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

DE-FE0004847

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National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage

August 21-23, 2012

Presentation Outline

- Benefit to the Program
- Project Overview
- Technical Status
- Conservative and Reactive Tracer Techniques
- 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.

- This research project is 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. This technology contributes to the Carbon Storage Program's effort of ensuring 99% CO_2 storage permanence in the injection zone.

Project Overview:
Goals and Objectives

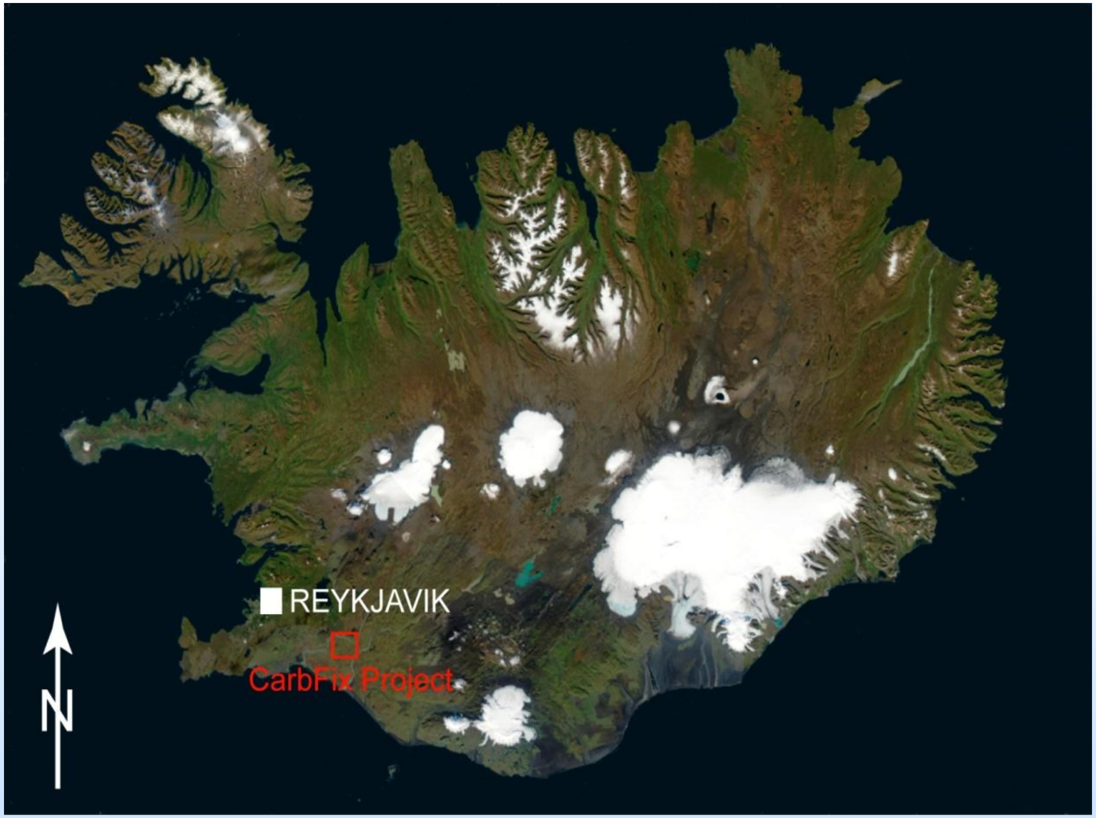
- Testing carbon-14 (^{14}C) as a reactive tracer for geochemical reactions (including mineral carbonation) caused by CO_2 injection at the CarbFix pilot injection site, Iceland.
- Monitor subsurface CO_2 transport with trifluormethylsulphur pentafluoride (SF_5CF_3) and sulfurhexafluoride (SF_6).
- Drilling 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.

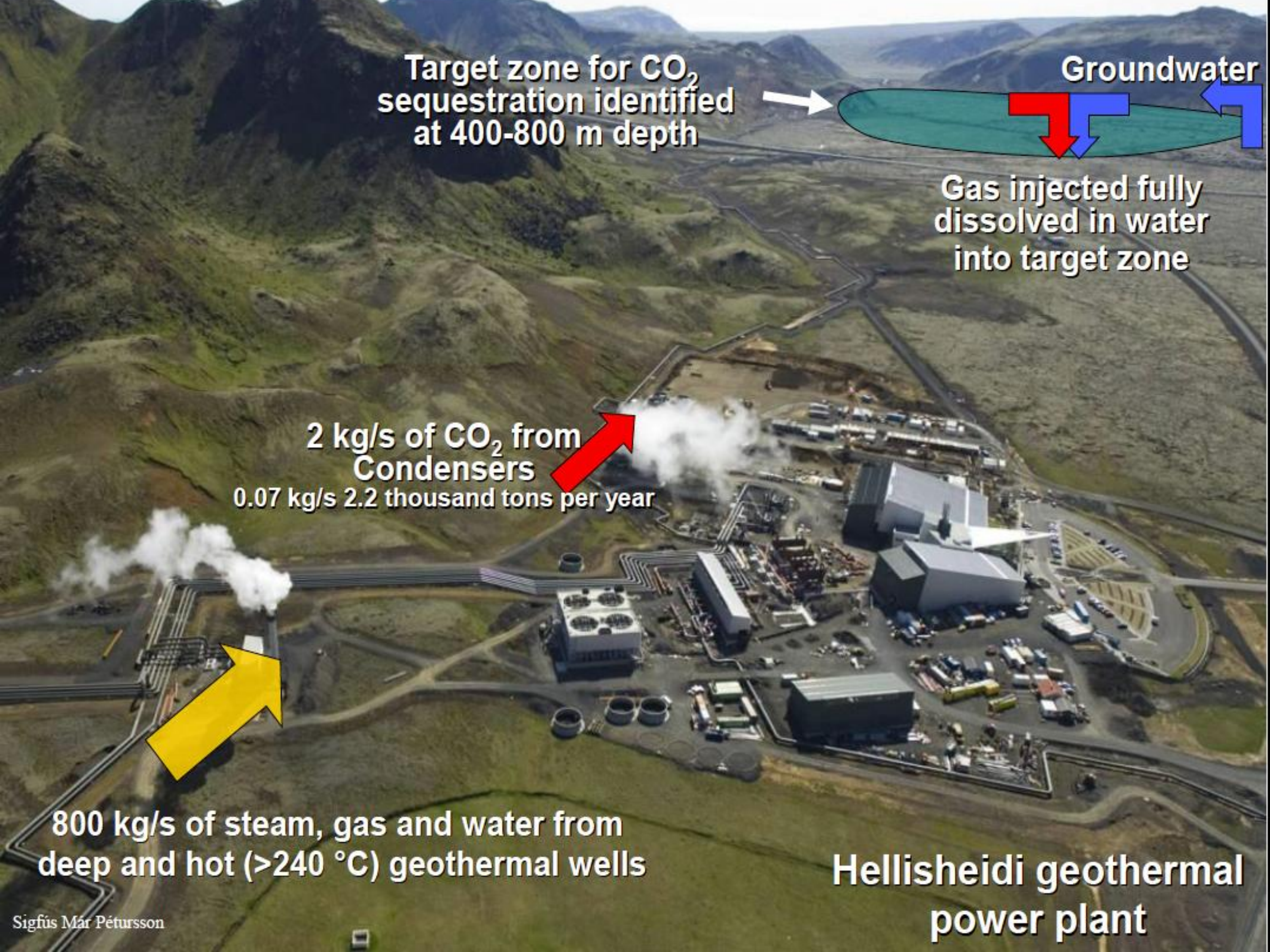
Project Overview: Success criteria

- Complete collection and analysis of fluid and gas samples for ^{14}C and $\delta^{13}C_{DIC}$ analysis under reservoir conditions in the injection and monitoring wells.
- Complete collection and analysis of fluid and gas samples for SF_5CF_3 and SF_6 analysis under reservoir conditions in the injection and monitoring wells.
- Complete set of breakthrough curves established for monitoring wells.
- Successful drilling of small diameter wells and core recovery at injection reservoir depth with wireline coring.
- Complete quantitative characterization of CO_2-rock reactions caused by CO_2 injection. Determination of in situ mineralization rates.

Technical Status – CarbFix Project



- In situ CO_2 mineralization in basaltic rocks
- Advanced monitoring, verification and accounting of stored CO_2


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

CarbFix Partners

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

Injection Phases

Phase I

pure CO_2 injection of ~200 tons

(January 2012- March 2012)

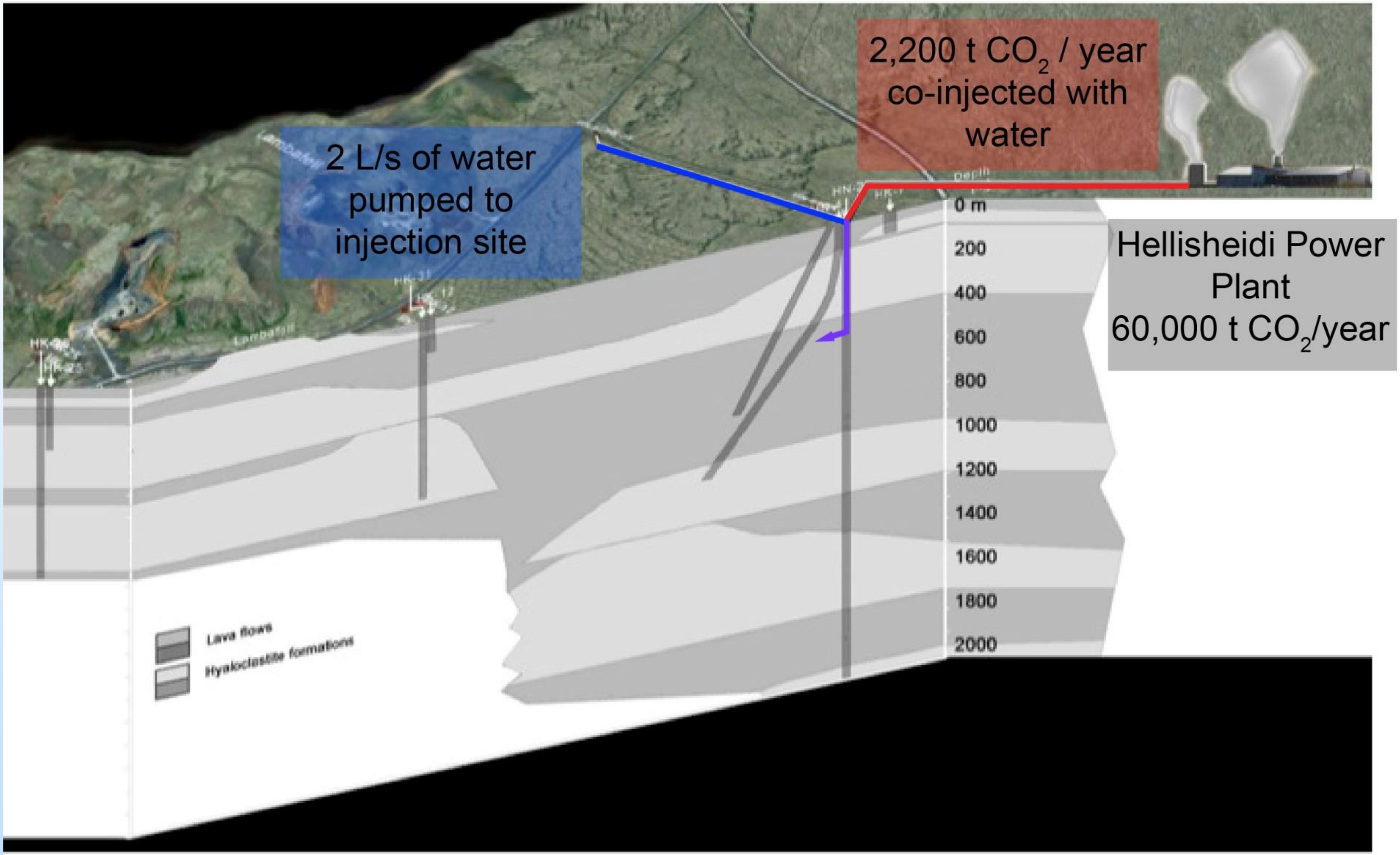
Phase II

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

1800 tons of CO_2,

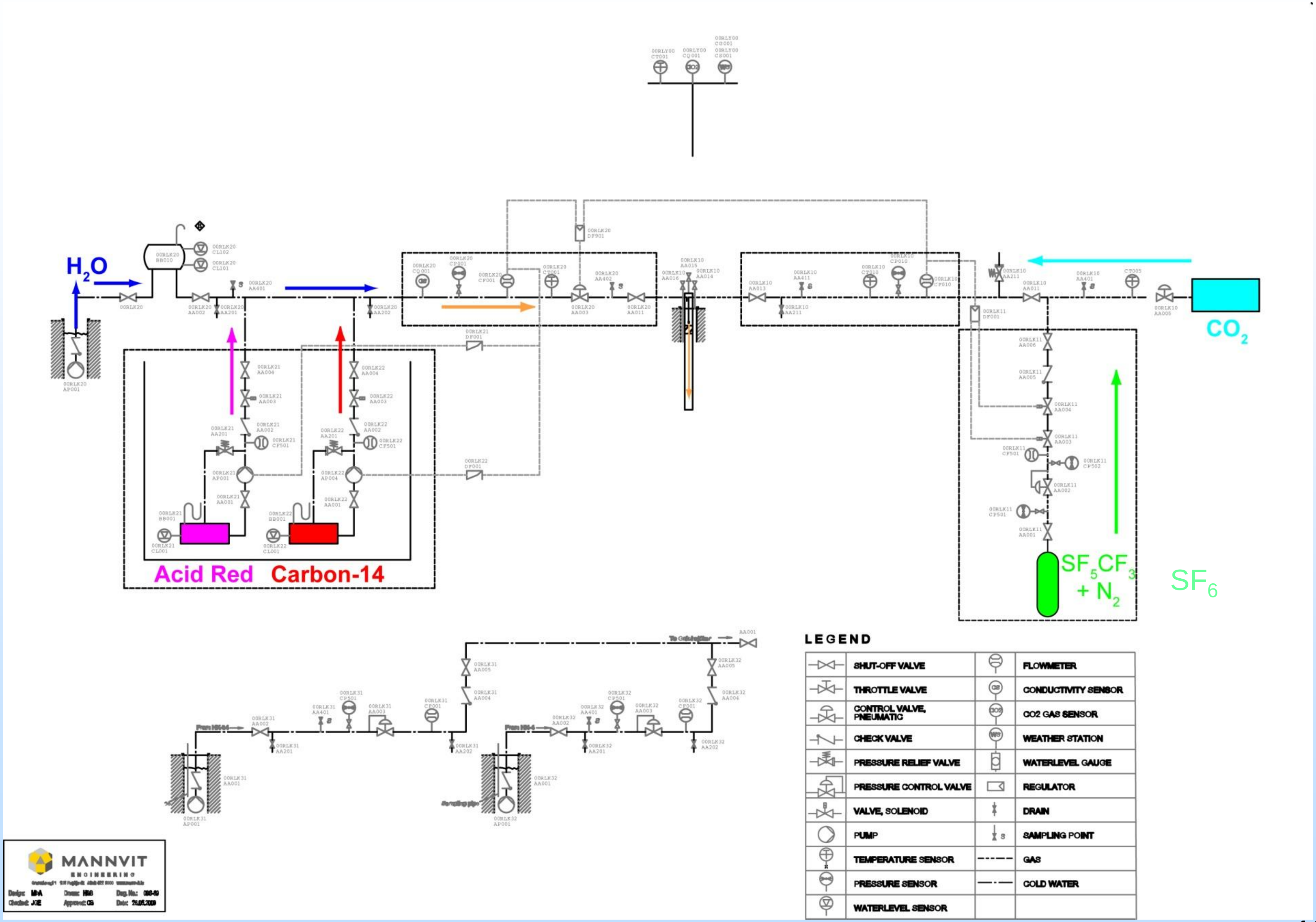
(June 2012 – ?)

Injection Process

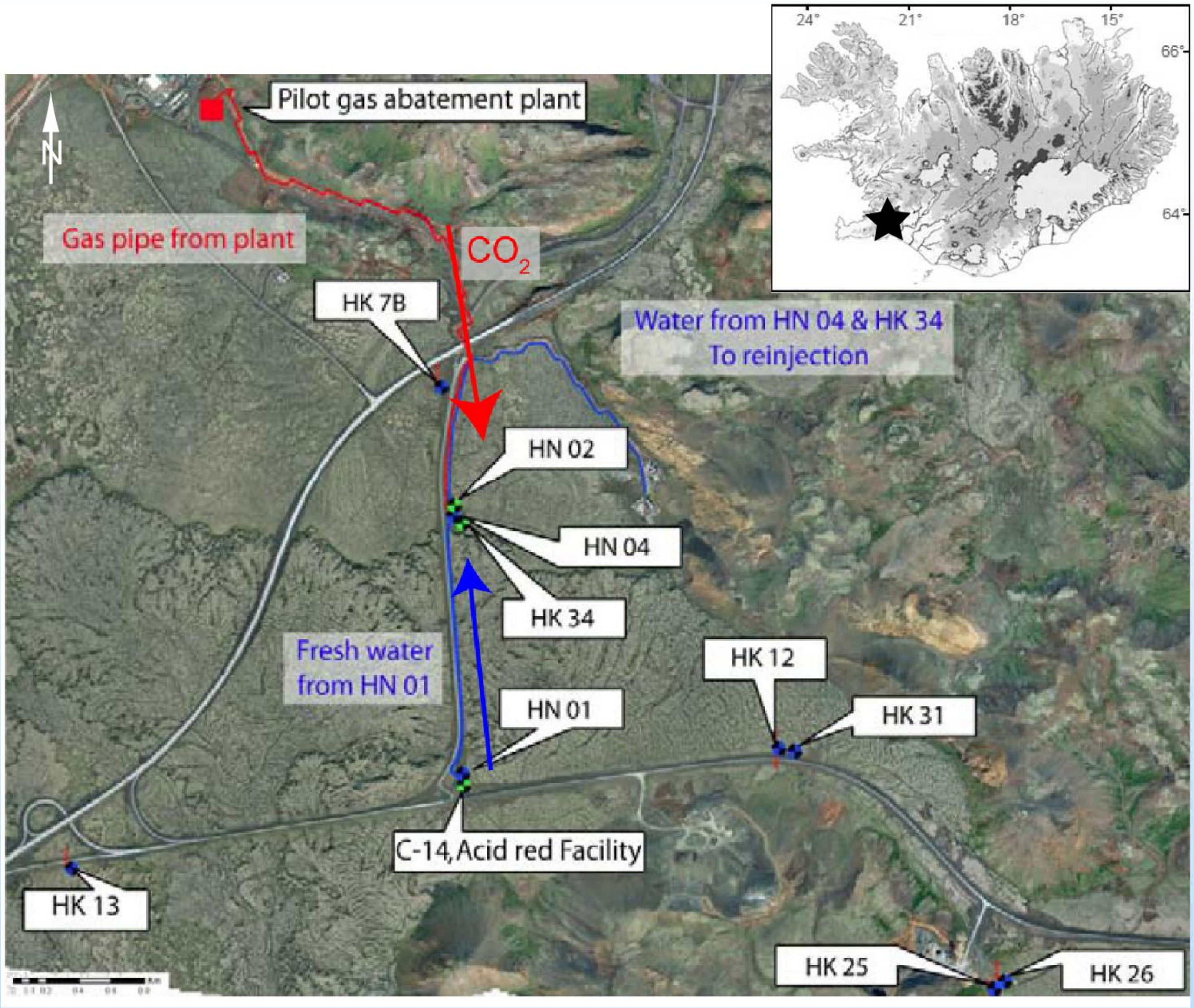


Alfredsson et al. (2012)

Monitoring/Verification Approach



Monitoring/Verification Infrastructure

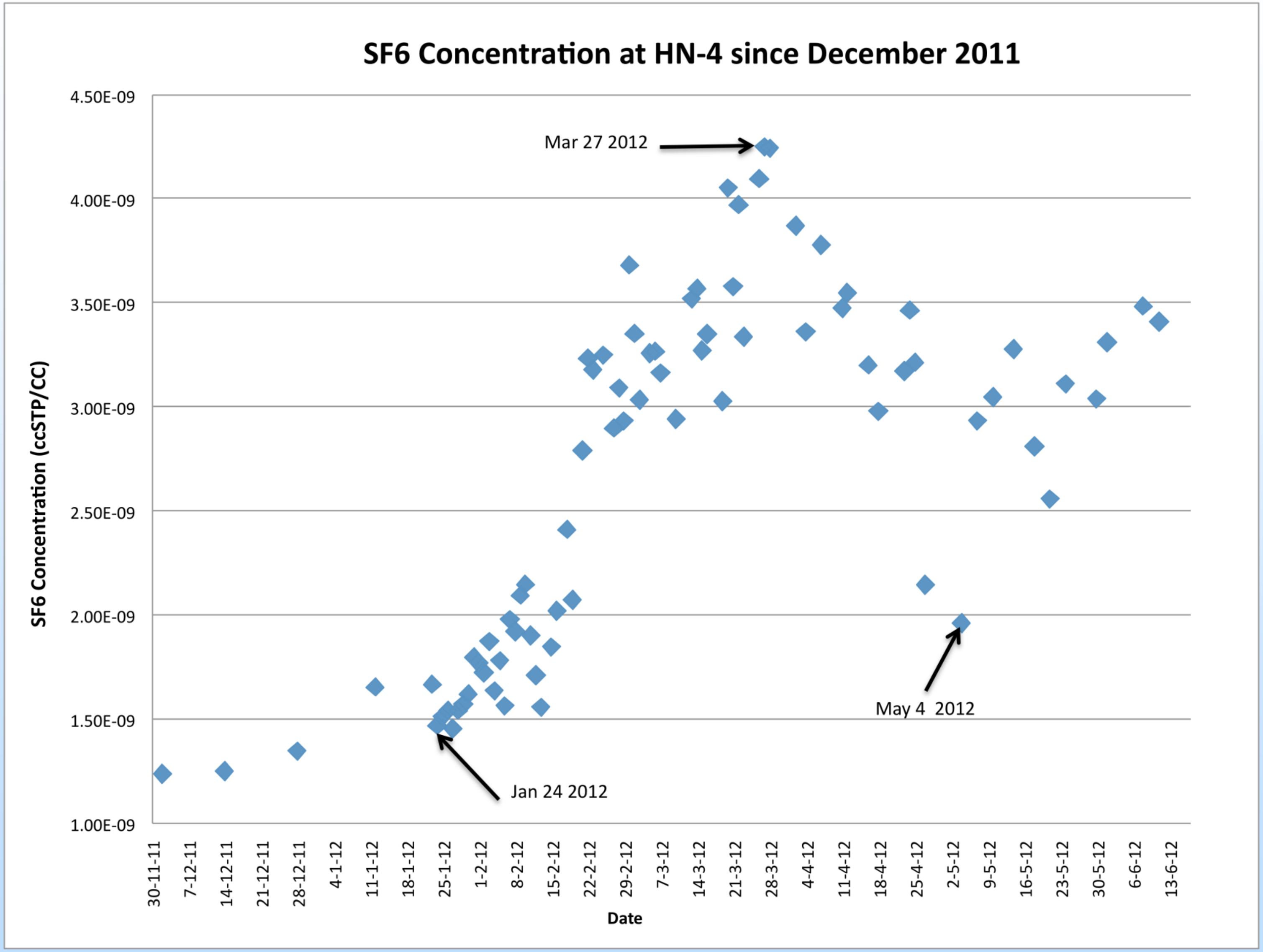


SF_6 Monitoring Results

- Goal: Monitor advective and dispersive transport of injected solution

- Labeling injected CO_2 with SF_6 in Phase I
- Breakthrough curve at HN4 initial peak after 63 days
- Decrease in concentration for a further 38 days
- Continue to monitor SF_6 throughout and beyond Phase II
- No SF_6 at HK-34 or other wells
- Sample analysis with gas chromatography

SF_6 Monitoring Results cont.



Carbon-14 Monitoring

- Goal: distinguish stored CO_2 from natural CO_2 sources

- Labeling injected CO_2 with carbon isotopic tracer:

$$^{12}CO_2 \rightarrow {}^{14}CO_2$$

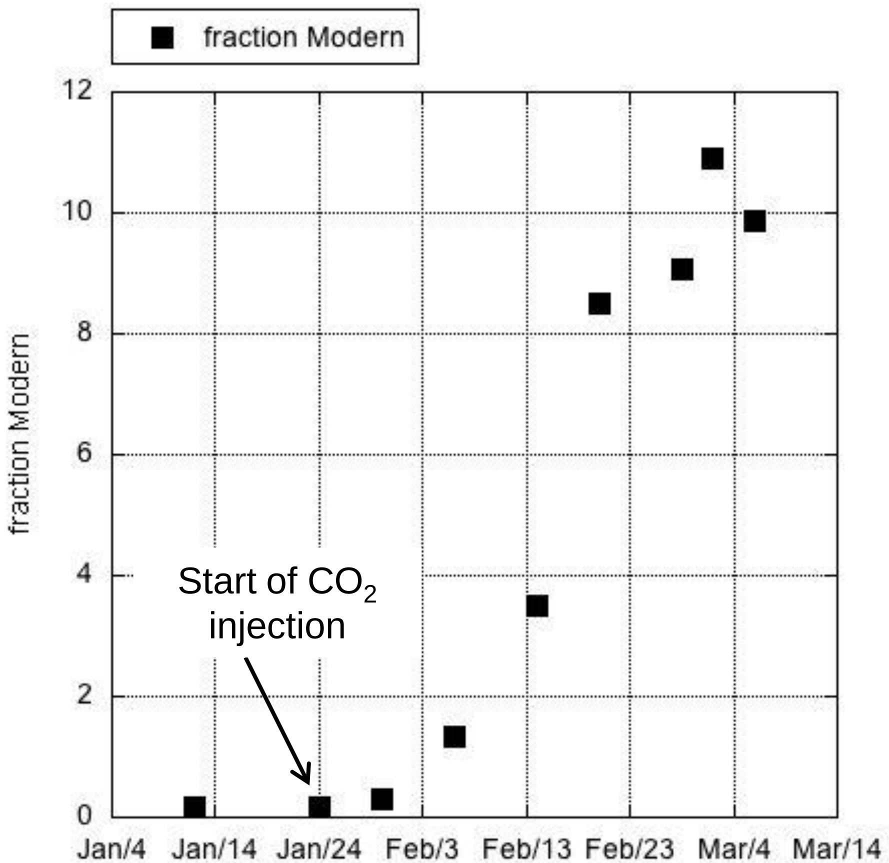
- $NaH^{14}CO_3$ stock solution for labeling with an ^{14}C activity of 20 mCi (7.4×10^8 Bq) for 12 months injection

- ^{14}C activity in injected CO_2 saturated solution is 320 PicoCi/L (12 Bq/L)

- Sample analysis with accelerator mass spectrometry

Carbon-14 Monitoring

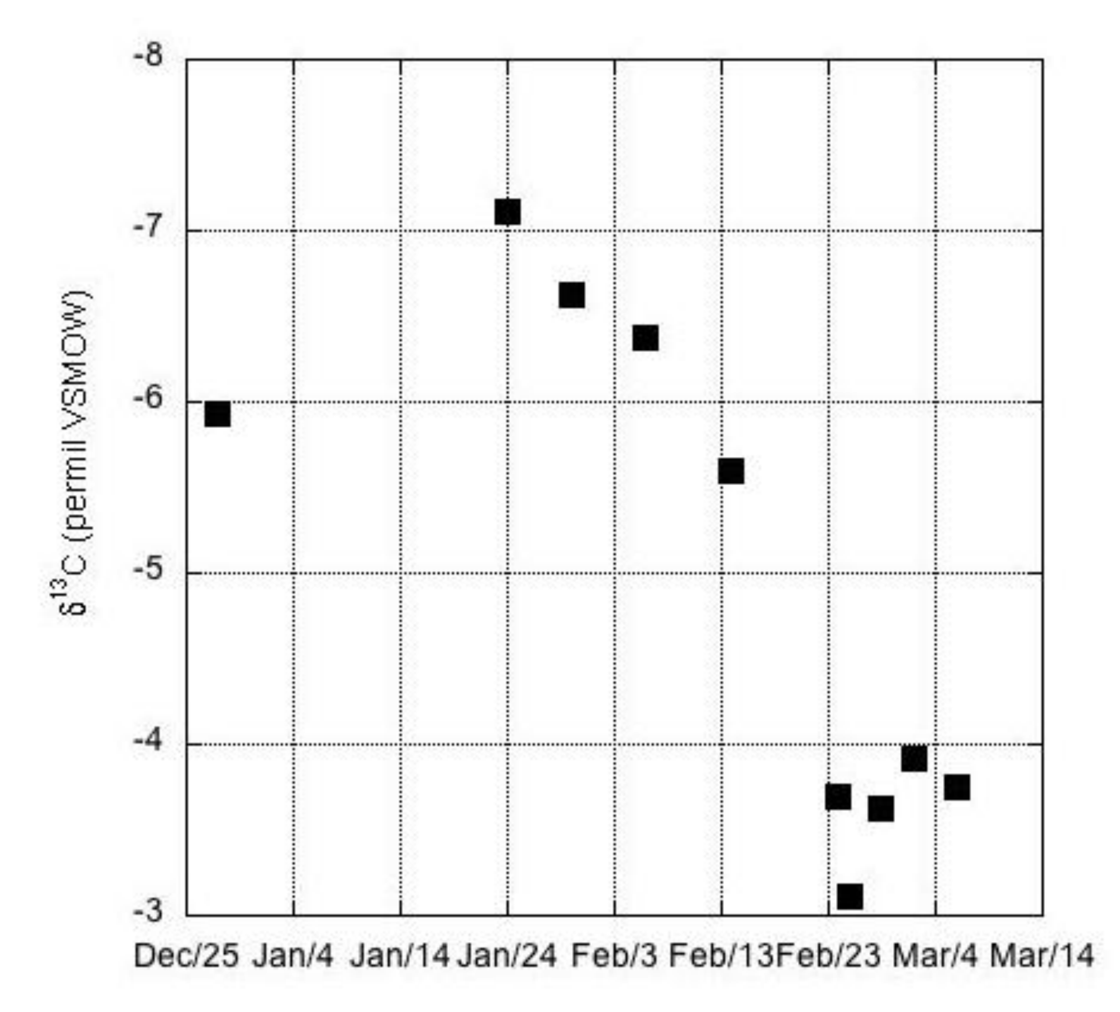
HN4 monitoring well during pure CO_2 injection



- Input concentration of ^{14}C tracer in the injection well was 6 x too high due to a malfunction of the tracer input microprocessor pump.
- ^{14}C in fraction modern in HN4 monitoring well is 2 x too high.
- Tracer microprocessor pump was replaced and successful ^{14}C labeling is ongoing.

$\delta^{13}C$ Monitoring

HN4 monitoring well during pure CO_2 injection



- Trend to less negative $\delta^{13}C$ values indicate CO_2-rock reactions (calcite dissolution)
- We need more geochemical data from the injection and monitoring wells to quantify the degree of these reactions.

Accomplishments to Date

- Tracer injection and monitoring infrastructure including monitoring plan established.
- Pure CO_2 injection completed.
- Continuous sampling in injection and monitoring wells for tracer analysis was initiated.
- First set of gas and fluid samples for SF_6, ^{14}C and $\delta^{13}C$ analysis collected and analyzed.
- CO_2 + H_2S injection was initiated.
- Monitoring the CO_2 + H_2S injection with SF_5CF_3, ^{14}C and $\delta^{13}C$ was initiated.
- The developed technology has the capability to detect and quantify in situ geochemical reactions (see tracer breakthrough curves).

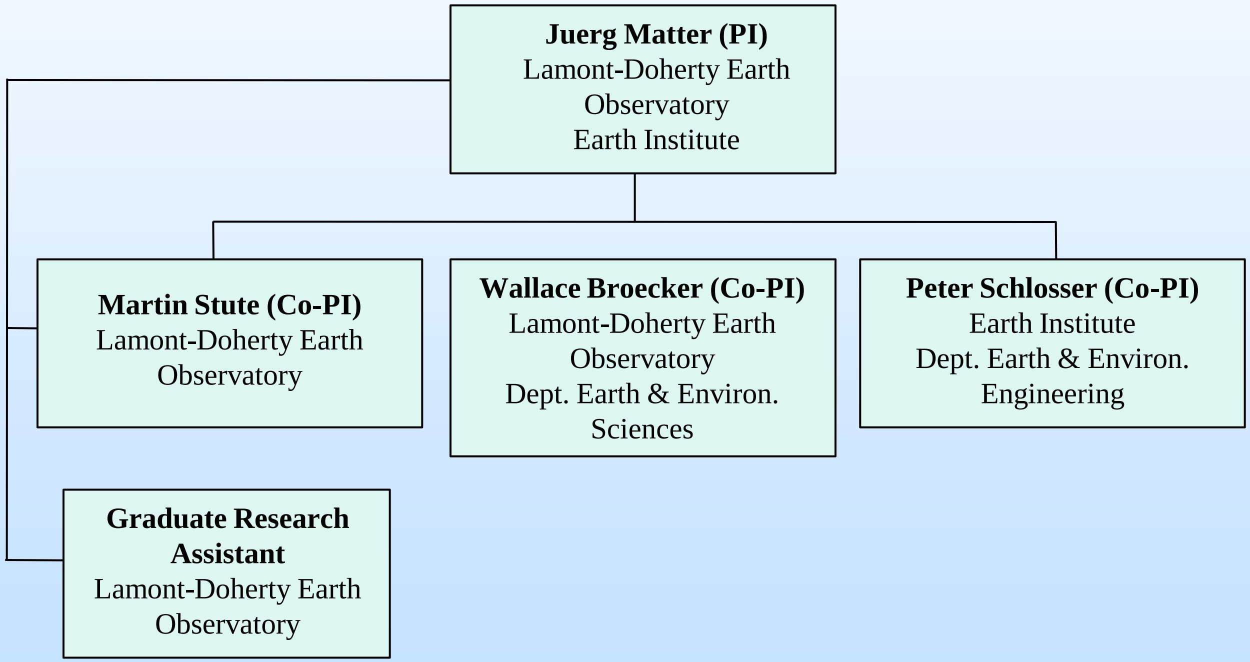
Summary

- Currently injecting gas from the power plant
- Successful and ongoing collection and analysis of tracer samples
- Observed breakthrough curves
- Identified that reactions are occurring

- Next Steps:
  - Continuation of Phase II injection
  - Continuation monitoring through SF_6, $SF_5CF_{3,}$ ^{14}C and $\delta^{13}C$ analysis
  - Plan drilling of well for core samples
  - Quantify CO_2-water-rock reactions

Appendix

Organization Chart



Gantt Chart

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

Major milestones: bold capital letters