Radiocarbon as a Reactive Tracer for Tracking Permanent CO_2 Storage in Basaltic Rock

DE-FE0004847

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS
August 12-14, 2014

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Presentation Outline

- Benefit to the Program
- Project Overview
- The CarbFix Project, Iceland
- Monitoring & Verification Results
- Accomplishments to Date
- Summary

Benefit to the Program

- The goal of the project is to develop and test novel geochemical tracer techniques for quantitative monitoring, verification and accounting of stored CO_2. These techniques contribute to the Carbon Storage Program's effort of ensuring 99% storage permanence.

Benefit to the Program cont.

- We are developing and testing the feasibility of carbon-14 (^{14}C) as a reactive tracer for quantitative monitoring and accounting of geological CO_2 storage.
- ^{14}C is the only feasible tracer tagging the CO_2 molecule itself
- Our approach provides a surveying tool for **dissolved** or **chemically transformed** CO_2.
- The technology, when successfully demonstrated, will provide an improvement over current monitoring practices.

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Project Overview: Goals and Objectives

- Monitoring subsurface CO_2 transport with trifluormethylsulphur pentafluoride (SF_5CF_3) and sulfurhexafluoride (SF_6).
- Testing carbon-14 (^{14}C) as a reactive tracer for geochemical reactions (including mineral carbonation) caused by CO_2 injection at the CarbFix pilot injection site, Iceland.
- Drilling small diameter coreholes into injection zone for mineral carbonation study on core samples.
- Quantify the extent of mineral carbonation in the CarbFix basalt CO_2 storage reservoir.

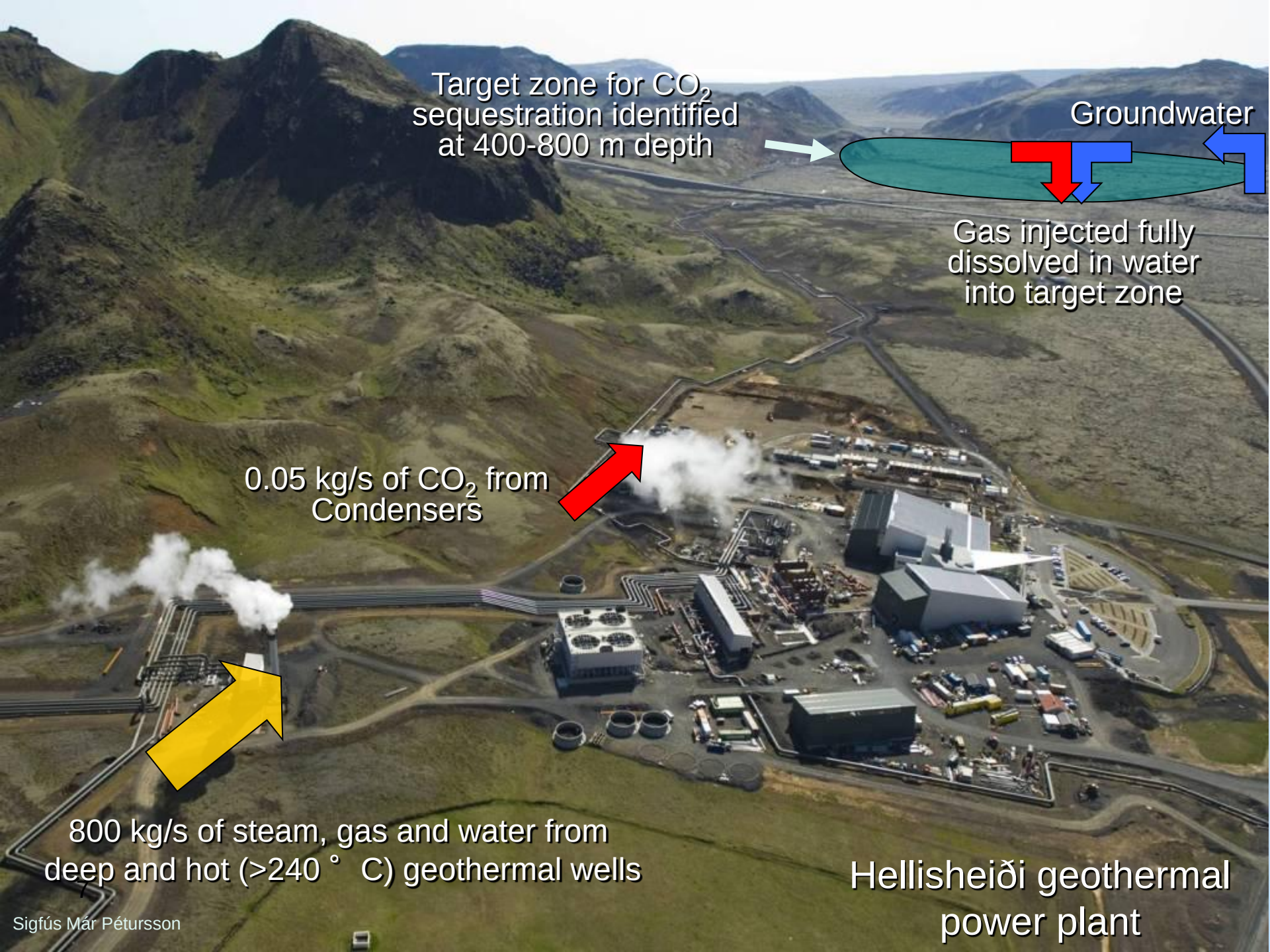
➢ This research leads to advanced monitoring and accounting of geologic CO_2 storage.

Technical Status – CarbFix Project

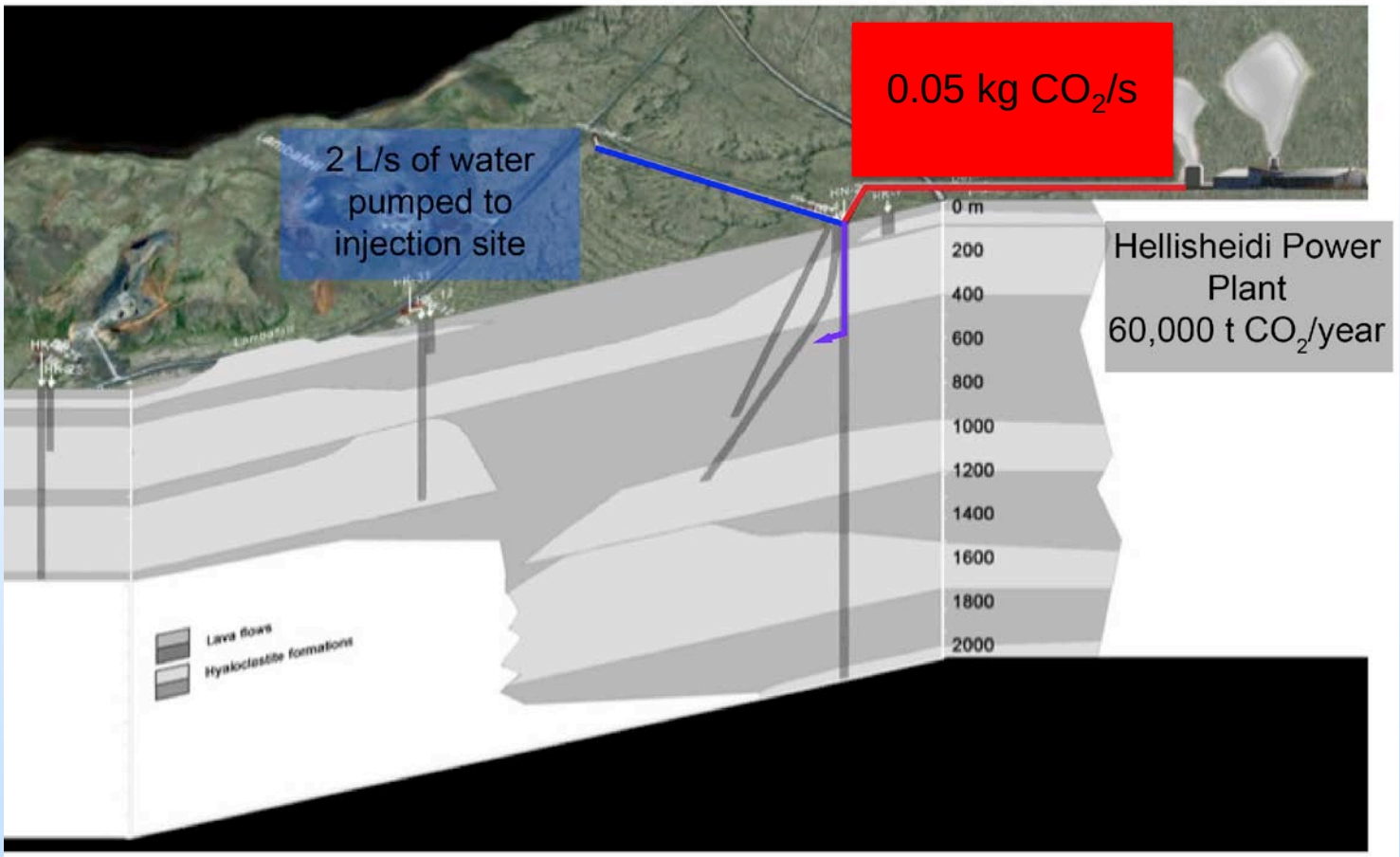
- **~200 tons of CO_2 injected in January 2012**
- **~73 tons of CO_2/H_2S were injected starting June 2012**

CarbFix partners:

- **Orkuveita Reykjavikur (Reykjavik Energy), Iceland**
- **University of Iceland, Iceland**
- **CNRS, University of Toulouse, France**
- **Columbia University, New York, USA**


Target zone for CO_2 sequestration identified at 400-800 m depth
Groundwater
Gas injected fully dissolved in water into target zone
0.05 kg/s of CO_2 from Condensers
800 kg/s of steam, gas and water from deep and hot (>240 ° C) geothermal wells
Hellisheiði geothermal power plant
Sigfús Már Pétursson

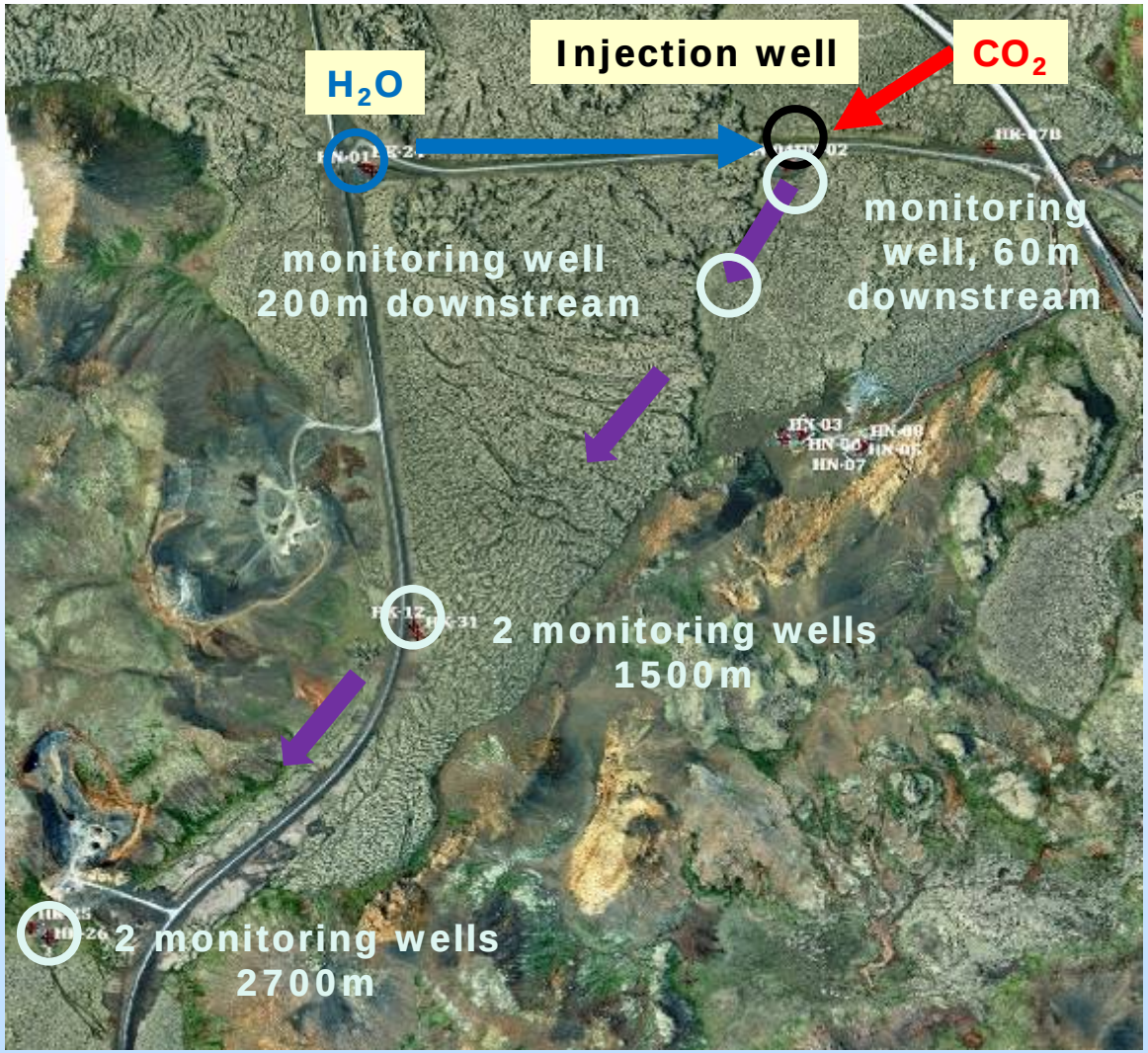
Injection Process

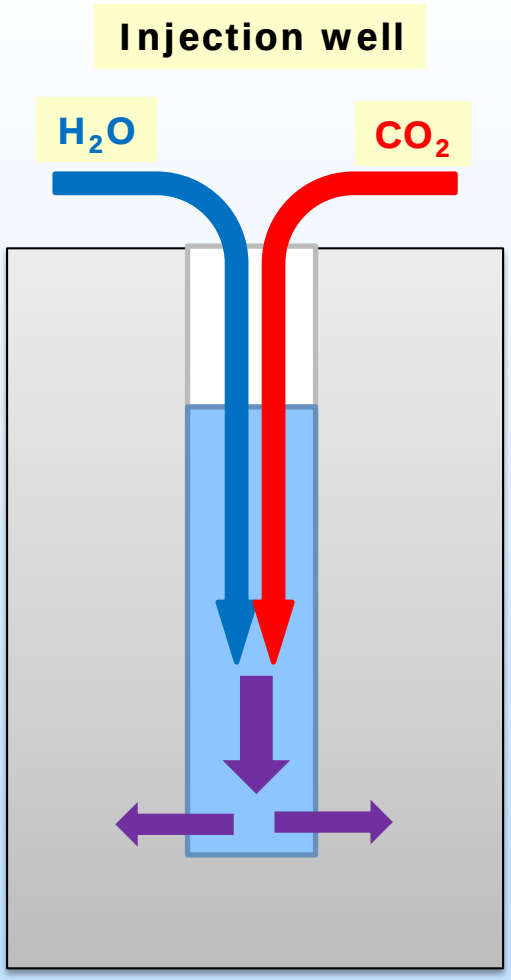


distance between injection and first monitoring well is 60 m at injection interval depth

Alfredsson et al. (2012)

Monitoring Infrastructure





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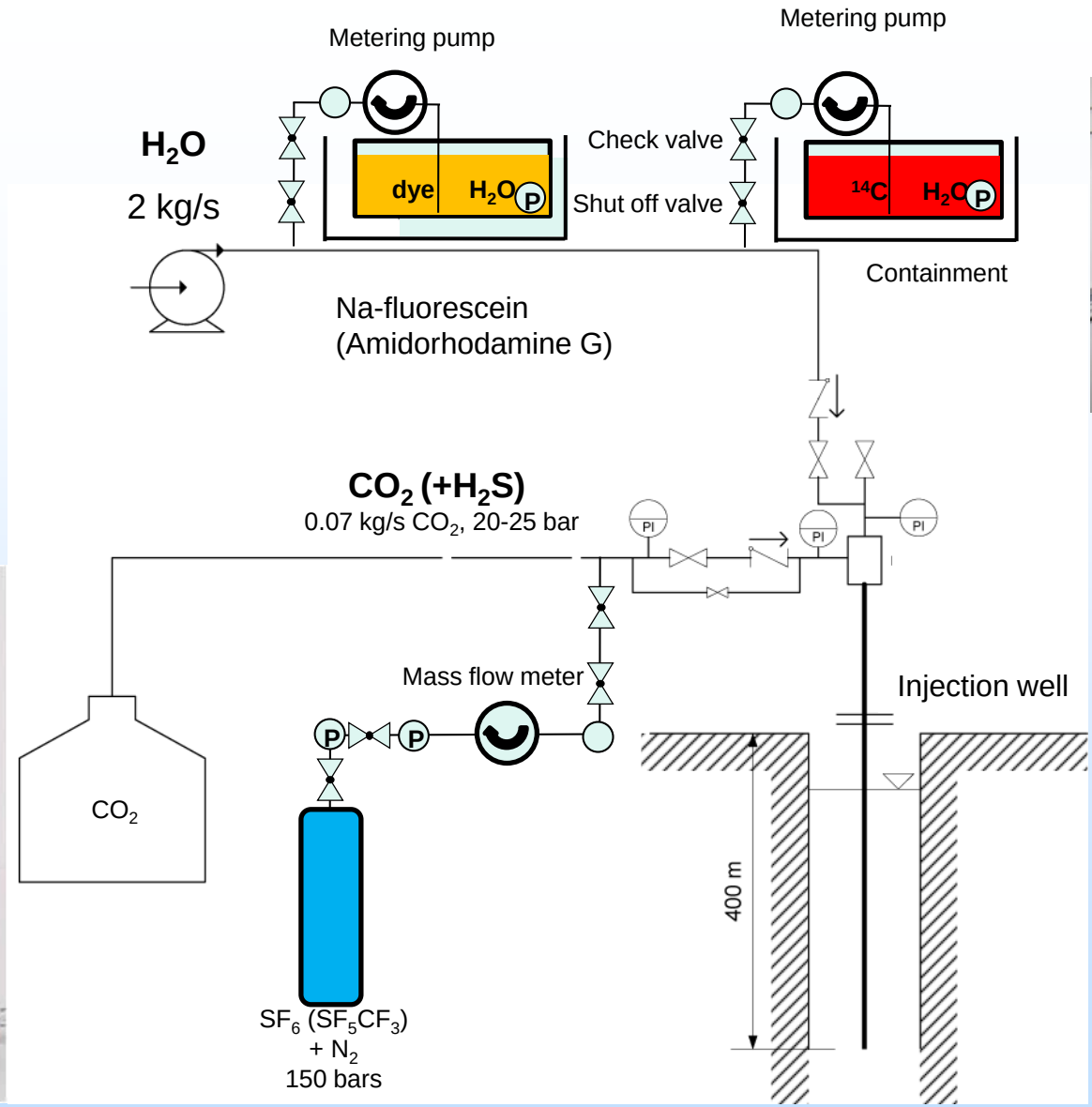
Tracer injection system



Injection Phases

Phase I

pure CO_2 injection of ~200 tons

(January – February 2012)

SF_6 & ^{14}C as tracers

Phase II

CO_2+H_2S injection (80% CO_2, 20% H_2S)

~73 tons of CO_2 (June 2012 – March 2013)

(stopped because of (bio)-clogging)

SF_5CF_3, AmidRhod G & ^{14}C

Phase III (outside of this project)

CO_2+H_2S injection (70% CO_2, 30% H_2S)

~10000 tons of CO_2 (2014)

SF_5CF_3, sulfonate, iodide & ^{14}C

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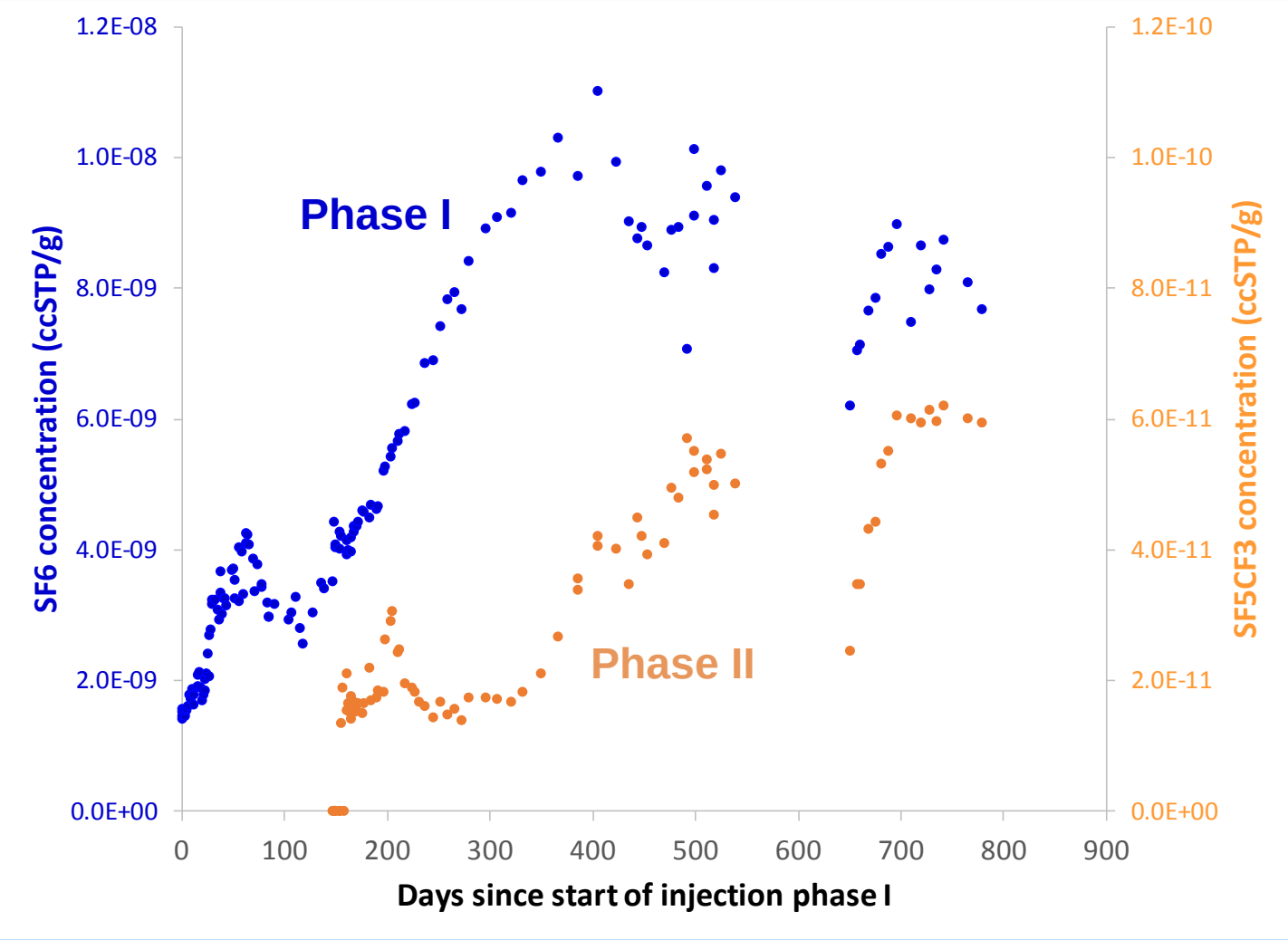
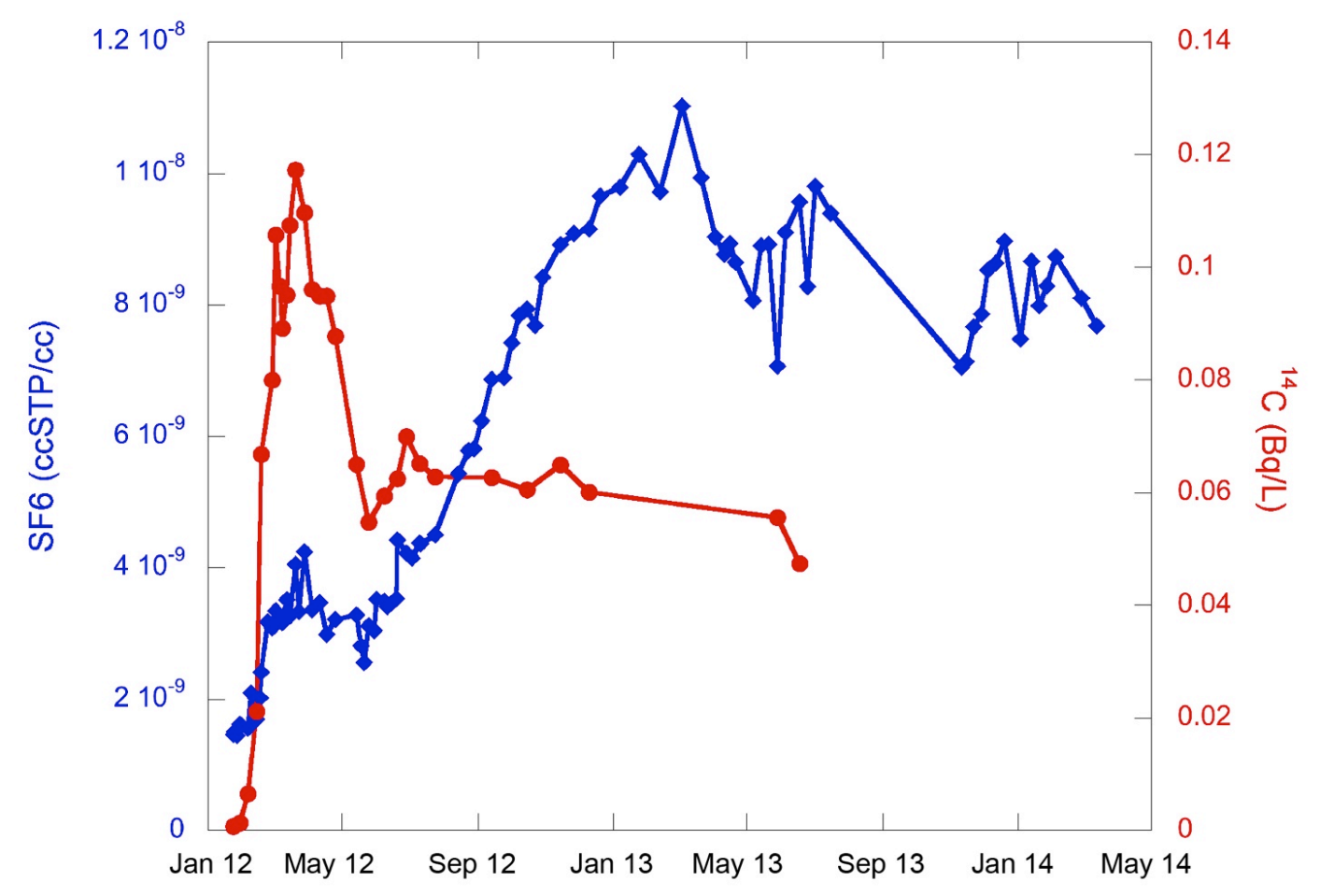
Phase I & II: SF_6 & SF_5CF_3 Monitoring Results

- Goal: Monitor advective and dispersive transport of injected solution



Phase I: ^{14}C Monitoring

- Goal: Monitor CO_2-fluid-rock reactions (carbon mass balance)



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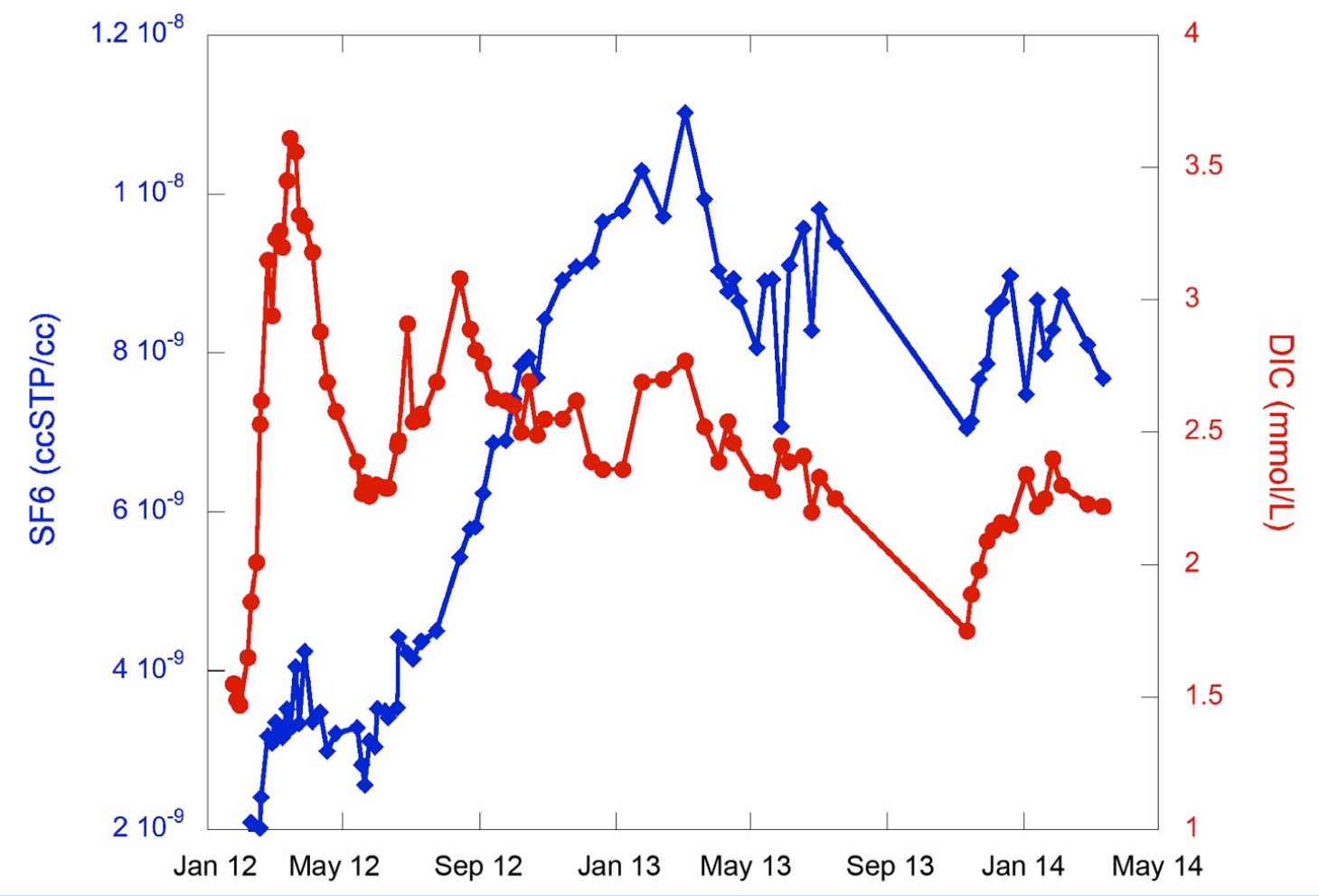
Phase I: Dissolved Inorganic Carbon Monitoring



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Carbon Mass Balance

1. Calculating mixing between injected solution and reservoir fluid using SF_6

$$[SF_6]_i = X[SF_6]_{IS} + (1-X)[SF_6]_{BW}$$

2. Calculating theoretical dissolved inorganic carbon concentration (DIC_{mix}) due to pure mixing in the reservoir

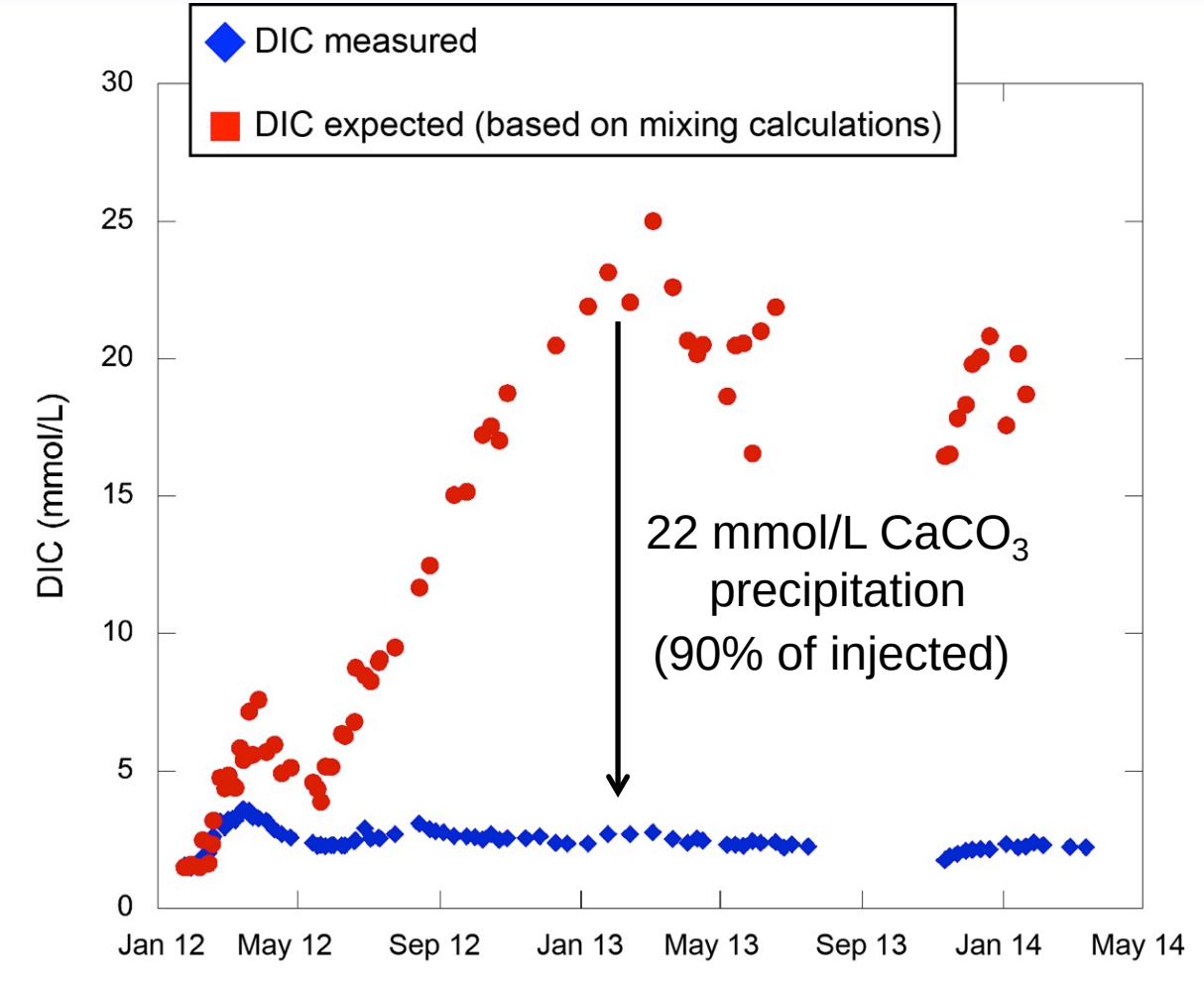
$$DIC_{mix} = X_{SF6} \cdot DIC_{IS} + (1 - X_{SF6}) \cdot DIC_{BW}$$

3. Calculating difference between measured and theoretical DIC

$$\Delta DIC = DIC_{sample} - DIC_{mix}$$

Carbon Mass Balance

expected vs. measured DIC concentration



- Data gap from Aug 2013 – Dec 2013 because of submersible pump failure

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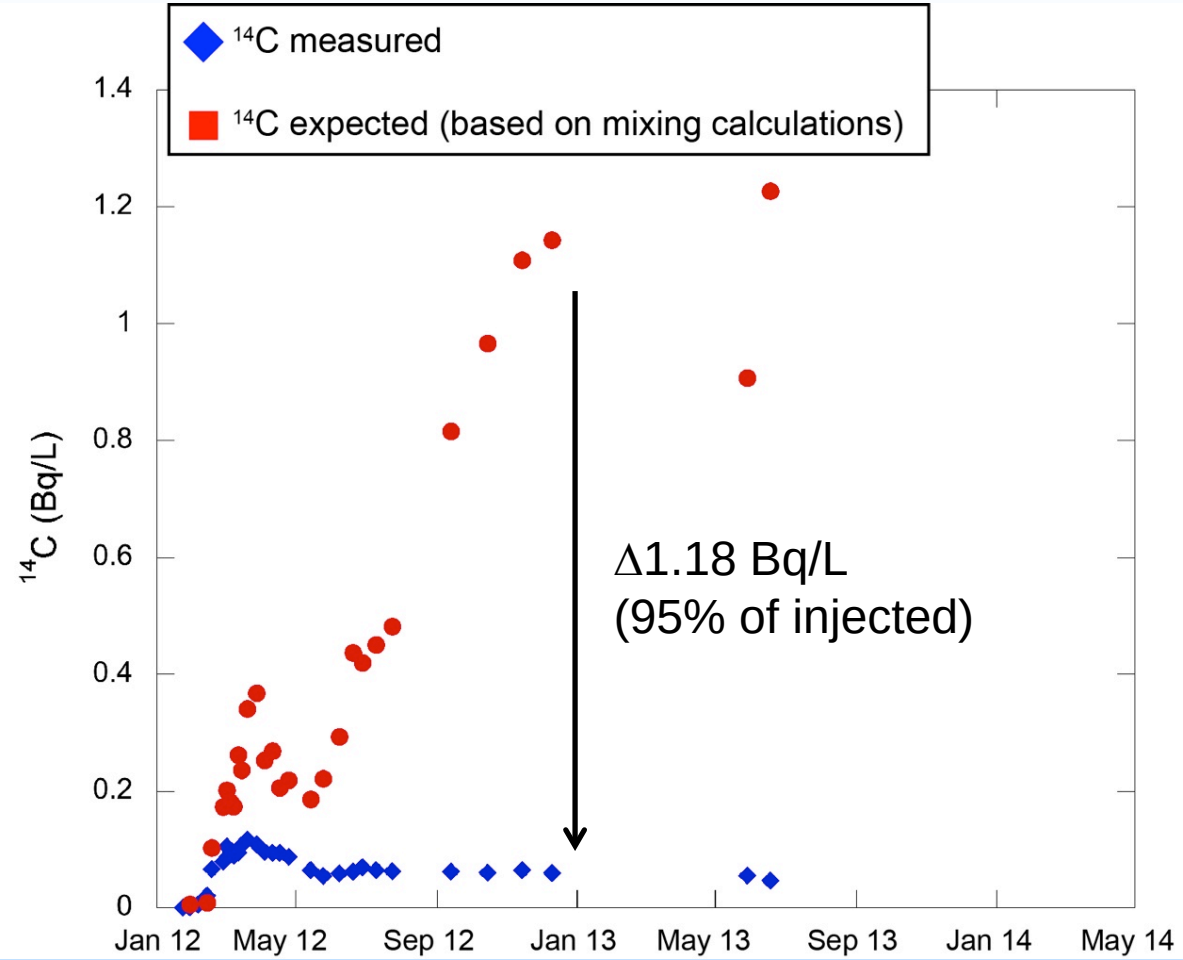
^{14}C Mass Balance

expected vs measured ^{14}C concentration



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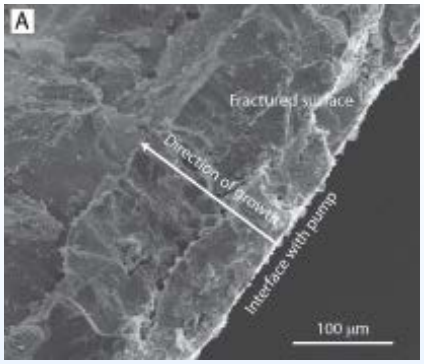
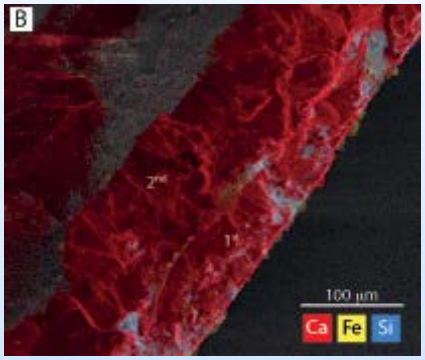
Carbonate Precipitation in Reservoir



SEM image of precipitate sample including interface with submersible pump



EDX map of precipitate sample, showing Ca, Fe, Si distribution

Dideriksen K (unpublished data)

Sample ID	Name	$^{14}C/^{12}C$ Fraction modern
2013-5	2013-5-carbonate	7.82±0.05
2013-6	2013-6-carbonate	7.48±0.08

Average $^{14}C/^{12}C$ in last 10 water samples: 7.93±0.05

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Accomplishments to Date

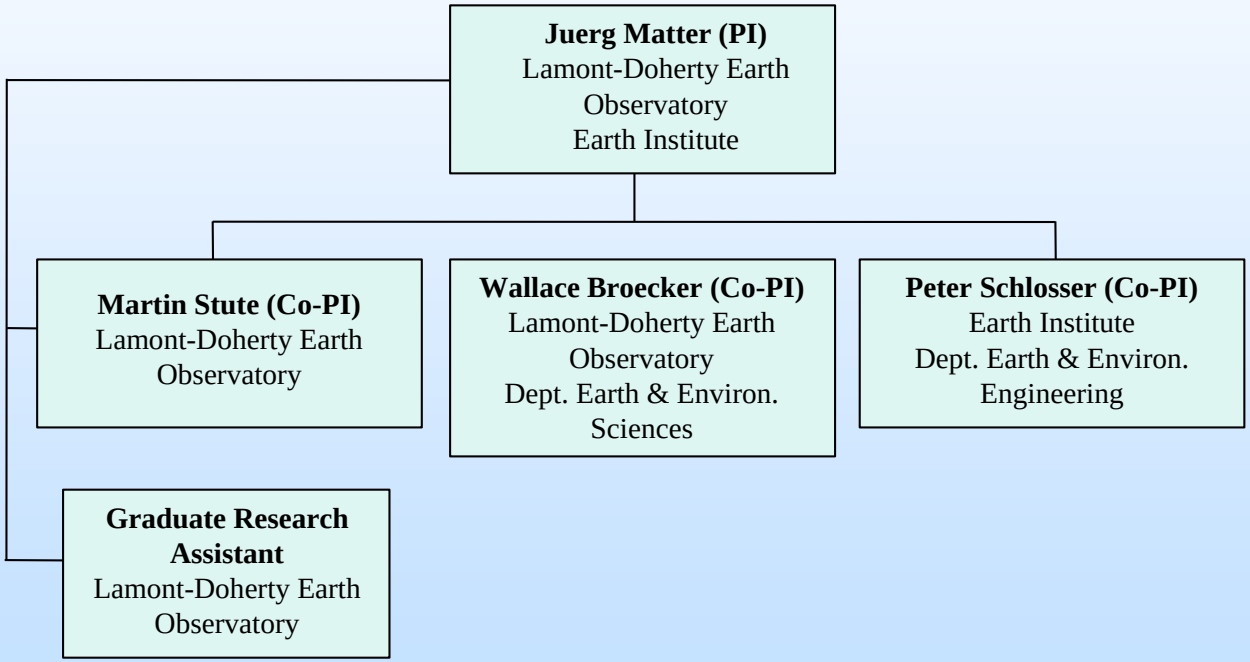
- Pure CO_2 injection (Phase I) was successfully completed.
- The mixed gas CO_2+H_2S injection (Phase II) was conducted for 6 months. Injection finalized due to wellbore clogging (biofilm and mineralization).
- Continuous collection of fluid and gas samples for chemical and tracer analyses is being conducted in injection and monitoring wells for Phase I and Phase II injection.
- Successful monitoring and verification of subsurface CO_2 mineralization along the flow path from injection to monitoring well by using $^{14}C_{DIC}$ as a reactive tracer.
- Positive proof of subsurface CO_2 mineralization in monitoring well by secondary carbonate minerals with elevated (above modern carbon) $^{14}C/^{12}C$ ratios.
- Drilling of 600m hole into formation currently going on, coring planned for fall of 2014

Summary

- Preliminary analysis of the tracer data from the Phase I (pure CO_2 injection) indicates CO_2 mineralization via CO_2-fluid-basalt reactions.
- Mass balance calculation reveals that over 90% of the injected CO_2 has been mineralized within less than a year.
- The developed and applied tracer techniques are successful surveying tools for dissolved and chemically transformed CO_2, leading to a quantification (mass balance) of stored CO_2 in geologic reservoirs.

Appendix

Organization Chart



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Gantt Chart

Tasks	BP I					BP II								BP III			
	Qt1	Qt2	Qt3	Qt4	Qtr5	Qt1	Qt2	Qt3	Qt4	Qt5	Qt6	Qt7	Qt8	Qt1	Qt2	Qt3	Qt4
Task 1.0 Project Management, Planning and Reporting							E					J					
Task 2.0 Monitoring the CO_2 movement with SF_5CF_3 in the basalt formation							E					J					
Subtask 2.1 Monitoring the SF_5CF_3 concentration in target injection interval and overlying shallow aquifer		A						**F**		I				M			
Subtask 2.2 SF_5CF_3 Data Analysis			C					**G**		I				M			
Task 3.0 Monitoring of geochemical reactions and in situ mineral carbonation with ^{14}C							E					J					
Subtask 3.1 Monitoring the ^{14}C concentration in target injection interval and overlying shallow aquifer			**B**					F		I				M			
Subtask 3.2 Carbon-14 and $d^{13}C$ Analysis					**D**			G		I			**K**	M			
Task 4.0 Mineral carbonation studies on core samples																	
Subtask 4.1 Wireline core drilling																	
Subtask 4.1.1 Drilling plan									**H**				L				
Subtask 4.1.2 Drilling and coring																N	
Subtask 4.2 Mineralogical and geochemical analysis of core samples																	**O**
Task 5.0 Quantification of mineral carbonation in the CarbFix basalt storage reservoir																	**P**

- Delay in completion of drilling core hole because of drill rig availability

Bibliography

- Journal, multiple authors:

Matter, JM, Broecker, W, Gislason, S, Gunnlaugsson, E, Oelkers, E, Stute, M, Sigurdardottir, H, Stefansson, A, Wolff-Boenisch, D, Axelsson, G, Sigfusson, B (2011), The CarbFix Pilot Project – storing carbon dioxide in basalt. Energy Procedia 4, 5579-5585.

Sigfusson, B, Gislason, SR, Matter, JM, Stute, M, Gunnlaugsson, E, Gunnarsson, I, Aradottir, ES, Mesfin, K, Alfredsson, HA, Wolff-Boenisch, D, Arnarson, MT, Oelkers E (2014), Injection of dissolved CO_2 into the subsurface: a novel carbon storage method. International Journal of Greenhouse Gas Control (in review).