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

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National Energy Technology Laboratory
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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.
- None of the currently applied CO_2 monitoring approaches are able to provide a surveying tool for **dissolved** or **chemically transformed** CO_2.
- The technology, when successfully demonstrated, will provide an improvement over current monitoring practices.

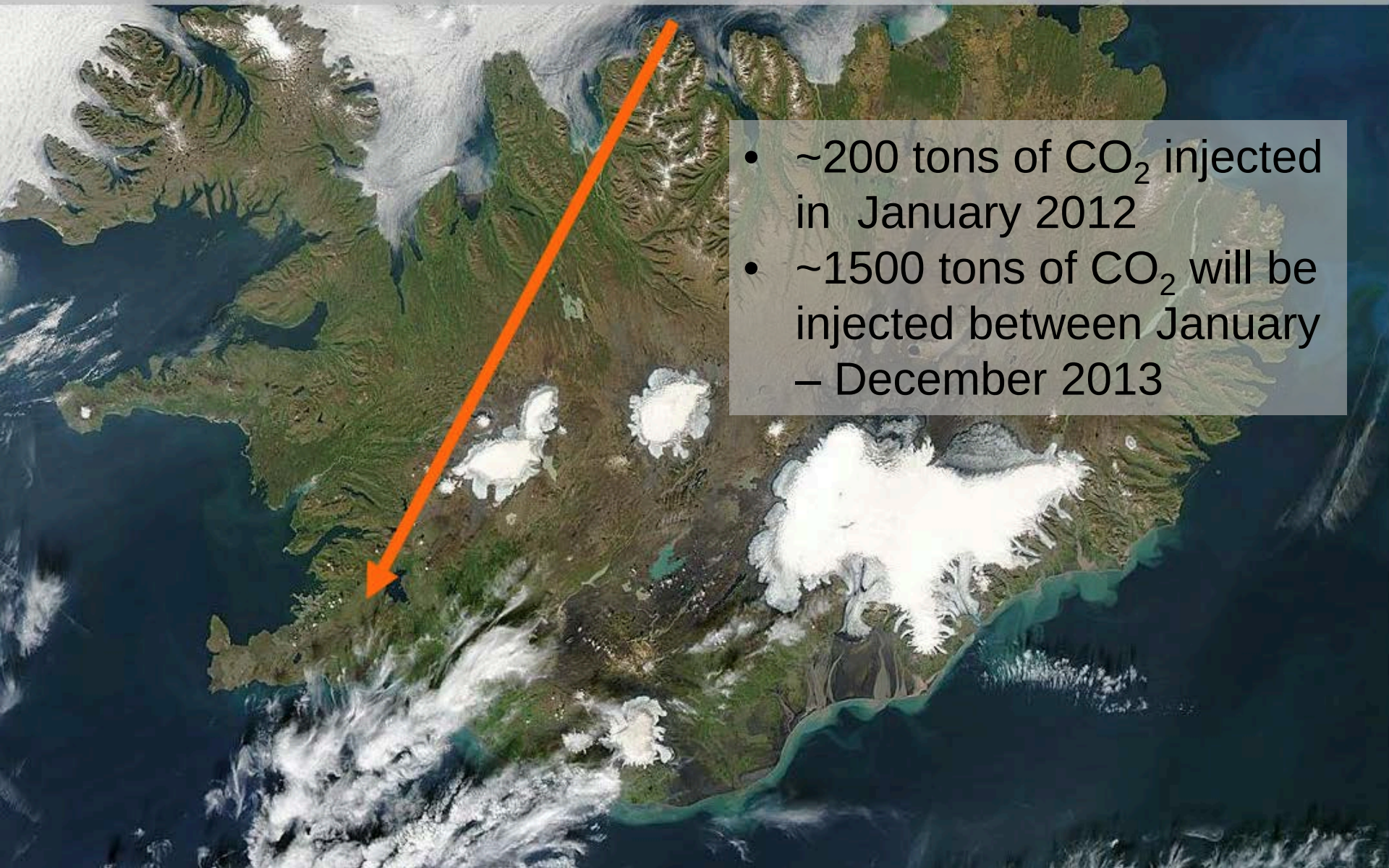
Project Overview:
Goals and Objectives

- Monitor 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.

MINERAL CO_2 SEQUESTRATION INTO BASALT:

THE CARBFIX PROJECT



- ~200 tons of CO_2 injected in January 2012
- ~1500 tons of CO_2 will be injected between January – December 2013

CarbFix Partners

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

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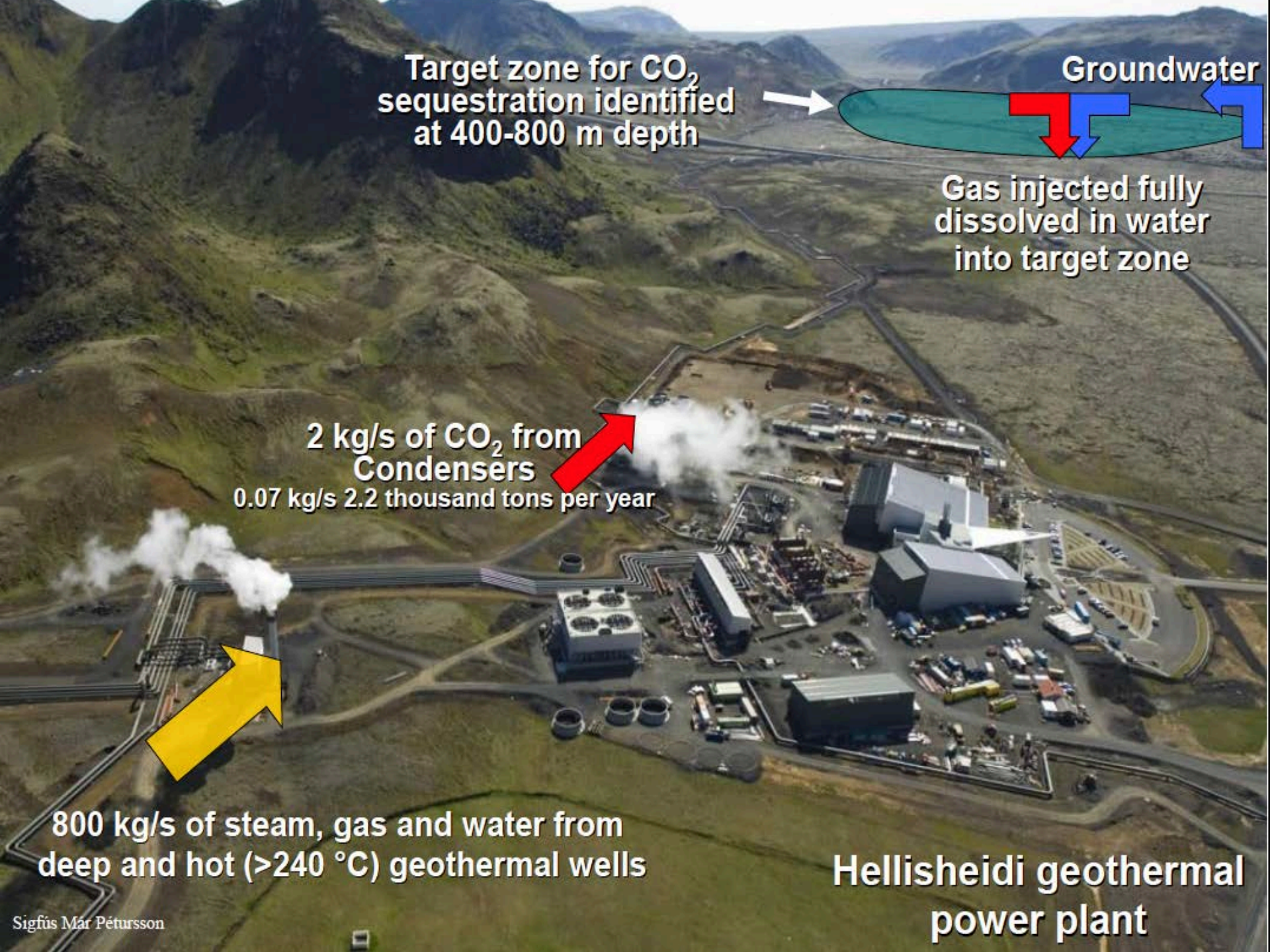
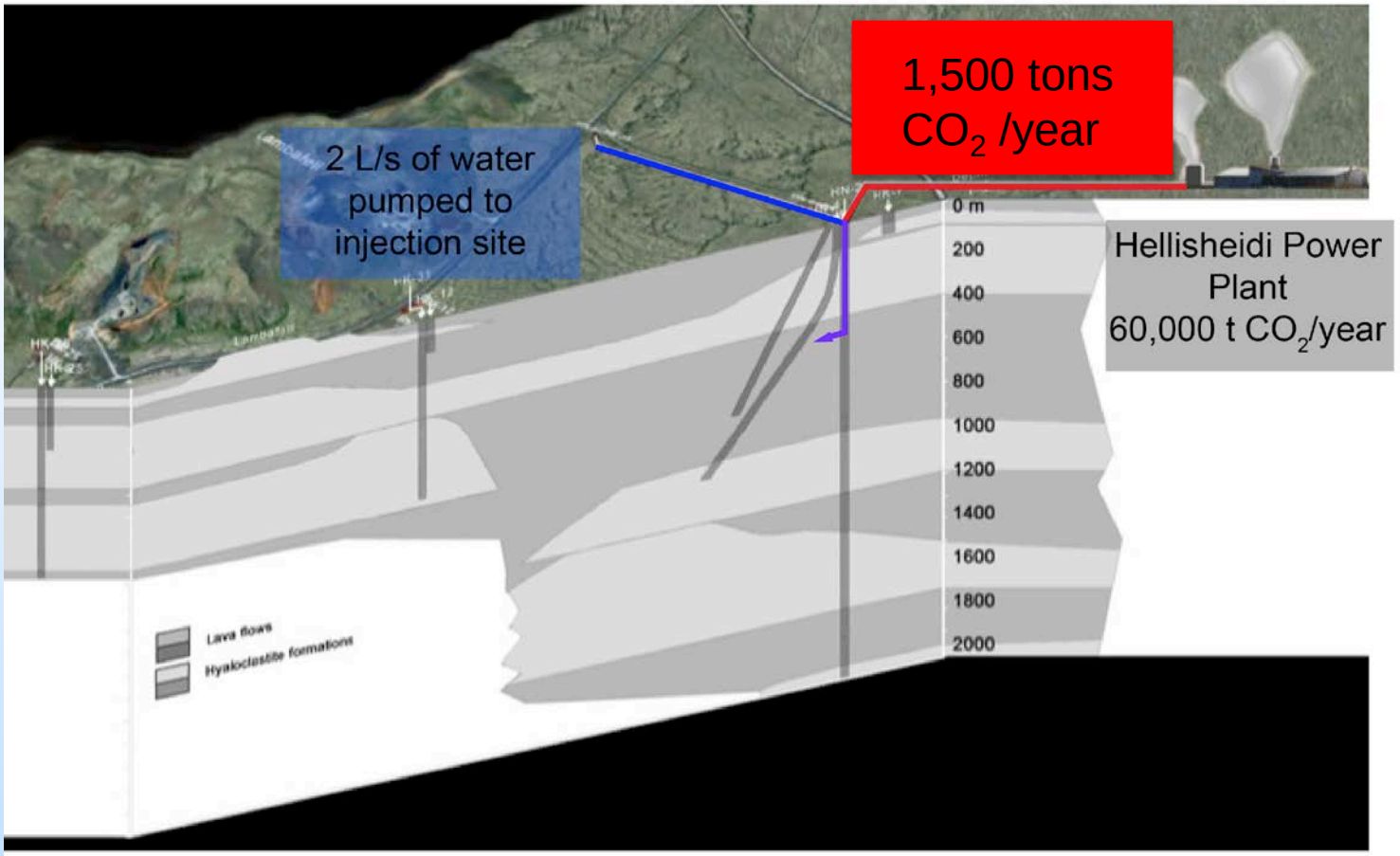

Target zone for CO_2 sequestration identified at 400-800 m depth
Groundwater
Gas injected fully dissolved in water into target zone
2 kg/s of CO_2 from Condensers
0.07 kg/s 2.2 thousand tons per year
800 kg/s of steam, gas and water from deep and hot (>240 °C) geothermal wells
Hellisheidi geothermal power plant
Sigfús Már Pétursson

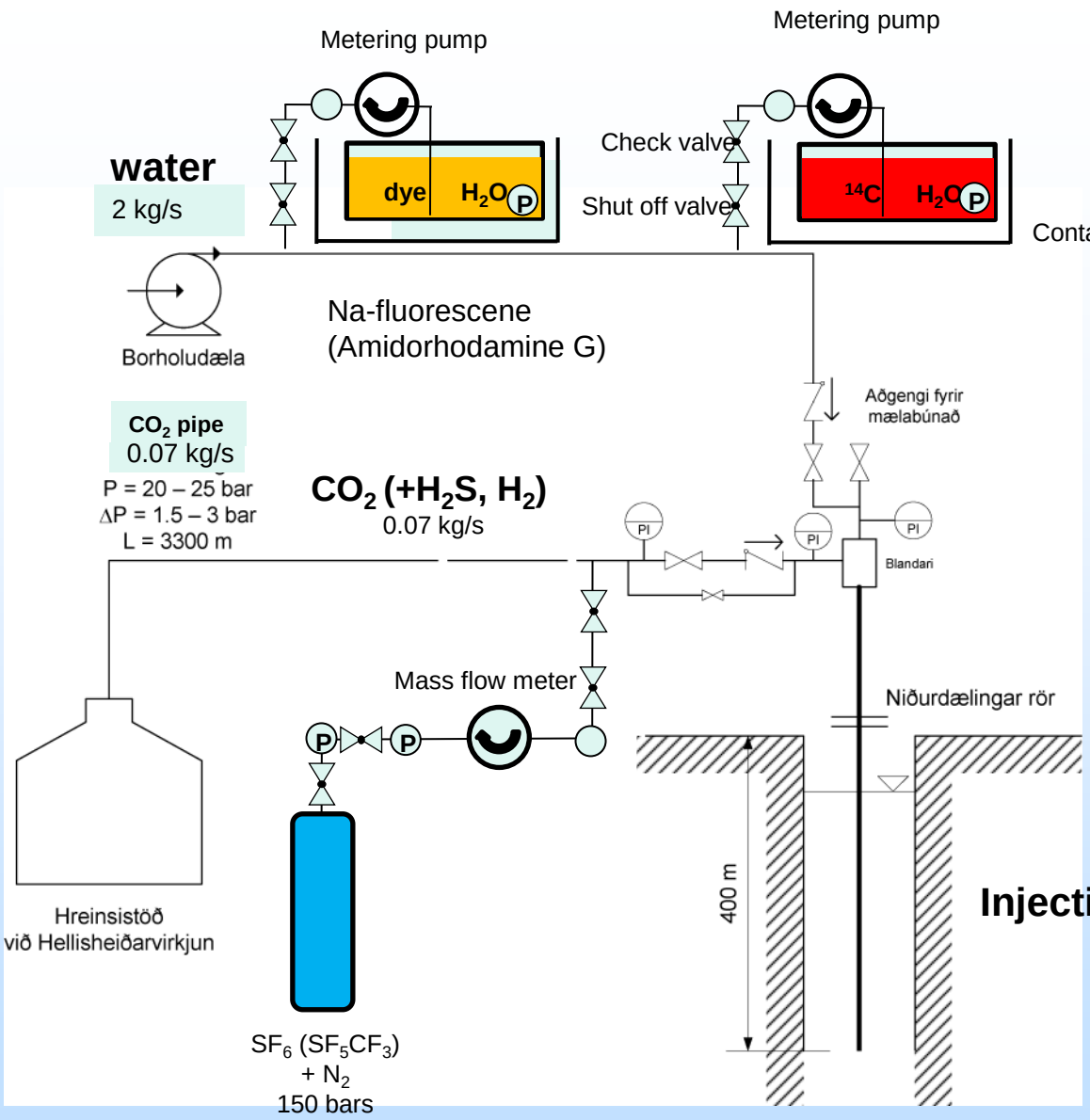
Injection Process



distance between injection and first monitoring well is 150 m

Alfredsson et al. (2012)

Tracer injection system



Injection Phases

Phase I

pure CO_2 injection of ~200 tons

(January – February 2012)

SF_6 & ^{14}C tracers

Phase II

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

~1500 tons of CO_2

(2013)

SF_5CF_3, AmidRhod G & ^{14}C

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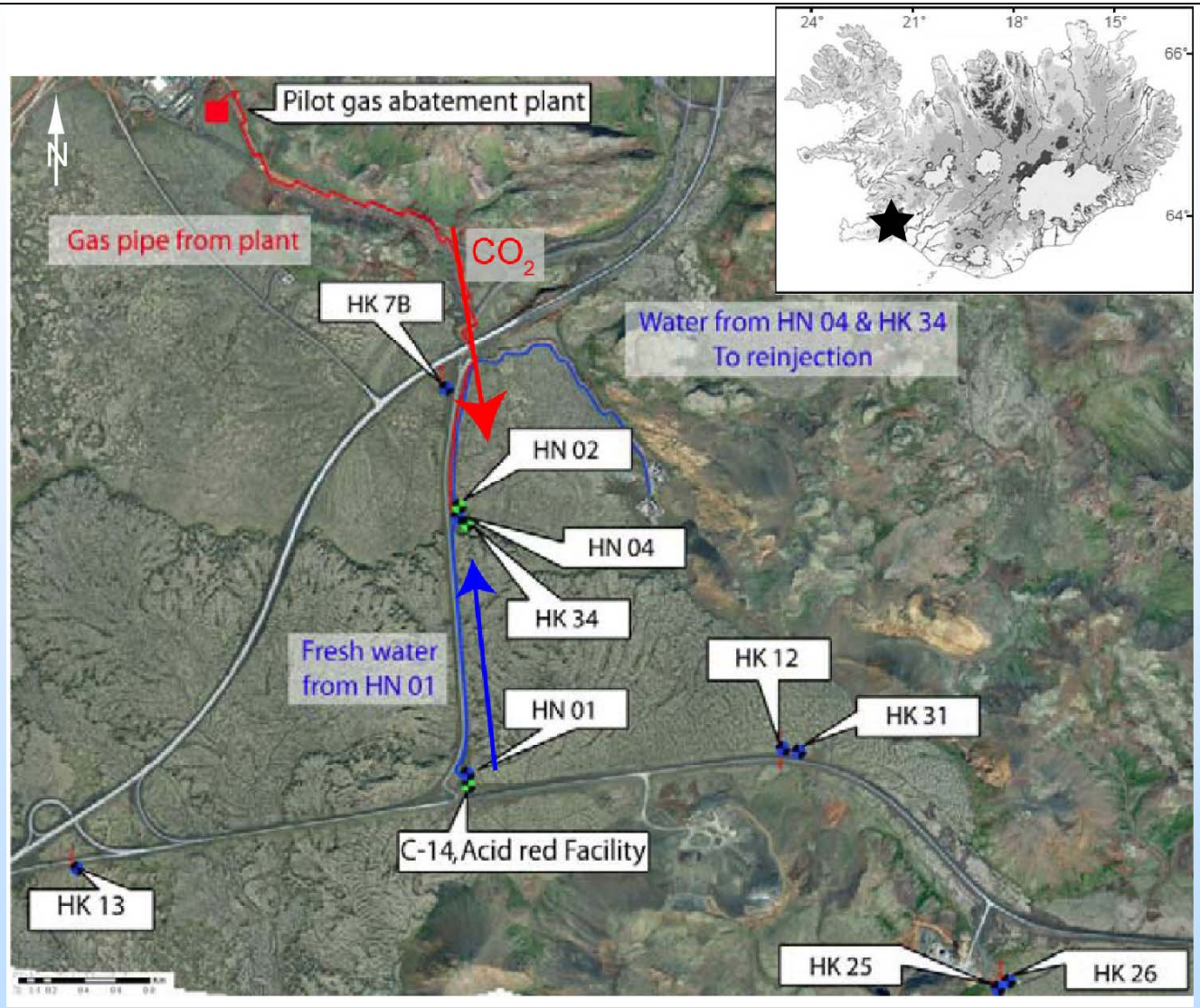
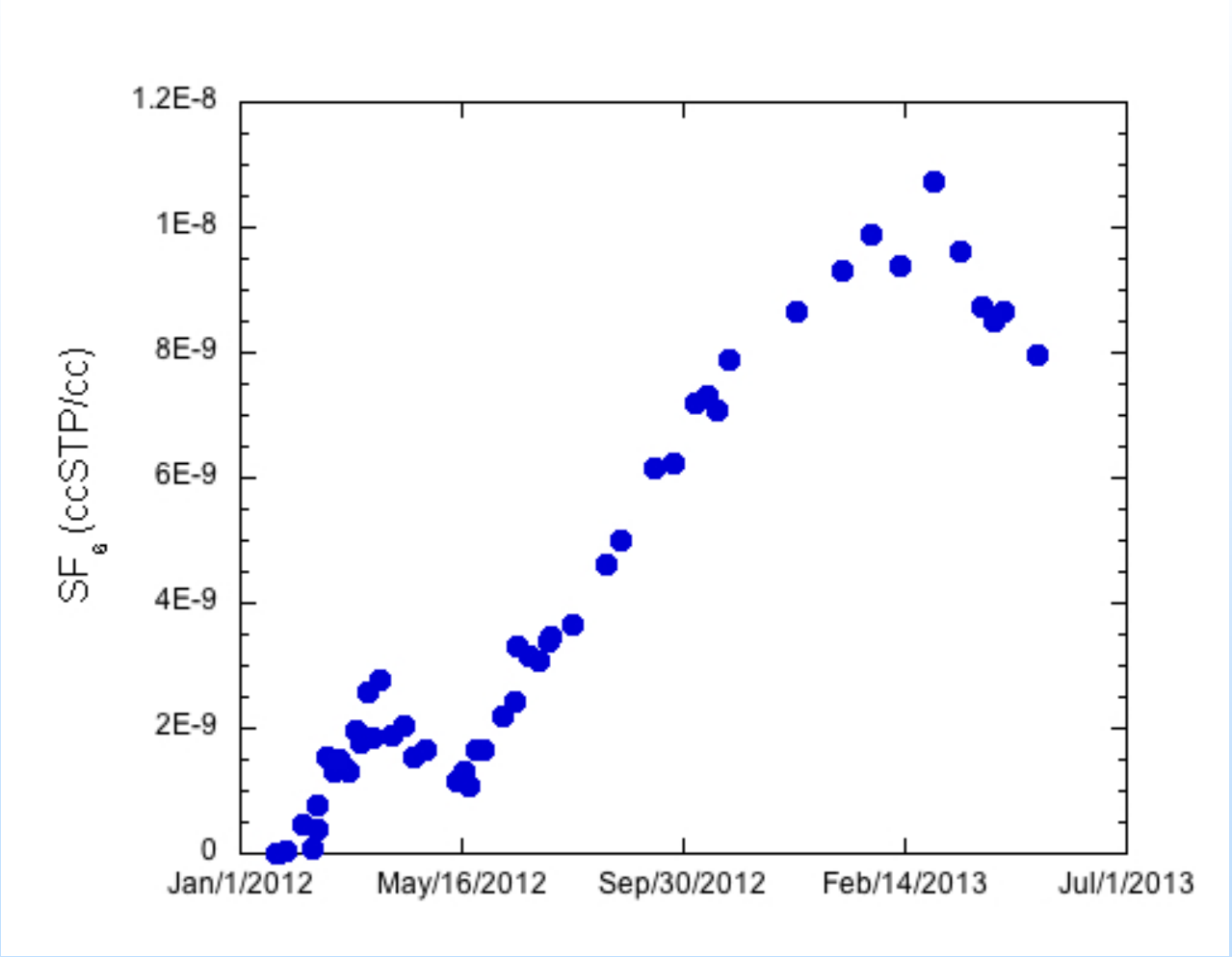
Monitoring Wells



Phase I: SF_6 Monitoring Results

- Goal: Monitor advective and dispersive transport of injected solution



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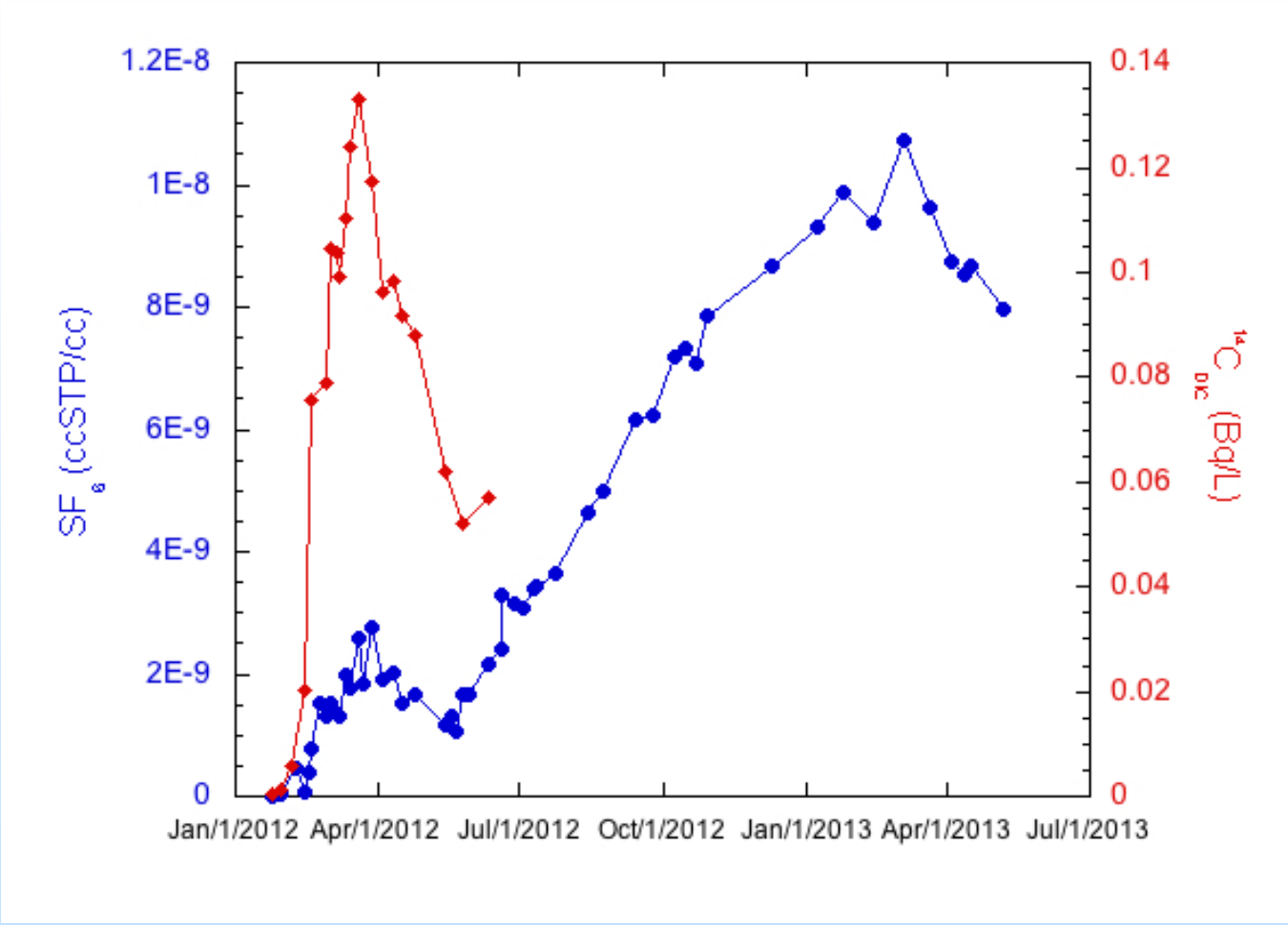
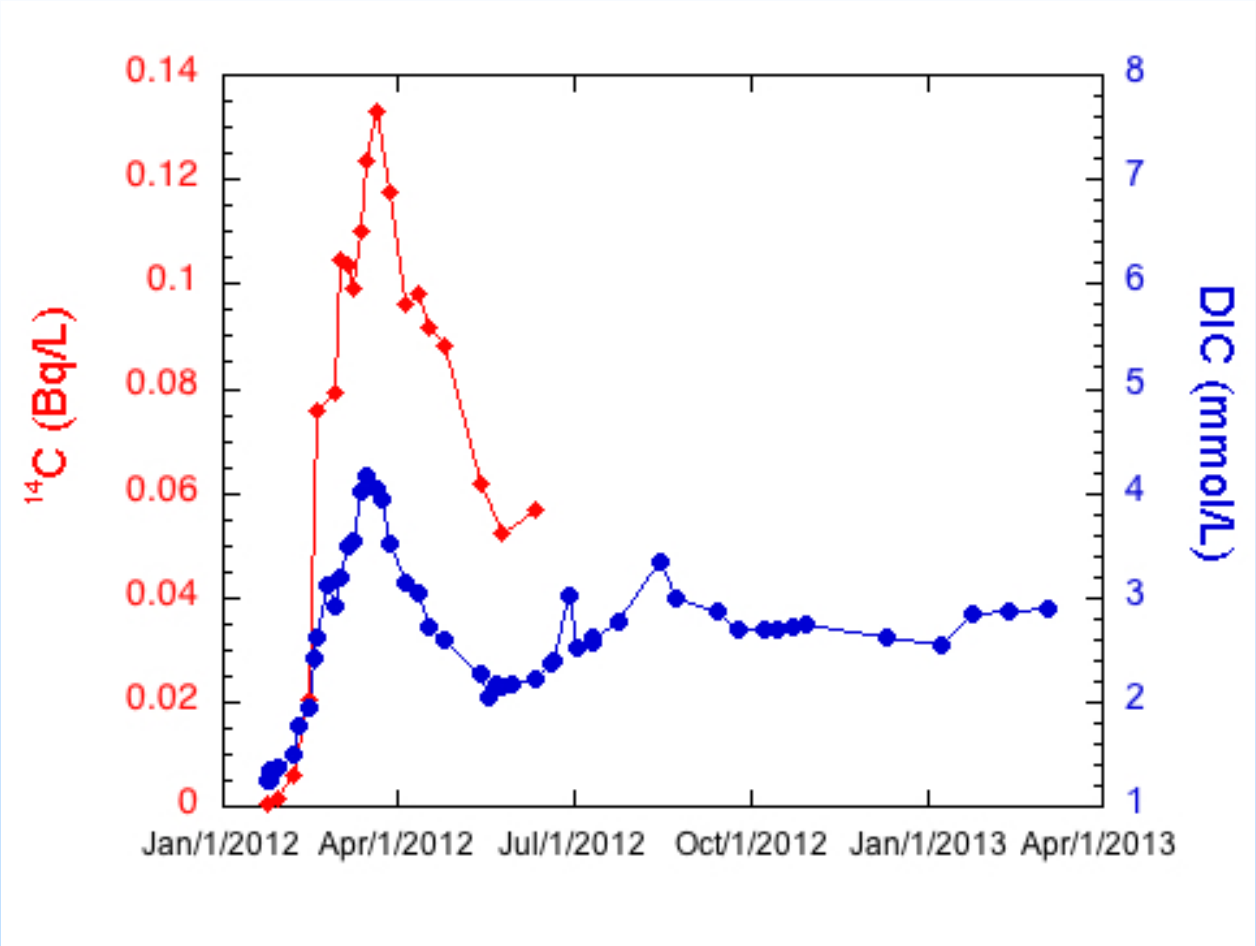
Phase I: ^{14}C Monitoring



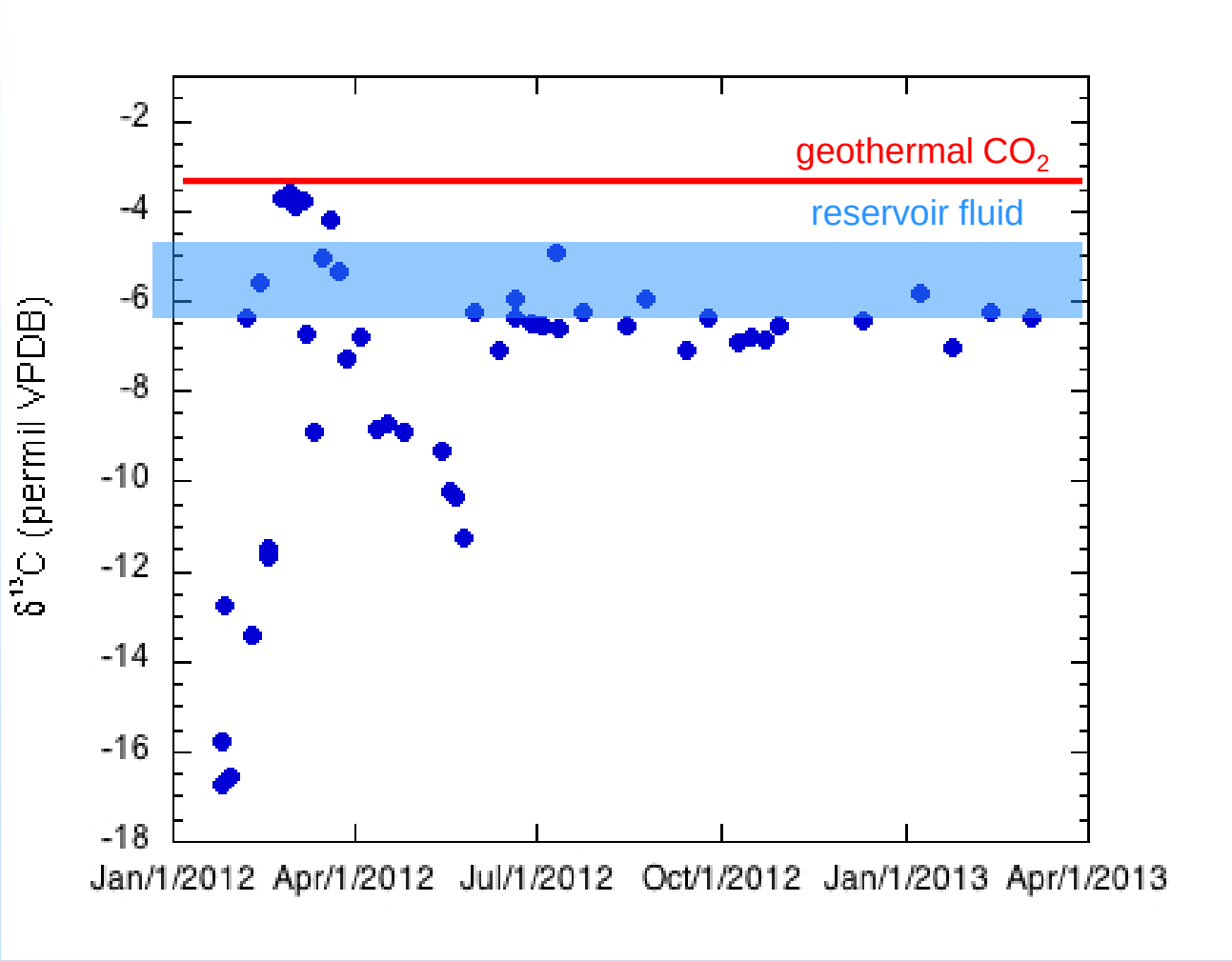
Phase I: ^{14}C Monitoring

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

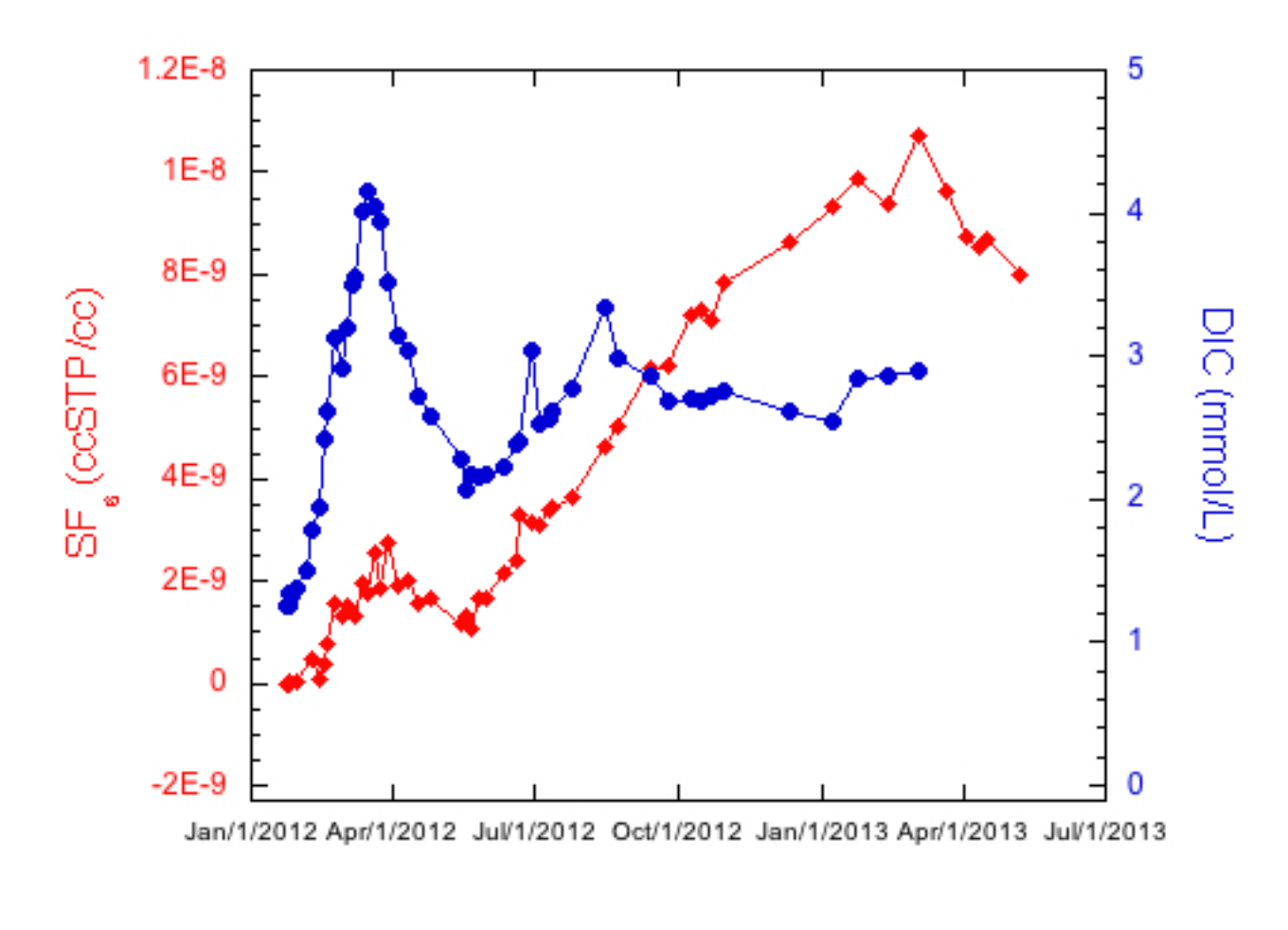


Phase I: $\delta^{13}C_{DIC}$ Monitoring Results

- Goal: Monitor CO_2-fluid-rock reactions



Phase I: CO_2 Reactivity



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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

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

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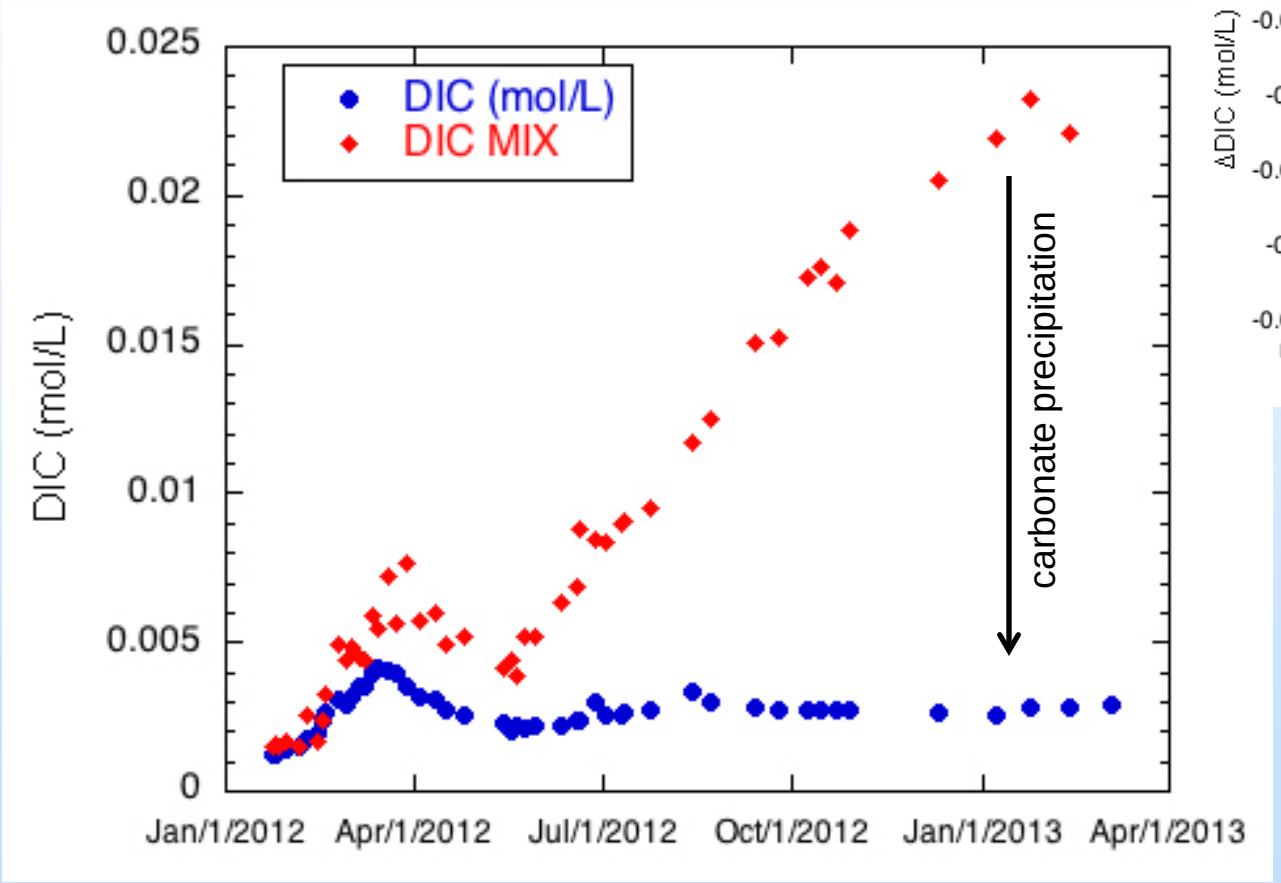
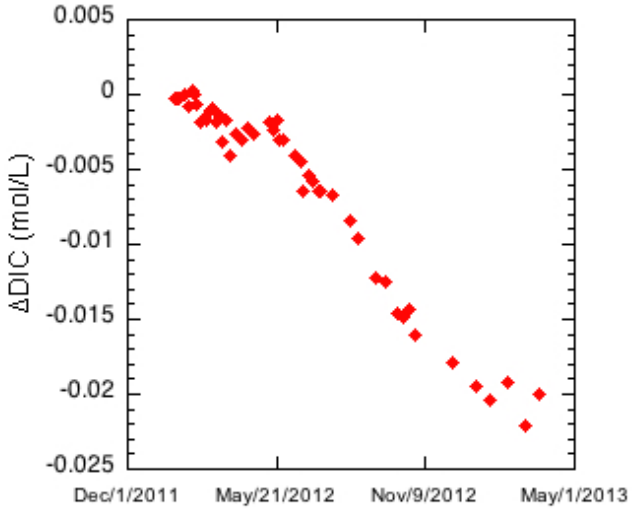
Carbon Mass Balance





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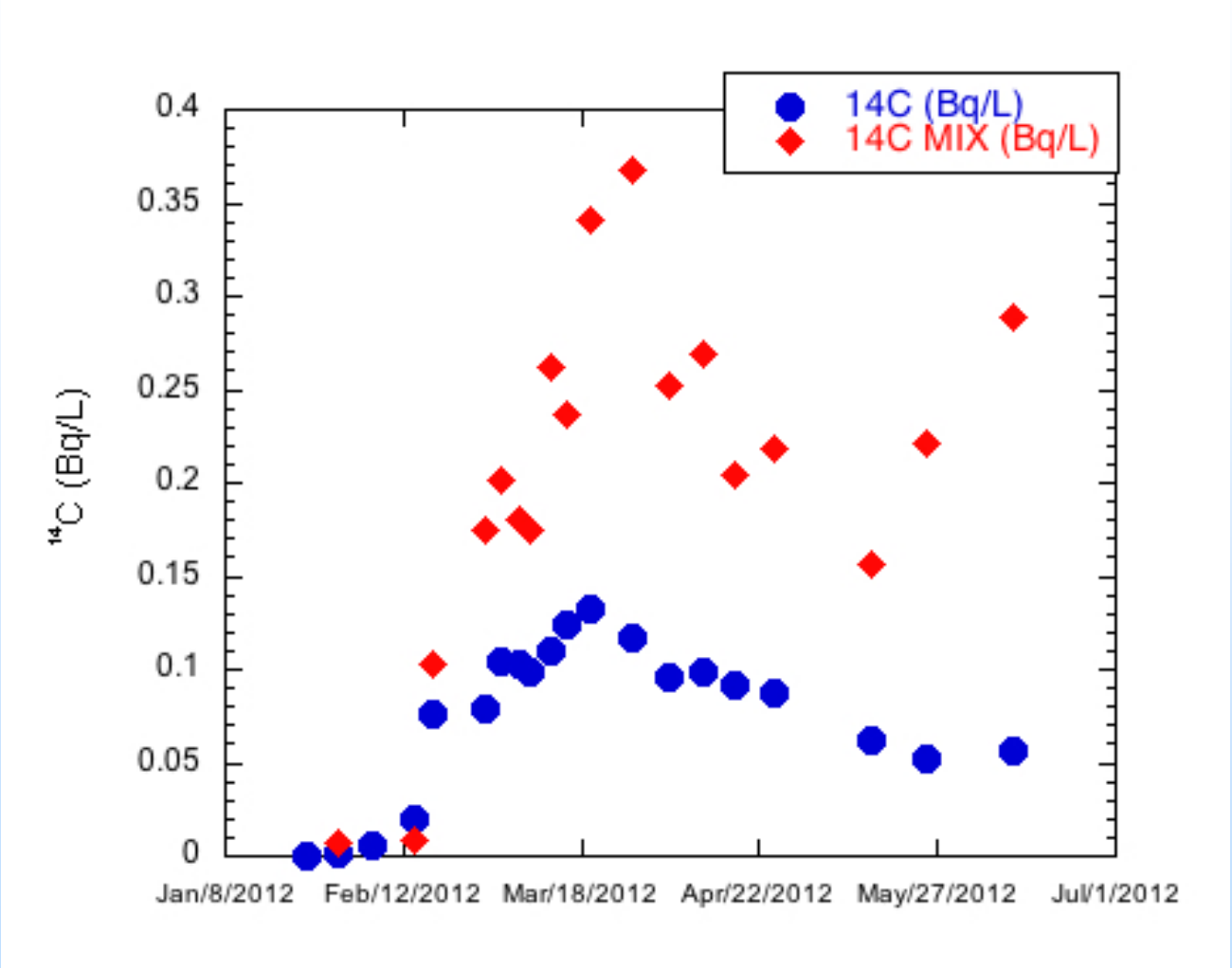
^{14}C Mass Balance



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Accomplishments to Date

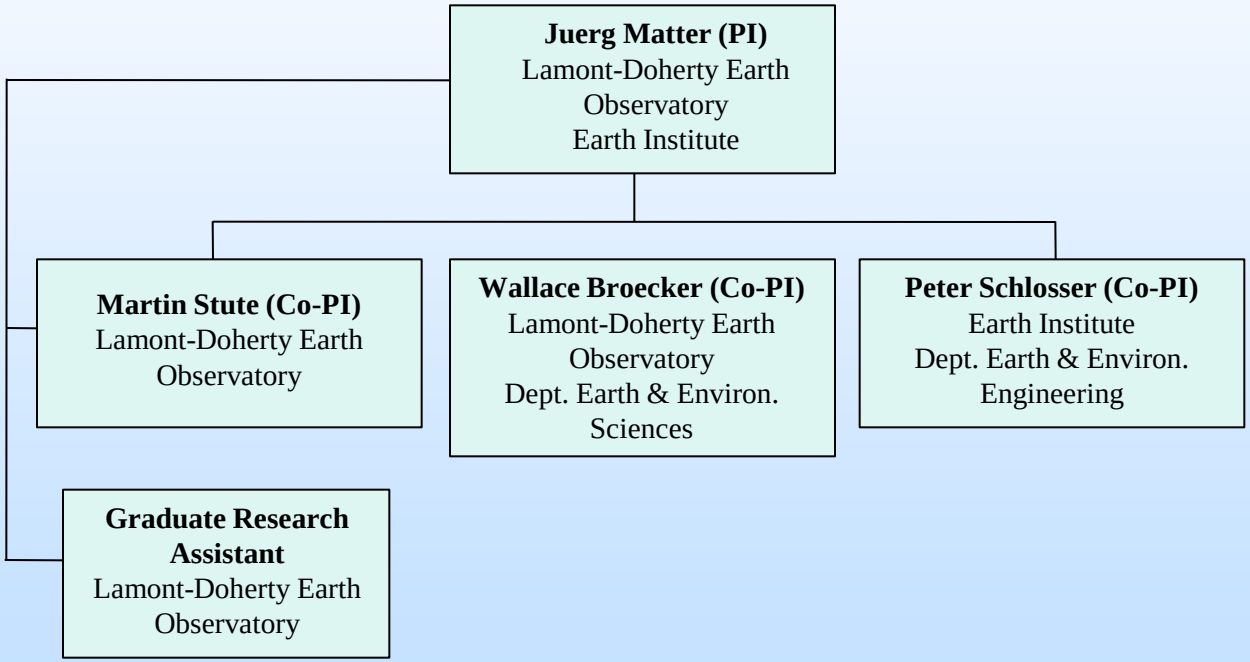
- Pure CO_2 injection (Phase I) was successfully completed.
- The mixed gas CO_2+H_2S injection (Phase II) is currently being performed.
- Continuous collection of fluid and gas samples for chemical and tracer analyses is being conducted in injection and monitoring wells for Phase I and Phase II injection.
- Initial and major breakthrough of CO_2 from Phase I in the first monitoring well occurred in April 2012 and February 2013, respectively.
- Initial breakthrough of injected CO_2 from Phase II occurred in August 2012.

Summary

- Preliminary analysis of the tracer data from the Phase I injection indicates CO_2 mineralization via CO_2-fluid-basalt reactions.
- Mass balance calculation reveals that over 85% of the injected CO_2 from Phase I has been mineralized.
- The developed and applied tracer techniques of non-reactive (SF_6, SF_5CF_3) and reactive tracers (^{14}C) allows for quantitative monitoring and verification of CO_2-fluid-rock reactions.
- 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			
	Qt 1	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 reservoir																**P**	