environmental Agency gave a positive statement for the CO<sub>2</sub> injection and the use of the tracers, trifluoromethylsulphur pentafluoride (SF<sub>5</sub>CF<sub>3</sub>), amidorhodamine G dye and radiocarbon <sup>14</sup>C. In June OR introduced the planned CO<sub>2</sub> injection to the Municipality of Olfus and on July 16<sup>th</sup> the Municipality of Olfus granted an operation license for the CO<sub>2</sub> injection. In August 2009 OR introduced the planned CO<sub>2</sub> injection to Icelandic Water Holdings ehf.

## Modelling

Geochemical and hydrological modelling provides tools to gain insight into the long-term management of the injection site and hopefully quantify the amount of CO<sub>2</sub> that can be mineralized. Chemical modelling scenarios are being performed by the IES and CNRS. In addition, laboratory experiments are performed to evaluate the thermodynamics and reaction kinetics of basaltic rocks. This is to ensure that future site activities can be modelled beforehand to be able to manage the CO<sub>2</sub> storage project better. iTOUGH2 and TOUGHREACT software have been used for developing reactive fluid flow models of the mineral CO<sub>2</sub> capture. Effort has already been put into developing an internally consistent database suitable for mineral reactions of interest for the CarbFix project. In 2009 hydrological parameters of a three dimensional field model covering all wells in the CarbFix reservoir have been calibrated using data from tracer tests that have been ongoing in Hellisheidi since 2007. Reactive chemistry is then coupled to the model, which consequently can be used to simulate different scenarios for the CO<sub>2</sub> injection. Reactive fluid flow models have already proven their value for the CarbFix project.

## Monitoring

In 2009 a monitoring and accounting plan has been developed, which integrates surface, subsurface and atmospheric monitoring.

Surface Monitoring involves CO<sub>2</sub> flux measurements (closed chamber method), sampling of injected gases from the power plant and pressure and temperature logging at the well heads. In July OR and ISOR located fixed monitoring sites near fractures in the lava field and along old roads in the vicinity in addition to carefully selected fixed monitoring sites laid out in 2008. These sites will serve as fixed monitoring sites for the duration of the CarbFix project (Figure 5). In September 2009, measurements were carried out at 165 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.



Figure 5 – A fixed monitoring site for CO<sub>2</sub> flux measurements. Photo: Hólmfríður Sigurðardóttir

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. Non-reactive and reactive tracers will be simultaneously injected with CO<sub>2</sub> and water for this purpose. Pressure transducers were already installed in most of the monitoring wells and the injection well in 2008.

Sampling Infrastructure. The subsurface monitoring requires fluid samples from the CarbFix storage reservoir. There are nine wells available for monitoring at the CarbFix site (Figure 2). Submersible pumps were installed in some of these wells in 2008. In November and December 2009 new fixed submersible pumps were installed at greater depth than before in two wells next to the injection well. This allows sampling of groundwater at reservoir conditions. In June IES and LDEO started designing and constructing a bailer that will be used to retrieve samples from the injection well HN-2 and the monitoring wells at reservoir conditions. Design of a sampling line started late 2009.

Atmospheric Monitoring. Since August OR has operated a weather station at the injection site for continuous monitoring of atmospheric CO<sub>2</sub>. The station is equipped with a Li-COR infrared CO<sub>2</sub> detector and is able to detect major leakage during the injection and will be used to validate CO<sub>2</sub> dissolution in the injection water. The station keeps track of all key parameters (pressure, flow, temperature and conductivity) regarding the “bookkeeping” of the injection and provides information online, available to all collaborators in the project.



## 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. The experiments with the plug are scheduled to start in 2010. Reactive transport models will be implemented to model the replacement reactions within the plug.

## 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](http://www.carbfix.com)). Detailed technical and scientific reports are also available on the limited access part of the project website. During summer 2009 the limited access part of the website was significantly improved.

## International Conference

In September 2009, 170 scientists and engineers attended a two-day International Conference on Carbon Capture and Storage at the Hellisheidi Geothermal Power Plant. Several research and pilot projects on carbon capture and geological storage were presented. Featured at the meeting was the CarbFix project.

## Meetings

The Scientific Steering Committee and the Management Team held the following joint meetings in 2009:

- Conference Call: January 13<sup>th</sup> and 29<sup>th</sup>, February 19<sup>th</sup>, March 5<sup>th</sup> and 13<sup>th</sup>, April 2<sup>nd</sup> and 30<sup>th</sup>, May 14<sup>th</sup>, June 3<sup>rd</sup>, August 6<sup>th</sup>, November 11<sup>th</sup>, December 10<sup>th</sup> and 22<sup>nd</sup>.
- Physical meetings in Iceland: September 4<sup>th</sup>.

Scientists in the CarbFix group held the following meetings on monitoring and modeling issues in 2009:

- Conference Call on Modeling: June 6<sup>th</sup> and 29<sup>th</sup>.
- Conference Call on Monitoring: June 11<sup>th</sup>.

Scientists and engineers at OR, Mannvit and EIS held design meetings on the following dates in 2009:

- Design Meetings: January 15<sup>th</sup>, February 6<sup>th</sup>, 16<sup>th</sup> and 27<sup>th</sup>, March 5<sup>th</sup> and 26<sup>th</sup>, April 29<sup>th</sup>, May 6<sup>th</sup>, 13<sup>th</sup> and 20<sup>th</sup>, June 12<sup>th</sup>, 18<sup>th</sup> and 29<sup>th</sup>, July 7<sup>th</sup>, 10<sup>th</sup> and 16<sup>th</sup>, August 6<sup>th</sup>, 11<sup>th</sup>, 18<sup>th</sup> and 25<sup>th</sup>, September 1<sup>st</sup>, 10<sup>th</sup> and 15<sup>th</sup>.

Engineers, technicians and scientists at OR, Mannvit and Verkis held Construction Meetings on the following dates in 2009:

- Construction Meetings: July 17<sup>th</sup>, August 13<sup>th</sup> and 25<sup>th</sup>, September 8<sup>th</sup>, 22<sup>nd</sup> and 24<sup>th</sup>, October 6<sup>th</sup> and 20<sup>th</sup>, November 3<sup>rd</sup>, 4<sup>th</sup>, 9<sup>th</sup> and 17<sup>th</sup>, December 1<sup>st</sup> and 15<sup>th</sup>.

Engineers, technicians and scientists at OR held meetings on the control system on the following dates in 2009: August 11<sup>th</sup> and 19<sup>th</sup>.

Scientists and PhD students at IES held meetings on the progress of the CarbFix project every week in 2009.

## Funding

Since 2006 the CarbFix project has been financed only by its partners. Now the project is seeking additional funding from different sources. In November an application was submitted to GEORG (Geothermal Research Group – see details at [www.georg.hi.is](http://www.georg.hi.is)) requesting USD 64,000 per year for 2010 and 2011 and 28,000 USD in 2012. In December an application was submitted to the EU-7<sup>th</sup> framework programme on research and development: Marie Curie Initial Training Networks (ITN) Call: FP7-PEOPLE- 2010-ITN requesting funding of USD 56,000 for researcher (post-Doc) to the CarbFix project. Results regarding outcome of these applications are expected by spring 2010. Late December a preparation started for an application to be submitted to the Global CCS Institute Project Funding and Support Program in January 2010.

---

## Financial Status and Outcome 2009

In Index I (see next page) the financial outcome of year 2009 (in addition to 2006, 2007 and 2008) is presented as well as the estimated forecast for 2010. The four participants in the CarbFix project have been performing preliminary studies in the field since 2006 and Orkuveita Reykjavíkur has been designing and constructing the injection facilities in 2009.

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. The segmentation between participants was estimated to be: EUR 3.304.970 for Orkuveita Reykjavíkur, EUR 2.243.792 for the University of Iceland - Institute for Earth Sciences, EUR 1.097.974 for Columbia University USA – Lamont-Doherty Earth Observatory and EUR 691.526 for the Centre National de la Recherche Scientifique. The referent exchange rate 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.

In order to save space, the following abbreviations are used in Index I:

OR: Orkuveita Reykjavíkur

IES: The University of Iceland – Institute of Earth Sciences

LDEO: Columbia University USA – Lamont-Doherty Earth Observatory

CNRS: The Centre National de la Recherche Scientifique, France

It was decided to present profit or loss for each year as shown in Index I. 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.

Orkuveita Reykjavíkur does not credit the CarbFix project accessibility of land and wells at the Hellisheiði field site. Orkuveita Reykjavíkur did not credit the CarbFix project the cost of drilling the new monitoring well HK-34 at the CO<sub>2</sub> injection site in early summer 2008. Furthermore Orkuveita Reykjavíkur sponsored the International Conference on Carbon Capture and Storage held at the Hellisheiði Geothermal Power Plant. Despite the difficult financial situation in Iceland since fall 2008 the Board of Directors at Orkuveita Reykjavíkur have placed the CarbFix project on the top of the list for innovative projects. It is a joint benefit for both Orkuveita Reykjavíkur and the CarbFix-project to grant the project this interest.

The CO<sub>2</sub> injection was planned in the fall 2008 but has been delayed until 2010. Therefore the estimated cost of design and construction is credited in 2009 and execution of the injection and monitoring will be credited in 2010.

**Index I – Financial Information**

CarbFix - Budget	EUR					NOTES
	2006 EUR real number	2007 EUR real number	2008 EUR real number	2009 EUR real number	2010 EUR estimated	
<b>Estimated Income</b>						
Contribution from OR	72.109	228.311	1.252.041	405.170	539.252	1,3,17
Contribution from IES	87.131	523.333	374.031	238.410	274.788	1,4,18,19
Contribution from LDEO	52.979	48.114	137.100	214.481	193.065	2,19
Contribution from CNRS	17.640	58.064	136.643	297.499	0	5
<b>Total Contribution</b>	<b>229.859</b>	<b>857.821</b>	<b>1.899.815</b>	<b>1.155.559</b>	<b>1.007.104</b>	
<b>Expences</b>						
Salaries and Wages - OR	45.848	114.048	106.685	169.320	219.674	6
Salaries and Wages - IES	49.075	163.180	181.838	208.632	196.587	
Salaries and Wages - LDEO	28.988	37.582	76.097	121.808	123.827	7
Salaries and Wages - CNRS	11.400	41.279	96.375	152.281	0	
<b>Total Salaries/Wages</b>	<b>135.311</b>	<b>356.089</b>	<b>460.995</b>	<b>652.041</b>	<b>540.088</b>	
Travel Cost - International - OR	0	9.835	1.535	0	1.703	
Travel Cost - International/Domestic - IES	16.961	34.930	32.698	38.380	0	
Travel Cost - International - LDEO	8.130	2.298	9.909	12.500	10.619	
Travel Cost - International/Domestic - CNRS	2.500	5.020	9.870	30.200	0	
<b>Total Travel Cost - International</b>	<b>27.591</b>	<b>52.083</b>	<b>54.013</b>	<b>81.080</b>	<b>12.322</b>	
Operational and Equipment Cost - OR	26.261	97.776	266.288	425.401	312.198	8
Operational and Equipment Cost - IES	20.010	82.961	195.014	87.367	0	9
Operational and Equipment Cost - LDEO	12.489	1.958	33.211	52.791	37.024	10
Operational and Equipment Cost - CNRS	500	1.100	5.300	60.375	0	11
<b>Total Operational and Equipment Cost</b>	<b>59.261</b>	<b>183.794</b>	<b>499.813</b>	<b>625.934</b>	<b>349.222</b>	
Website and conference-OR	0	7.741	3.626	11.538	5.676	12
Website and conference-IES	0	0	0	38.720	0	20
<b>Total Website and Conference - RE and IES</b>	<b>0</b>	<b>7.741</b>	<b>3.626</b>	<b>11.538</b>	<b>5.676</b>	
Indirect cost recovery-IES	15.884	54.626	64.980	74.038	0	13
EI Cost Recovery (15%) - LDEO	3.371	6.276	17.883	27.382	25.182	14
Indirect cost recovery - CNRS	3.240	10.665	25.098	54.643	0	15
<b>Other Operational Cost</b>	<b>22.495</b>	<b>71.566</b>	<b>107.960</b>	<b>156.062</b>	<b>25.182</b>	
<b>Total Operational Cost-OR</b>	<b>72.109</b>	<b>229.400</b>	<b>378.134</b>	<b>606.259</b>	<b>539.252</b>	
<b>Total Operational Cost-IES</b>	<b>101.930</b>	<b>335.697</b>	<b>474.530</b>	<b>447.137</b>	<b>196.587</b>	
<b>Total Operational Cost-LDEO</b>	<b>52.979</b>	<b>48.114</b>	<b>137.100</b>	<b>214.481</b>	<b>196.652</b>	
<b>Total Operational Cost-CNRS</b>	<b>17.640</b>	<b>58.064</b>	<b>136.643</b>	<b>297.499</b>	<b>0</b>	
<b>Total Operational Cost</b>	<b>244.658</b>	<b>671.275</b>	<b>1.126.407</b>	<b>1.565.375</b>	<b>932.491</b>	
<b>Profit/Loss</b>						
Profit (loss)-OR	0	-1.090	873.907	-201.090	0	
Profit (loss)-IES	-14.799	187.636	-100.499	-208.727	78.201	
Profit (loss)-LDEO	0	0	0	0	-3.588	
Profit (loss)-CNRS	0	0	0	0	0	
<b>Total Profit (Loss)</b>	<b>-14.799</b>	<b>186.546</b>	<b>773.408</b>	<b>-409.816</b>	<b>74.613</b>	
<b>Balance</b>						
Balance from previous year- OR		0	-1.090	872.817	671.727	16
Balance from previous year - IES		-14.799	172.837	72.338	-136.389	
Balance from previous year- LDEO		0	0	0	0	
Balance from previous year- CNRS		0	0	0	0	
<b>Total Balance from Previous Year</b>		<b>-14.799</b>	<b>171.747</b>	<b>945.155</b>	<b>535.339</b>	



## Notes

Note			
1	Average Exchange Rate 2006	87,72 ISK/EUR	Central bank of Iceland
	Average exchange rate 2007	87,6 ISK/EUR	Central bank of Iceland
	Average Exchange Rate Jan-June 2008	110,1 ISK/EUR	Central bank of Iceland
	Average Exchange Rate July-Sept 2008	125,6 ISK/EUR	Central bank of Iceland
	Average Exchange Rate Oct-Dec 2008	163,5 ISK/EUR	Central bank of Iceland
	Average Exchange Rate Jan-Mar 2009	153,2 ISK/EUR	Central bank of Iceland
	Average Exchange Rate Apr-June 2009	172,4 ISK/EUR	Central bank of Iceland
	Average Exchange Rate July-Sept 2009	180,7 ISK/EUR	Central bank of Iceland
	Average Exchange Rate Oct-Dec 2009	183,8 ISK/EUR	Central bank of Iceland
	Average Exchange Rate Jan-Mar 2010	176,2 ISK/EUR	Central bank of Iceland
2	Average Exchange Rate 2006	0,797 USD/EUR	
	Average Exchange Rate 2007	0,731 USD/EUR	
	Average Exchange Rate 2008	0,683 USD/EUR	
	Average Exchange Rate 2009	0,719 USD/EUR	
	Average Exchange Rate Jan-Mar 2010	0,718 USD/EUR	
3	Estimated number 2009 published in Annual Status Report 2008 calculated with actual exchange rate 2009.		
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 2010 the support from OR is estimated to be 41%. 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.		
5	The number for 2010 for CNRS were not delivered for the Annual Status Report.		
6	Salaries: Project Manager, Research Scientists, Lawyer and Technicians		
7	Includes salary and wages for personnel and fringe benefits (30.8%)		
8	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 cost of designing and constructing the injection setup		
9	Laboratory and filed supply and analyses		
10	Laboratory and filed supply and analyses		
11	Laboratory and filed supply and analyses		
12	Cost of the CarbFix website, meetings and the International Conference on Carbon Capture and Storage held at the Hellisheidi Geothermal Power Plant in September 2009		
13	Overhead cost according to the Managing Director at the Science Institute of University of Iceland		
14	ICR on direct costs for internally funded projects (not including permanent equipment)		
15	Overhead cost		
16	The CO <sub>2</sub> injection was planned in the fall 2008 but was delayed until 2009. Therefore the estimated cost of design, execution of the injection and monitoring is credited in 2009 and 2010		
17	OR has raised the estimated amount contributed to CarbFix 2010		
18	IES contributed more to CarbFix in 2009 than estimated		
19	IES and LDEO have raised the estimated amount contributed to CarbFix 2010		
20	IES cost of International Conference on Carbon Capture and Storage held at Hellisheidi September 2009		

---

## Summary

In the year 2009 the CarbFix project continued addressing background fluid chemistries at the injection site and characterizing the target reservoir for the planned CO<sub>2</sub> injection in year 2010. Numerous groundwater samples have been collected by Orkuveita Reykjavíkur and the Institute of Earth Sciences at the injection site during 2009. The samples have been analysed at the Iceland Geosurvey, Institute of Earth Sciences in Iceland and Columbia University. In late 2009 a down hole camera was used to scan the injection well and the observation well next to it. The scanning confirmed the estimation of the main feed-zones in these wells.

A monitoring and accounting plan was developed by the CarbFix group, which integrates surface, subsurface and atmospheric monitoring. OR is operating a weather station at the injection site for continuous monitoring of atmospheric CO<sub>2</sub> 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<sub>2</sub> injection.

Environmental authorities and the Municipality Ölfus have granted licenses for the CO<sub>2</sub> injection and the tracers, based on a detailed monitoring plan of the injection facilities in the pilot project.

In the first half of 2009 a decision was made by the CarbFix group on the CO<sub>2</sub> injection system. The decision was based on Orkuveita Reykjavíkur's and Mannvit's design and model calculations, Columbia University's execution of a representative scaled down version of the planned CO<sub>2</sub> injection scenario at Hellisheidi and Iceland Geosurvey's temperature log. Furthermore, decisions were taken on type, flow and logging of tracers. Following, viable offers for equipment were sought out and shipped to Iceland. A pumping test in the injection well in spring confirmed a relatively slow groundwater flow rate at the injection site. Therefore a decision was taken on pumping the two observation wells next to the injection well to drive the flow of CO<sub>2</sub> rich water through the bedrock. This requires a disposal of tracer rich fluid in a well east of the CarbFix injection site. Changes of assumptions in 2009 did impact the time and cost of design, equipment and construction.

In July the CarbFix group signed a construction contract with Orkuveita Reykjavíkur's construction department following the approval of estimated cost of construction and equipment by Orkuveita Reykjavíkur's Purchase Council. In the fall a 3 km long CO<sub>2</sub> pipeline from the pilot gas treatment plant to the injections site was installed, as well as a 1 km long subsurface water pipeline and necessary fibre optic cables, facilities for tracers, data loggers and other sensors and valves. Late 2009 down hole pumps were installed in the two observation wells next to the injection well and pipes and equipments in the injection well. At the end of the year the construction was in its last phase and test runs of certain equipment were to start.

IES designed and constructed a bailer that will be used to retrieve samples at reservoir conditions.

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. Hydrological parameters of a three dimensional field model covering all wells in the CarbFix reservoir have been calibrated using data from tracer tests that have been ongoing in Hellisheidi since 2007. In 2009 Institute of Earth Sciences in collaboration with Orkuveita Reykjavíkur and the Centre National de la Recherche Scientifique, finished designing and constructing a 2,5 m long laboratory plug flow reactor that will be filled with basaltic material. The experiments with the plug are scheduled in 2010.

Eight PhD students and one MSc student were working on science projects, closely linked to the CarbFix project.

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 are available on the project website ([www.carbfix.com](http://www.carbfix.com)). During summer 2009 the limited access part of the website was significantly improved. In September an International Conference on Carbon Capture and Storage was held at the Hellisheidi Geothermal Power Plant.

## Appendix I – List of Selected Publications and Presentations 2009

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

2009

Name	Talk	Poster	Abstract	Paper/Report	Radio/TV interview
W.S. Broecker	1				
J. M. Matter	3			1	3
M. Stute*					
<b>Summary</b>	<b>4</b>			<b>1</b>	<b>3</b>

\* See J.M. Matter

Wallace S. Broecker 2009. Climate and carbon dioxide. Talk at the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheidi Iceland 5.-12 September 2009.

Juerg M. Matter, 2009. Invited presentation at the Delhi Sustainable Summit, Delhi, India, February 4.

J.M. Matter, 2009. C-storage in ultramafic rocks. Invited keynote presentation at the 22rd Kongsberg Seminar, Kongsberg, Norway May 6-8.

J. M. Matter, 2009. Mineral sequestration in ultramafic rocks. Talk at the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheidi Iceland 5.-12 September 2009.

Matter, J.M., W.S. Broecker, M. Stute, S.R. Gislason, E.H. Oelkers, A. Stefansson, D. Wolff-Boenisch, E. Gunnlaugsson, G. Axelsson, and G. Björnsson (2009). **Permanent Carbon Dioxide Storage into Basalt: The CarbFix Pilot Project, Iceland.** Energy Procedia 1(2009), p. 3641-3646. (Counted by the first author).

#### Radio/TV interviews:

Boston NPR's News Source, Living on Earth, 13 March: CO<sub>2</sub>-Eating Rock (mentioning of CarbFix Project) <http://www.loe.org/shows/segments.htm?programID=09-P13-00011&segmentID=5>

PRI Public Radio International, The World, 30 September: Combating climate change by storing CO<sub>2</sub> underground. <http://www.pri.org/business/social-entrepreneurs/storing-co2-underground1645.html>

Earth Sky 28 December: Juerg Matter on Iceland's new carbon storage project. <http://earthsky.org/energy/juerg-matter-on-icelands-new-carbon-storage-project>

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

2009

Name	Talk	Poster	Abstract	Paper/Report	Radio/TV interview
E.H. Oelkers	1				
<b>Summary</b>	<b>1</b>				

Eric H. Oelkers, 2009. Mineral carbonization of CO<sub>2</sub>. Talk at the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheidi Iceland 5.-12 September 2009.

Flaathen, T.K., Gislason, S.R. and Oelkers, E.H. (2009). **Chemical evolution of the Mt. Hekla, Iceland, groundwaters: A natural analogue to CO<sub>2</sub> sequestration.** Applied Geochemistry 24, 463-474. (Counted by the first author).

Matter, J.M., W.S. Broecker, M. Stute, S.R. Gislason, E.H. Oelkers, A. Stefansson, D. Wolff-Boenisch, E. Gunnlaugsson, G. Axelsson, and G. Björnsson (2009). **Permanent Carbon Dioxide Storage into Basalt: The CarbFix Pilot Project, Iceland.** Energy Procedia 1(2009), p. 3641-3646. (Counted by the first author).

**Orkuveita Reykjavíkur (OR)****2009**

<b>Name</b>	<b>Talk</b>	<b>Poster</b>	<b>Abstract</b>	<b>Paper/Report</b>	<b>Radio/TV interview</b>
E. Gunnlaugsson	3				
H. Sigurdardottir	9			3	4
J.S. Fridriksson	1				
<b>Summary</b>	<b>13</b>			<b>3</b>	<b>4</b>

Holmfrídur Sigurdardóttir (2009). **Vöktunaráætlun. Binding CO<sub>2</sub> í basalti við Hellisheiðarvirkjun (Monitoring Report)**. Mars 2009.

H. Sigurdardóttir (2009). **CarbFix. CO<sub>2</sub> Fixation into Basalts, Hellisheiði, Iceland. Annual Status Report 2008**. April 2009.

H. Sigurdardóttir (2009). **Frá Kolviðarhóli til Kaupmannahafnar**. Morgunblaðið newspaper December 5, 2009.

Matter, J.M., W.S. Broecker, M. Stute, S.R. Gislason, E.H. Oelkers, A. Stefansson, D. Wolff-Boenisch, E. Gunnlaugsson, G. Axelsson, and G. Björnsson (2009). **Permanent Carbon Dioxide Storage into Basalt: The CarbFix Pilot Project, Iceland**. Energy Procedia 1(2009), p. 3641-3646. (Counted by the first author).

List of selected talks on the CarbFix project 2009:

Einar Gunnlaugsson. CarbFix A group of Nordic Scientists, 28 May.

E. Gunnlaugsson. Reykjavik Energy and CarbFix. A group of Icelandic High school Teachers 5 June.

E. Gunnlaugsson. Reykjavik Energy and CarbFix. A group of Swedish Scientists 27 August.

Holmfrídur Sigurdardóttir. The Seoul Shinmun News ePaper, 28 January.

H. Sigurdardóttir. The Rotary Club Reykjavik Árbær, 12 February.

H. Sigurdardóttir. School of Education at the University of Iceland, 25 March.

H. Sigurdardóttir. Group of organizers for the MIT Global Startup Workshop, 1 May.

H. Sigurdardóttir. CarbFix – CO<sub>2</sub> fixation into basalts at Hellisheiði, Iceland. World Energy Council Executive Assembly, 17 September.

H. Sigurdardóttir. The Progressive Party in Iceland, 11 November.

H. Sigurdardóttir. The Lesley University Maine, USA, for Ecological Living and Learning (CELL), 13 November.

H. Sigurdardóttir. The Australian Ambassador, 27 November.

H. Sigurdardóttir. CarbFix – CO<sub>2</sub> fixation into basalts at Hellisheiði, Iceland. Development of geothermal utilisation – opportunities for growth Conference of the Geothermal Association of Iceland (GAI), 8 December.

Jakob Sigurður Friðriksson. The European Investment Bank Site Event: UNFCCC COP 15 – Copenhagen, 14 December (mentioning of CarbFix Project).

Radio/TV interviews:

STÖÐ 2, Evening News, 7 September in connection to the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheiði Iceland 5.-12 September 2009 <http://vefmidlar.visir.is/VefTV/?channelID=STOD2&programID=d93d6ddc-f3df-4c27-90e2-28d49738f306&mediaSourceID=0f362a32-8a38-4ecd-97df-064fa6264b66&mediaClipID=608c8f55-7f10-4748-9d57-783c03c83c8b>

PRI Public Radio International, The World, 30 September: Combating climate change by storing CO<sub>2</sub> underground. <http://www.pri.org/business/social-entrepreneurs/storing-co2-underground1645.html>

Clean Skies News, 25 November 2009: Iceland's Effort to Store CO<sub>2</sub> Emissions. [www.cleanskies.com/videos/icelands-effort-store-co2-emissions](http://www.cleanskies.com/videos/icelands-effort-store-co2-emissions).

Ríkisútvarpið RUV - The Icelandic National Broadcasting Service, 17 December 2009. The CarbFix project. <http://dagskra.ruv.is/sjonvarpid/4506448/2009/12/17/>.

**The University of Iceland – Institute of Earth Sciences (IES)****2009**

<b>Name</b>	<b>Talk</b>	<b>Poster</b>	<b>Abstract</b>	<b>Paper/Report</b>	<b>Radio/TV interview</b>
S.R. Gislason	4		1		1
D. Wolf-Boenisch	1		1		
H.A. Alfredsson	2	2	2		
E.S. Aradottir*	3		1		
T.K. Flaaten	1	1	1	2	
S. Gudbrandsson	1	3	1		
A. P. Gysi	2	2	2		
G.J. Stockmann	3	1	1		
A. Stefansson**					
<b>Summary</b>	<b>17</b>	<b>9</b>	<b>10</b>	<b>2</b>	<b>1</b>

\*The University of Iceland – Department of Chemistry

\* See A.P. Gysi

Helgi Arnar Alfredsson and S. Guðbrandsson, 2009. CarbFix, CO<sub>2</sub> sequestration in basaltic rock, Hellisheidi, SW-Iceland. Poster at the International Conference on CO<sub>2</sub> Sequestration Processes, Reykjavik, 7-8th September 2009.

H. A. Alfredsson and S.R. Gislason, 2009. CarbFix - CO<sub>2</sub> sequestration in basaltic rock: Chemistry of the rocks and waters at the injection site, Hellisheidi, SW-Iceland. Poster at the International Conference on CO<sub>2</sub> Sequestration Processes, Reykjavik, 7-8th September 2009.

H. A. Alfredsson and S.R. Gislason, 2009. CarbFix - CO<sub>2</sub> sequestration in basaltic rock: Chemistry of the rocks and waters at the injection site, Hellisheidi, SW-Iceland. Geochim. Cosmochim. Acta. Abstract and talk at the Goldschmidt Conference, Davos, Switzerland, 21-26th June 2009.

H. A. Alfredsson and S. R. Gislason, 2009. CarbFix – Binding kolefnis í basalti – Efnafræði bergs og vatns á niðurrennsliðsvæðinu í Þrengslum, Hellisheidi. Abstract and talk at the Spring Conference of the Geological Society of Iceland.

Edda Sif Aradottir, 2009. Development of a coupled reactive fluid flow model for mineral CO<sub>2</sub> capture in Hellisheidi, Iceland. Extended abstract and talk at the TOUGH Symposium 2009. September 14-16, 2009, Berkeley.

E.S. Aradottir, 2009. The TOUGH Codes. Talk at the ICSS: Icelandic Center of Computational Sciences, October 8, 2009.

E.S. Aradottir, 2009. Carbon capture and sequestration: Local solutions to a global problem. Talk at the 5th Conference of the Icelandic Chemical Society, November 14, 2009.

Sigurður R. Gislason, 2009. The CarbFix project: Mineral CO<sub>2</sub> sequestration into basalt. Invited talk at the Kiel University, Germany, January 26th 2009.

S.R. Gislason, 2009. Carbon sequestration in basaltic rock. The carbfix project. Talk at the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheidi Iceland 5.-12 September 2009.

S.R. Gislason 2009. The CarbFix project: Mineral CO<sub>2</sub> sequestration into basalt. Talk at the Delta-min first meeting. Granada Spain, September 2009.

S.R. Gislason, 2009. The CarbFix project: Mineral CO<sub>2</sub> sequestration into basalt. Invited talk at the Oslo University, Norway, December 2009.

S.R. Gislason, W.S. Broecker, E.H. Oelkers EH, E. Gunnlaugsson, H. Sigurdardottir, A. Stefansson, D. Wolff-Boenisch, J. Matter, M. Stute and G. Axelsson, 2009. The Carbfix project: Mineral CO<sub>2</sub> sequestration into basalt. GEOCHIMICA ET COSMOCHIMICA ACTA Volume: 73 Issue: 13 Pages: A440-A440 Supplement: Suppl. S Published: June 2009 .

Snorri Guðbrandsson and H.A. Alfreðsson, 2009. CarbFix, CO<sub>2</sub> sequestration in basaltic rock, Hellisheidi, SW-Iceland. Poster at the International Conference on CO<sub>2</sub> Sequestration Processes, Reykjavik, 7-8th September 2009.

S. Gudbrandsson, S. Wolff-Boenisch, S.R. Gislason, and E.H Oelkers, 2009. Dissolution rates of crystalline basalt at pH 2 – 11 and 5 °C to 75 °C. Poster at the International Conference on CO<sub>2</sub> Sequestration Processes, Reykjavík, 7-8th September 2009.

S. Gudbrandsson, S. Wolff-Boenisch, S.R. Gislason, and E.H Oelkers, 2009. Dissolution rates of crystalline basalt at pH 2 – 11 and 5 °C to 75 °C. Poster and abstract at the 4th Annual meeting of Nordisk Mineralogical Network, Helsinki, Finland, 28th September to 1st October 2009.

S. Gudbrandsson, S. Wolff-Boenisch, S.R. Gislason, and E.H Oelkers, 2009. Dissolution rates of crystalline basalt as a function of temperature and solution composition. *Geochim. Cosmochim. Acta*. Abstract and talk at the Goldschmidt Conference, Davos, Switzerland, 21-26th June 2009.

Alex P. Gysi and A Stefánsson, 2009. Low temperature CO<sub>2</sub> mineralization into basalt: solution chemistry and secondary mineral assemblages. Abstract and poster at the AGU Fall Meeting, San Francisco, USA, 14th December 2009.

A. P. Gysi, 2009. CO<sub>2</sub>-water-basalt interaction: experiments and modelling. Talk at the Folda Seminar, Series, University of Iceland, Iceland, 29th October 2009.

A. P. Gysi and A. Stefánsson, 2009. CO<sub>2</sub> mineralization into basalt: experimental results. Poster at the International Conference on CCS, Reykjavík, Iceland 7-8 September 2009.

A. P. Gysi and A. Stefánsson, 2009. CO<sub>2</sub>-water-basalt interaction: geochemical modelling and experiments. *Geochim. Cosmochim. Acta*. Abstract and talk at the Goldschmidt, Davos, Switzerland, 21-26th June 2009.

Therese K. Flaathen, E. H. Oelkers, S. R. Gislason, 2009. An experimental study of the effect of sulphate on calcite precipitation rates and CO<sub>2</sub> sequestration. 9th Annual V. M. Goldschmidt Conference, Davos, Switzerland. Abstract and poster.

Flaathen, T.K., Gislason, S.R. and Oelkers, E.H. (2009). **Chemical evolution of the Mt. Hekla, Iceland, groundwaters: A natural analogue to CO<sub>2</sub> sequestration.** *Applied Geochemistry* 24, 463-474.

Flaathen, T.K. (2009). **Water-rock interaction during CO<sub>2</sub> sequestration in basalt.** Oddi, Reykjavik, Iceland, 2009 ISBN: 978-9979-9914-1-0. PhD Thesis and talk.

Matter, J.M., W.S. Broecker, M. Stute, S.R. Gislason, E.H. Oelkers, A. Stefánsson, D. Wolff-Boenisch, E. Gunnlaugsson, G. Axelsson, and G. Björnsson (2009). **Permanent Carbon Dioxide Storage into Basalt: The CarbFix Pilot Project, Iceland.** *Energy Procedia* 1(2009), p. 3641-3646. (Counted by the first author).

Gabriella J. Stockmann, D. Wolff-Boenisch, S.R. Gislason and E. H. Oelkers, 2009. Can carbonate coatings inhibit in-situ mineral carbonatization? Poster at the International Conference on CO<sub>2</sub> Sequestration Processes, Reykjavik, Iceland, September 2009.

G. J. Stockmann, D. Wolff-Boenisch, S. R. Gislason and E. H. Oelkers, 200. Can carbonate coatings inhibit in-situ mineral carbonatization? Abstract and talk at the Goldschmidt conference 2009, Davos, Switzerland, June 2009.

G. J. Stockmann, 2009. The effect of carbonate coating on the dissolution rate of basaltic glass and diopside, Talk at the Internal meeting, CNRS/LMTG, Université Paul Sabatier, Toulouse, France, April 2009.

G. J. Stockmann, 2009: CO<sub>2</sub> fixation - Effect of carbonate precipitation on dissolution of basaltic rocks, Talk at the Folda Seminar Series, Institute of Earth Sciences, University of Iceland, February 2009.

Domenik Wolff-Boenisch, S.R. Gislason, E.H. Oelkers, W.S. Broecker, J.M. Matter, M. Stute, A. Stefánsson, E. Gunnlaugsson, G. Björnsson, and G. Axelsson, 2009. In-situ carbonatization of CO<sub>2</sub> - The CarbFix project in Iceland. Talk and abstract at the European Geosciences Union General Assembly 2009 Vienna, Austria, 19 – 24 April 2009. Vol. 11, EGU2009-9451.

#### Radio/TV interviews:

Clean Skies News, 1 December 2009: CarbFix: International Research on Carbon Storage.  
[www.cleanskies.com/videos/carbfix-international-research-carbon-storage](http://www.cleanskies.com/videos/carbfix-international-research-carbon-storage)



---

**Reykjavik Energy Graduate School of Sustainable Systems (REYST)**
**2009**

<b>Name</b>	<b>Talk</b>	<b>Poster</b>	<b>Abstract</b>	<b>Paper/Report</b>	<b>Radio/TV interview</b>
E. V. Ragnheidardottir	1	2			
<b>Summary</b>	<b>1</b>	<b>2</b>			

Elísabet V. Ragnheidardottir, 2009 Costs, Profitability and Potential Gains of the CarbFix Program. Poster at the International Conference on Carbon Capture & Storage, Reykjavík, Iceland, 7-9 September, 2009.

E. V. Ragnheidardottir, 2009 Costs, Profitability and Potential Gains of the CarbFix Program. Poster at the World Energy Council, Executive Assembly 2009, Reykjavík, Iceland, 16-19 September, 2009.

E. V. Ragnheidardottir, 2009 Costs, Profitability and Potential Gains of the CarbFix Program. Talk at the Reykjavík Climate Change Conference, Reykjavík, Iceland, 11 November, 2009.

## Appendix II - CarbFix in the Media 2009

From the beginning, CarbFix has stressed the importance of sharing the generated knowledge with the public, environmental authorities, industry and the scientific/engineering community. The CarbFix project has been featured in the following media in 2009:

Boston NPR's News Source, Living on Earth, 13 March: CO<sub>2</sub>-Eating Rock (mentioning of CarbFix Project) <http://www.loe.org/shows/segments.htm?programID=09-P13-00011&segmentID=5>

Economist 7 September: [www.economist.com/daily/columns/greenview/displaystory.cfm?story\\_id=14396594](http://www.economist.com/daily/columns/greenview/displaystory.cfm?story_id=14396594).

Morgunblaðið newspaper 7 September. An interview with Sigurdur R. Gislason and Eric Oelkers in connection to the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheidi Iceland 5.-12 September 2009

STÖÐ 2, Evening News, 7 September in connection to the International conference on CO<sub>2</sub> Sequestration Processes, Hellisheidi Iceland 5.-12 September 2009 <http://vefmidlar.visir.is/VefTV/?channelID=STOD2&programID=d93d6ddc-f3df-4c27-90e2-28d49738f306&mediaSourceID=0f362a32-8a38-4ecd-97df-064fa6264b66&mediaClipID=608c8f55-7f10-4748-9d57-783c03c83c8b>

Science September 25, 2009 Issue. Hellisheiði Geothermal Power Plant on the Cover: <http://www.sciencemag.org/content/vol325/issue5948/cover.dtl>.

PRI Public Radio International, The World, 30 September: Combating climate change by storing CO<sub>2</sub> underground. <http://www.pri.org/business/social-entrepreneurs/storing-co2-underground1645.html>

Clean Skies News, 25 November: Iceland's Effort to Store CO<sub>2</sub> Emissions. [www.cleanskies.com/videos/icelands-effort-store-co2-emissions](http://www.cleanskies.com/videos/icelands-effort-store-co2-emissions).

Clean Skies News, 1 December: CarbFix: International Research on Carbon Storage. [www.cleanskies.com/videos/carbfix-international-research-carbon-storage](http://www.cleanskies.com/videos/carbfix-international-research-carbon-storage)

Morgunblaðið newspaper 5 December. An article by H. Sigurdardottir on the status of the CarbFix project.

Ríkisútvarpið RUV - The Icelandic National Broadcasting Service, 17 December. The CarbFix project. <http://dagskra.ruv.is/sjonvarpid/4506448/2009/12/17/>.

Earth Sky 28 December: Juerg Matter on Iceland's new carbon storage project. <http://earthsky.org/energy/juerg-matter-on-icelands-new-carbon-storage-project>