Academic studies related to CarbFix and SulFix

Sigurður Reynir Gíslason – Research Professor
University of Iceland – Reykjavík

III GGDP Roundtable, 26 April 2016

CarbFix started in 2007

(1) Institute of Earth Sciences, University of Iceland. (2) CNRS, Université Paul Sabatier, France

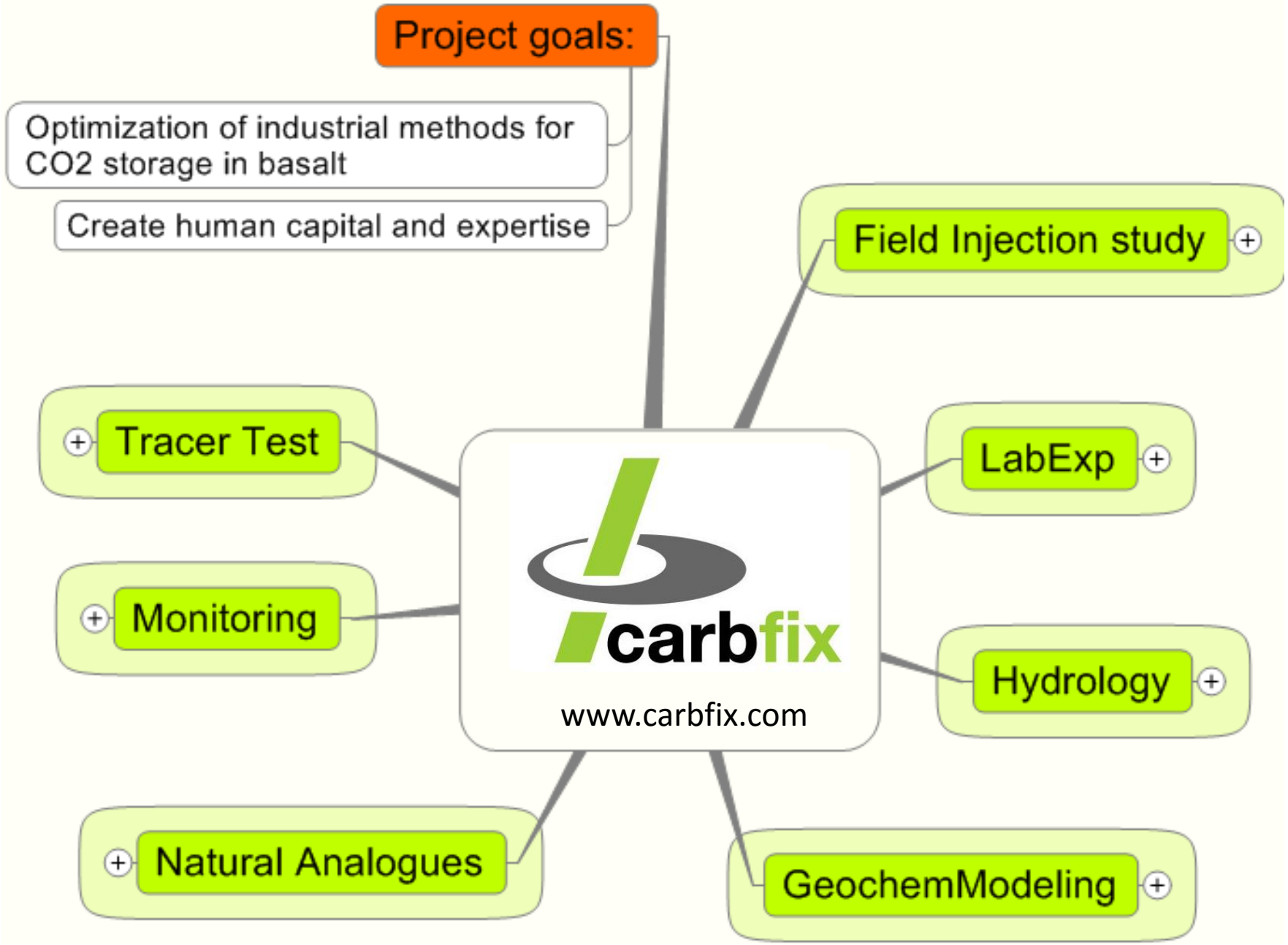
(3)Earth Institute, Columbia University, USA. (4) Reykjavik Energy, Iceland.

(5) ISOR Iceland GeoSurvey, Iceland. (6) Amphos 21 Consulting, Spain. (7) IPGP, Sorbonne Paris Cité, France.

(8) Nano-Science Center, University of Copenhagen, Denmark. (9) University of Durham, UK

Natural Sciences building
University of Iceland

Gislason[1], Oelkers[2], Broecker[3], Gunnlaugsson[4], Snæbjornsdottir[1], Clark[1], Mesfin[1], Alfredsson[1], Aradottir[4], Sigfusson[4], Gunnarsson[4], Stute[3], Matter[3], Hall[3], Ragnheidardottir[4], Sigurdardottir[4], Wolff-Boenisch[1], Stefansson[1],Galeczka[1], Guðbrandsson[1], Stockman[1], Gysi[1], Axelsson[5], Harðardottir[5], Friðriksson[5], Bruno[6], Grandia[6], Ménez[7], Campion[7], Trias[7], Didriksen[8] , Olsson[1,8], Stipp[8] and Burton[9]



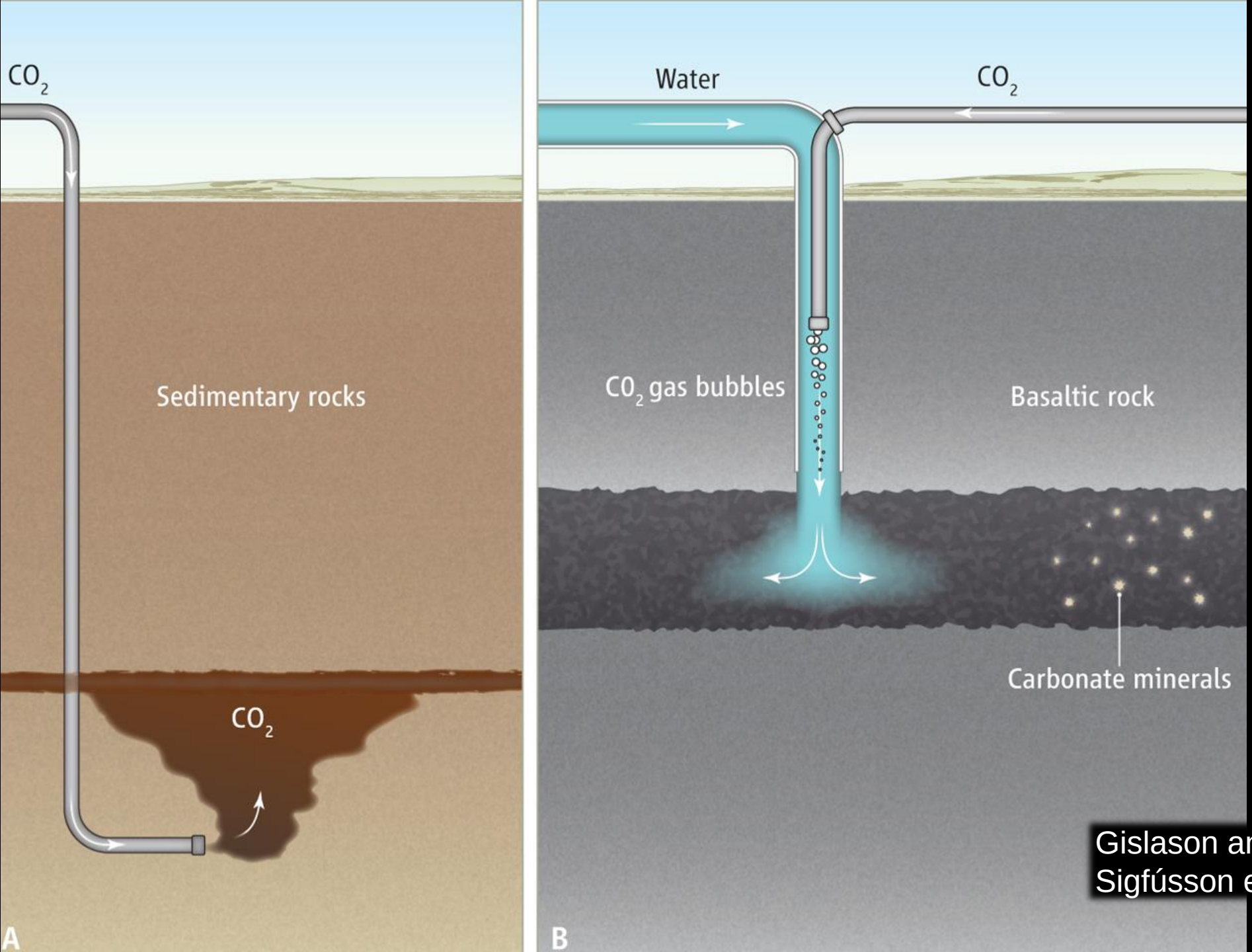
Graduate student projects
2007 – 2016

8 PhD projects finished
3 MSc projects defended
2 PhD projects ongoing

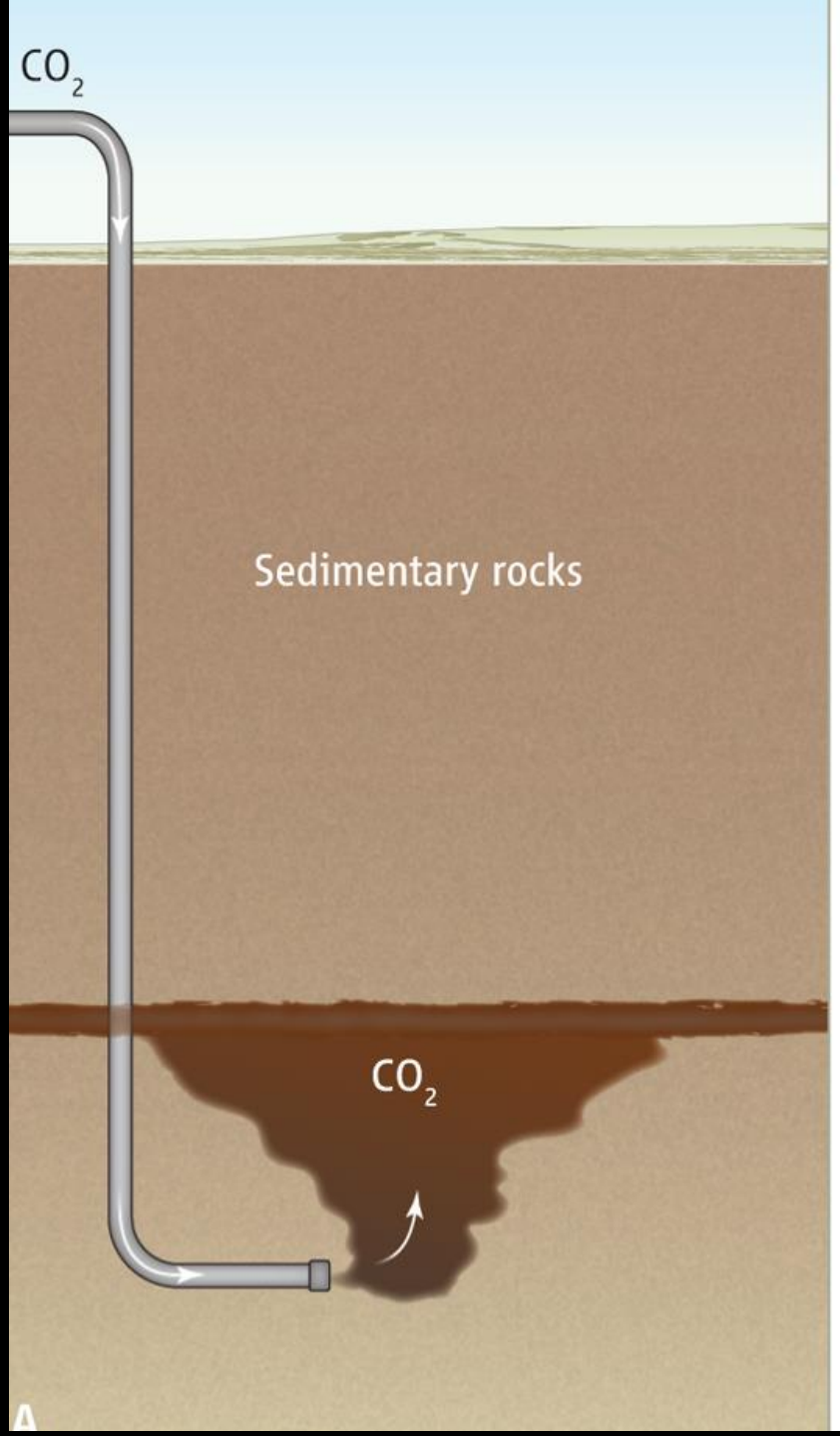
Graduate students in the CarbFix project 2007-2016

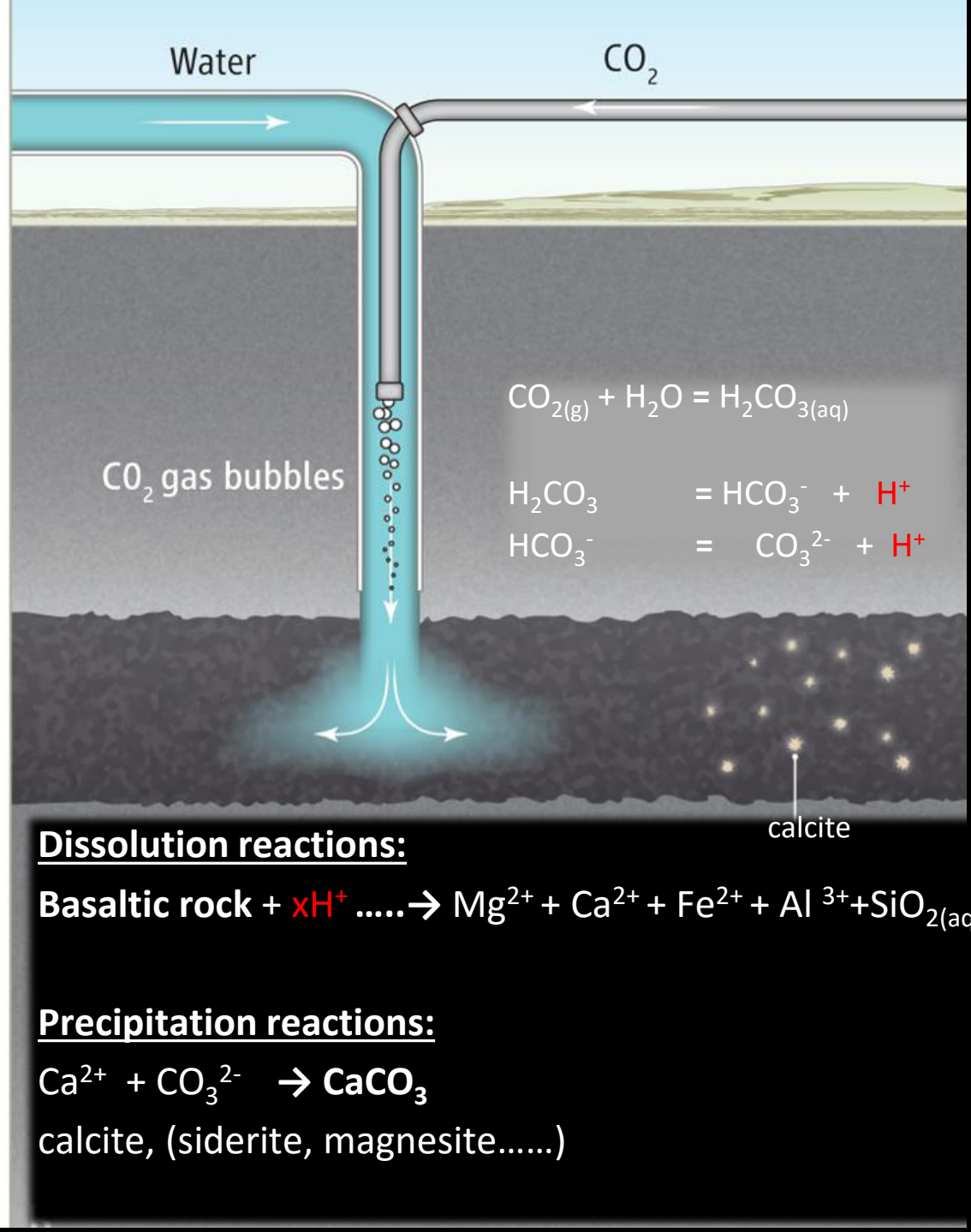
- Therese K. Flaathen. Natural analogue and the effect of SO4 on basaltic dissolution rate and carbonate precipitation rate.
- Gabrielle Stockman. The effect of carbonate coating and bacteria on the dissolution rate of basaltic glass and basaltic minerals.
- Mahnaz Rezvani Khalilabad. Aquifer characterization with tracer test technique
- Elísabet Vilborg Ragnheiðardóttir. Costs, profitability and potential gains of the CarbFix I Program
- Edda Sif Pind Aradóttir. Field scale reactive transport modelling (TOUGHREACT) of CO_2 injection
- Diana Fernandez de la Reguera. Monitoring and verification of geologic carbon dioxide (CO2) storage using tracer techniques , and kinetics of CO_2 dissolution in water
- Helgi A. Alfredsson. Stratigraphy and chemical composition of rocks and fluids at the CarbFix I injection site before injection
- Snorri Gudbrandsson. Dissolution rates of crystalline basalt and plagioclase as a function of temperature and solution composition
- Alex P. Gysi. Numerical and experimental modelling of CO_2-water-basalt interaction
- Iwona Galeczka . Plug flow experiment simulation of CO_2 injections
- Jonas Olsson. Natural analogue for CCS metal uptake by carbonates
- Sandra Ósk Snæbjörnsdóttir, carbon storage potential and monitoring of CarbFix I
- Deirdre Clark, Monitoring of CarbFix-Sulfix II and plug flow experiment simulation of CO_2 injections

The CarbFix1 method



Gislason and Oelkers, Science 2014,
Sigfússon et al., IJGGC 2015





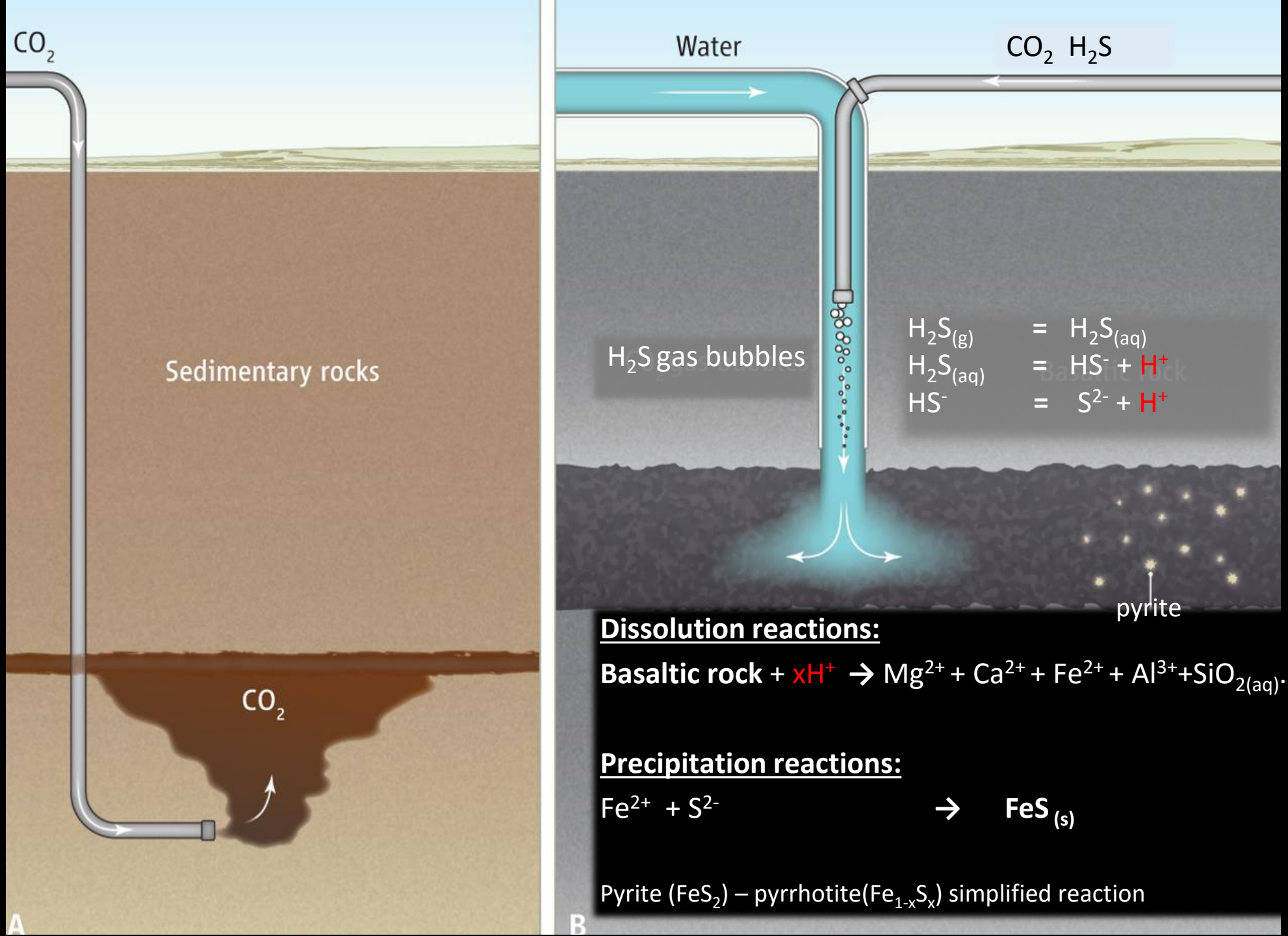
Dissolution reactions:

Basaltic rock + xH^+ .....→ $Mg^{2+} + Ca^{2+} + Fe^{2+} + Al^{3+} + SiO_{2(aq)}$....

Precipitation reactions:

$Ca^{2+} + CO_3^{2-}$ → **$CaCO_3$**

calcite, (siderite, magnesite……)



Dissolution reactions:

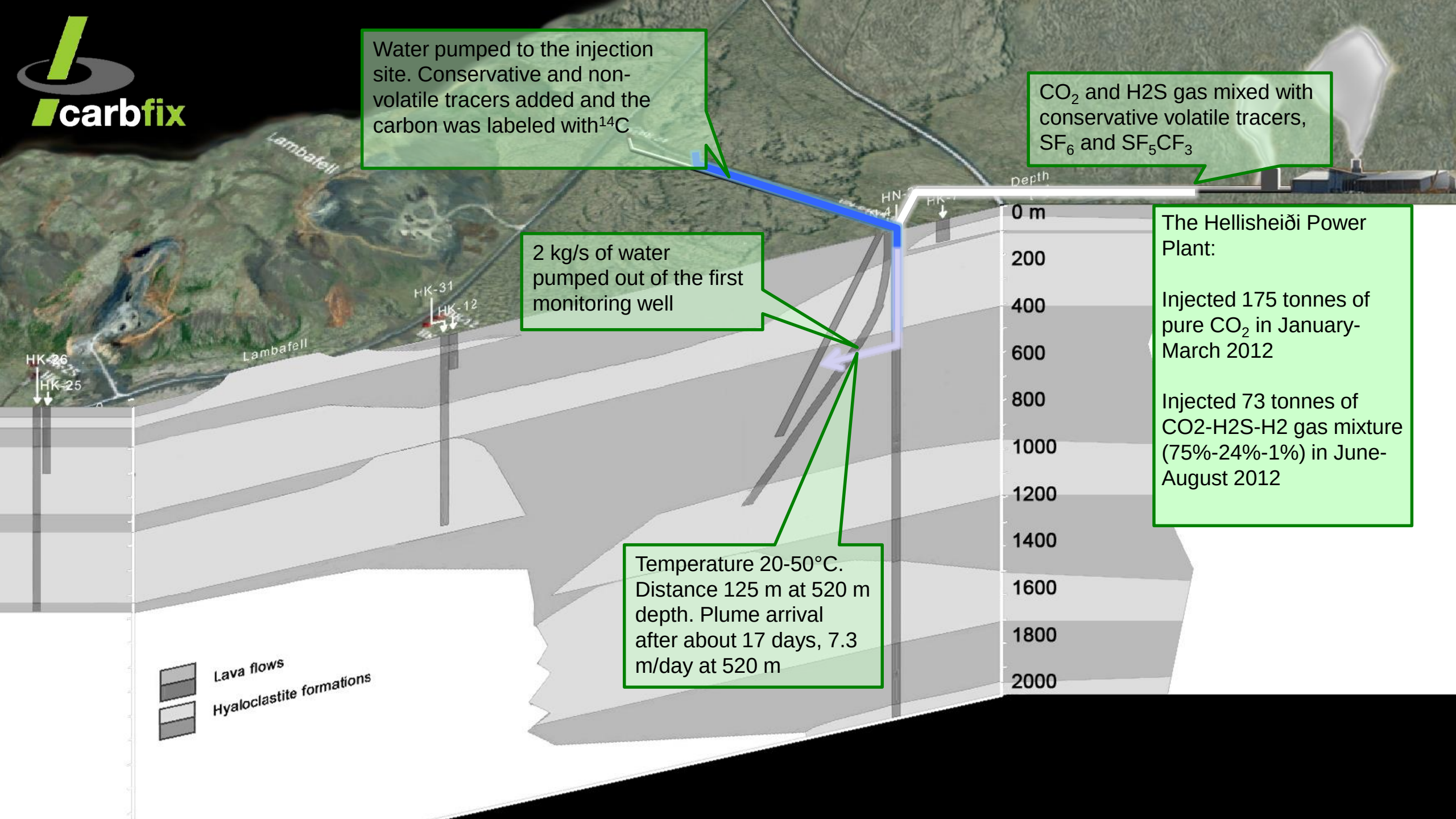
Basaltic rock + xH^+ → $Mg^{2+} + Ca^{2+} + Fe^{2+} + Al^{3+} + SiO_{2(aq)}$....

Precipitation reactions:

$Fe^{2+} + S^{2-}$ → **$FeS_{(s)}$**

Pyrite (FeS_2) – pyrrhotite($Fe_{1-x}S_x$) simplified reaction

CarbFix 1
Injection well HN-2


carbfix
Water pumped to the injection site. Conservative and non-volatile tracers added and the carbon was labeled with ^{14}C
CO_2 and H2S gas mixed with conservative volatile tracers, SF_6 and SF_5CF_3
2 kg/s of water pumped out of the first monitoring well
The Hellisheiði Power Plant:
Injected 175 tonnes of pure CO_2 in January-March 2012
Injected 73 tonnes of CO2-H2S-H2 gas mixture (75%-24%-1%) in June-August 2012
Temperature 20-50°C. Distance 125 m at 520 m depth. Plume arrival after about 17 days, 7.3 m/day at 520 m
Lambafell
Lambafell
HK-31
HK-12
HK-26
HK-25
Depth
0 m
200
400
600
800
1000
1200
1400
1600
1800
2000
Lava flows
Hyaloclastite formations

1 m

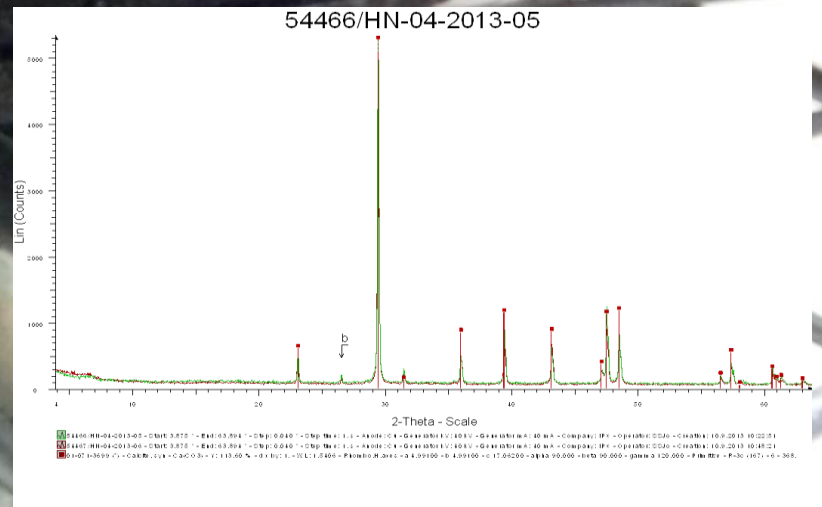


Photo: Ingvi Gunnarsson

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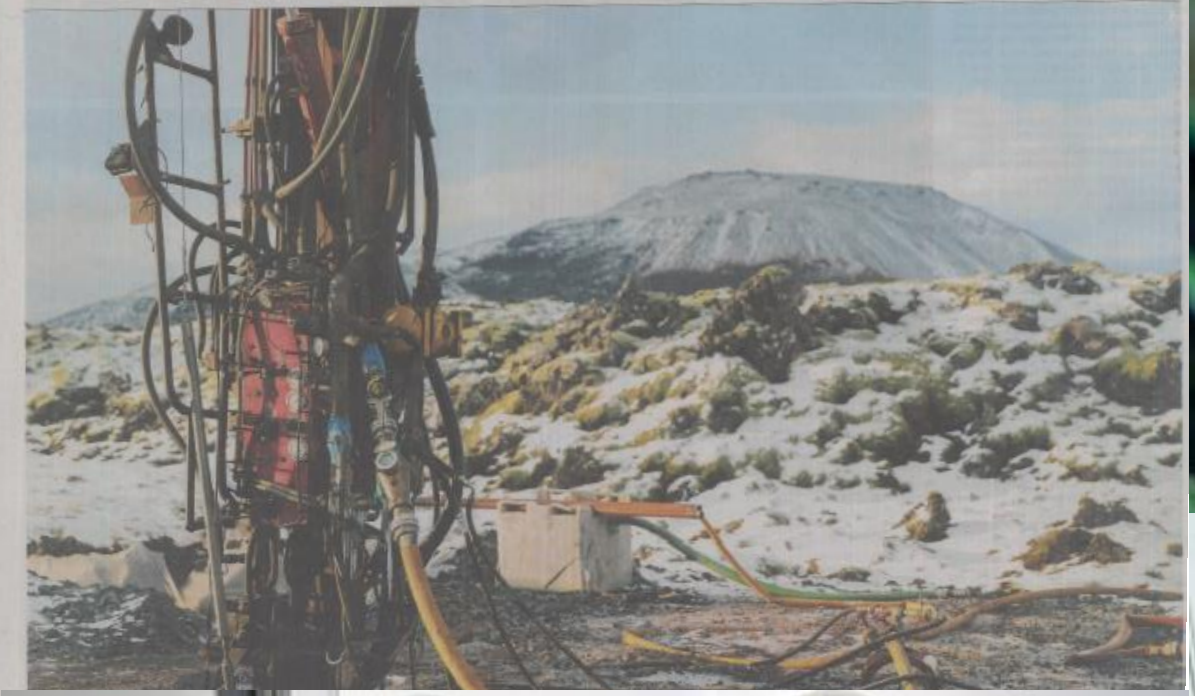
ScienceTimes

The New York Times

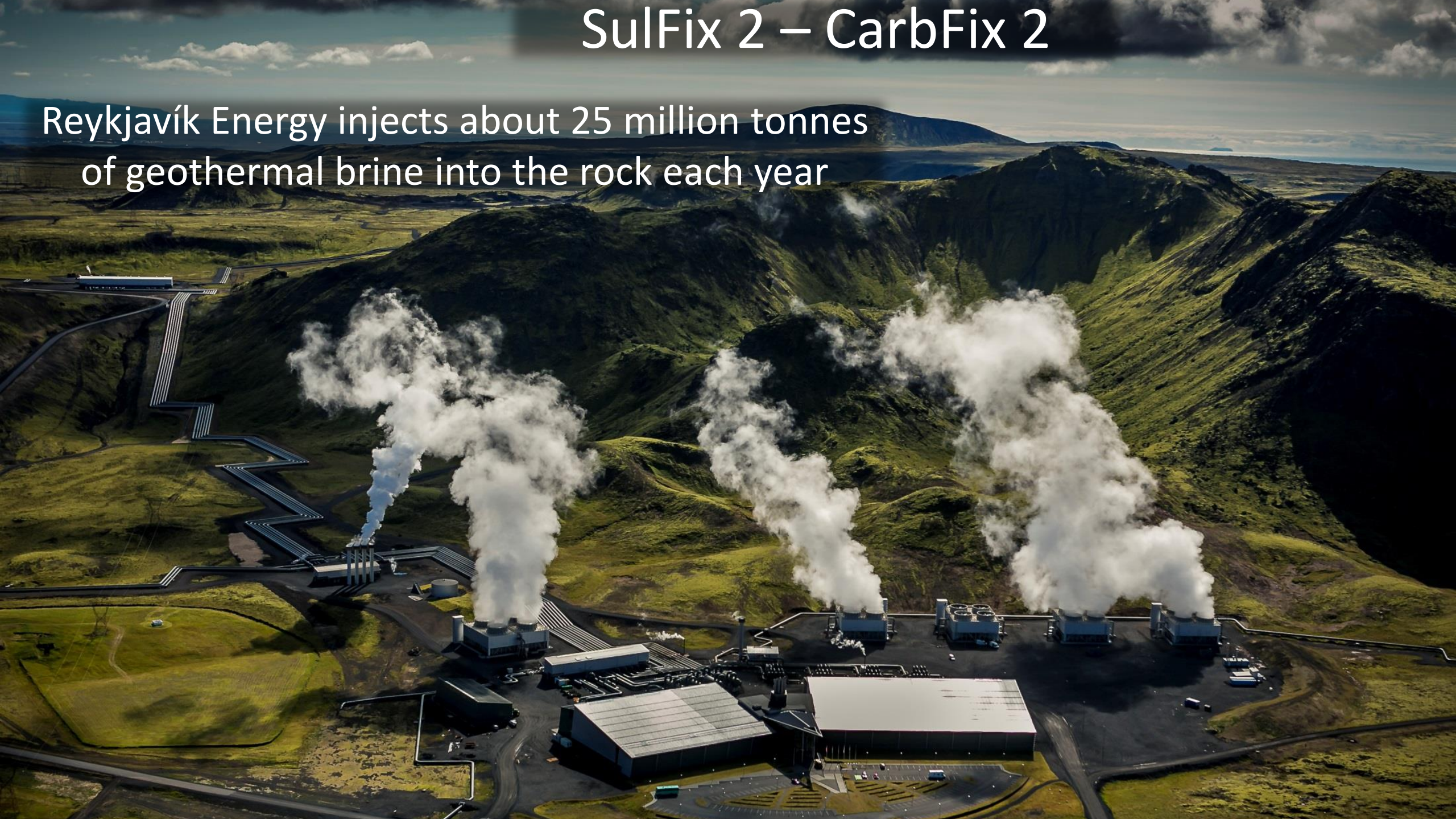
TUESDAY, FEBRUARY 10, 2015

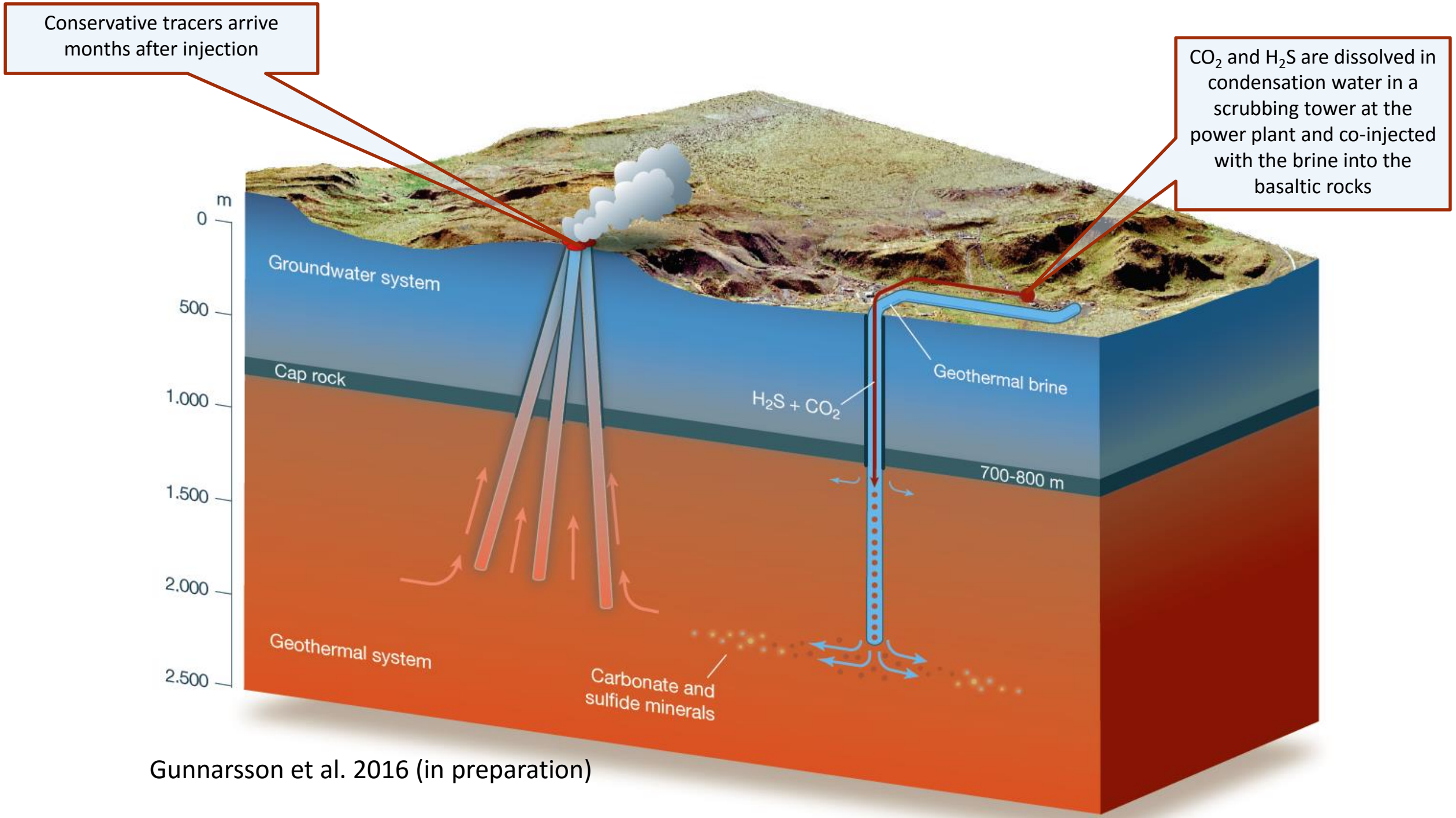


Photos: Bára Kristinsdóttir for NYT

SulFix 2 – CarbFix 2

Reykjavík Energy injects about 25 million tonnes of geothermal brine into the rock each year

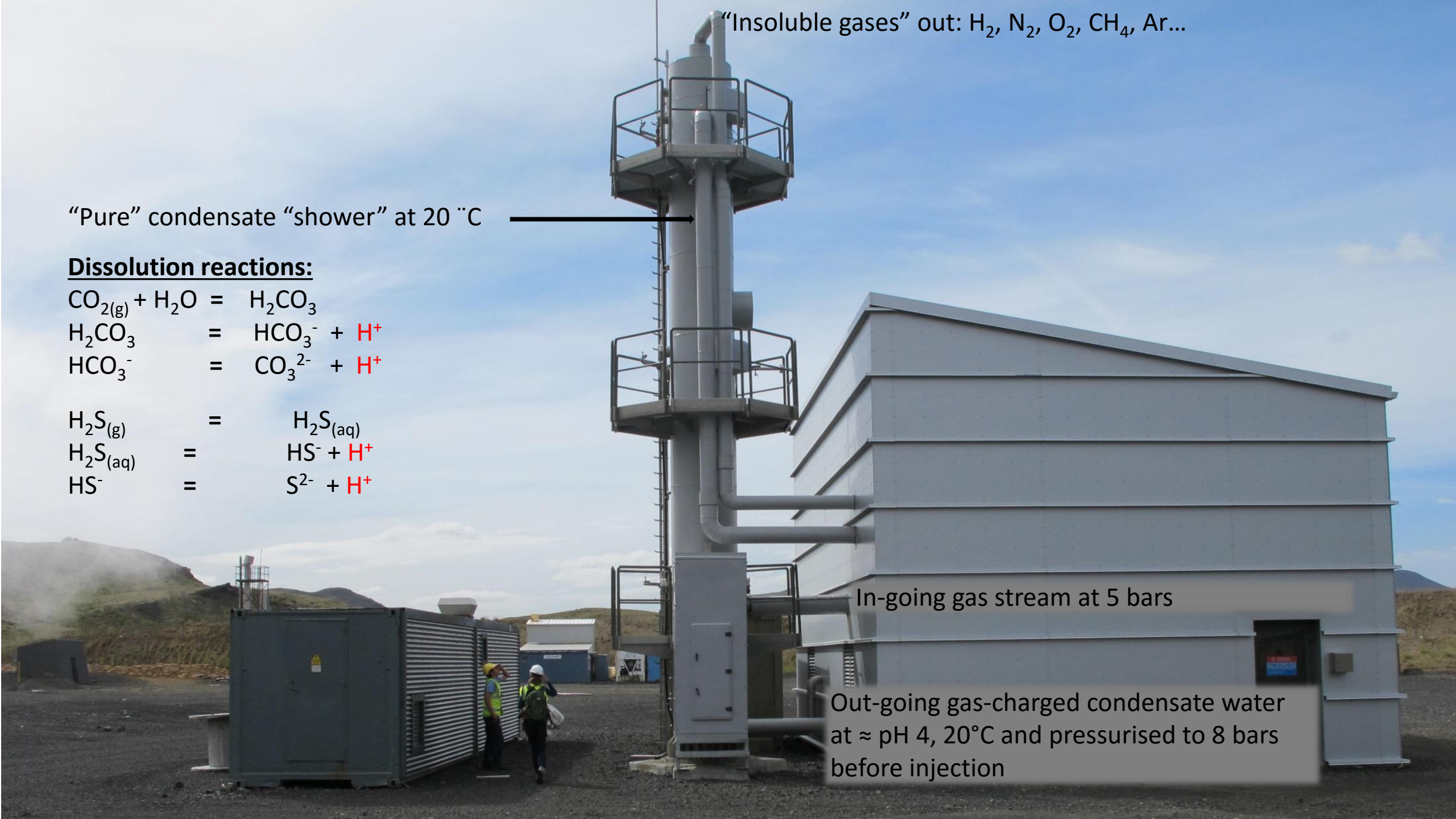


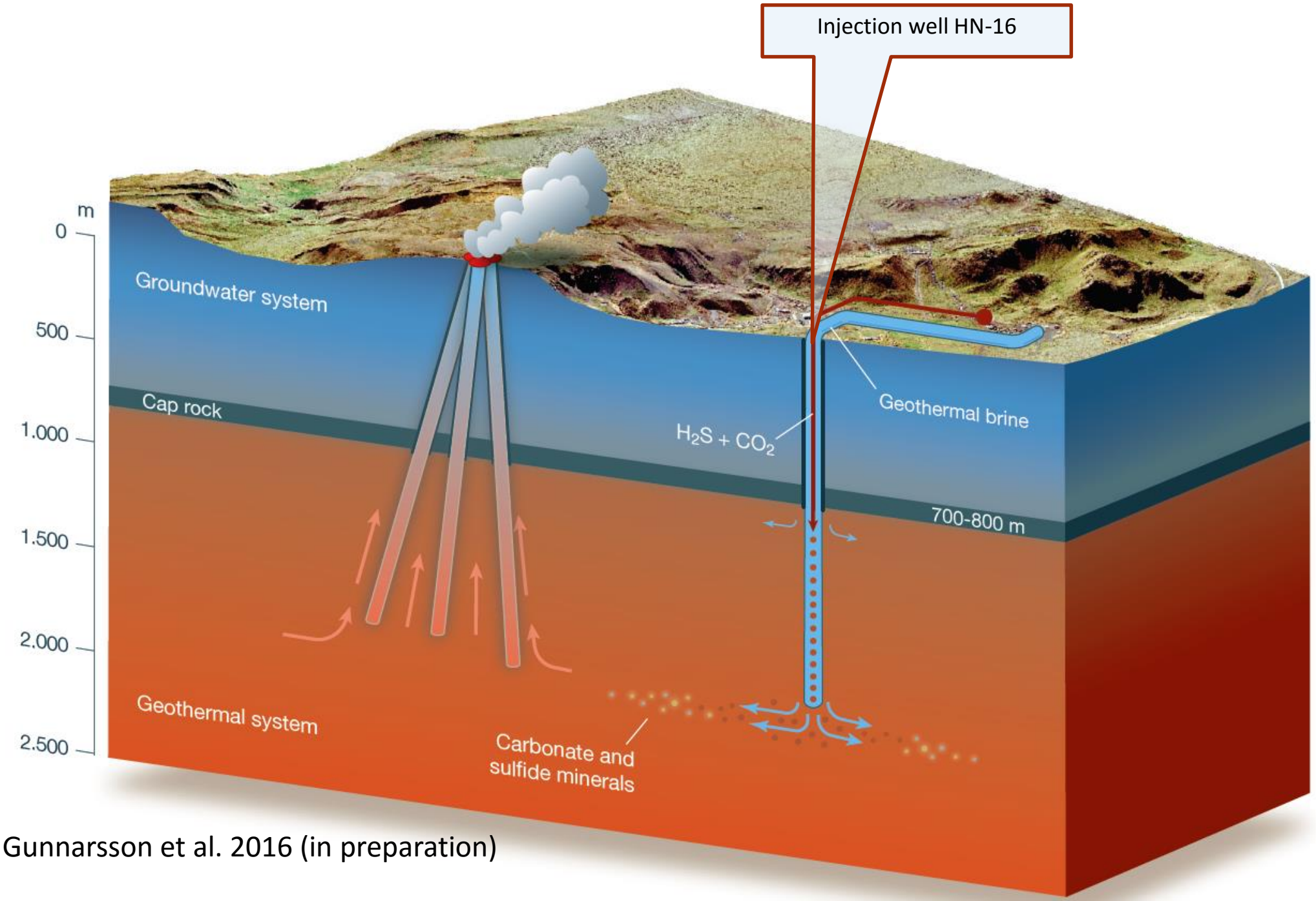


Gunnarsson et al. 2016 (in preparation)

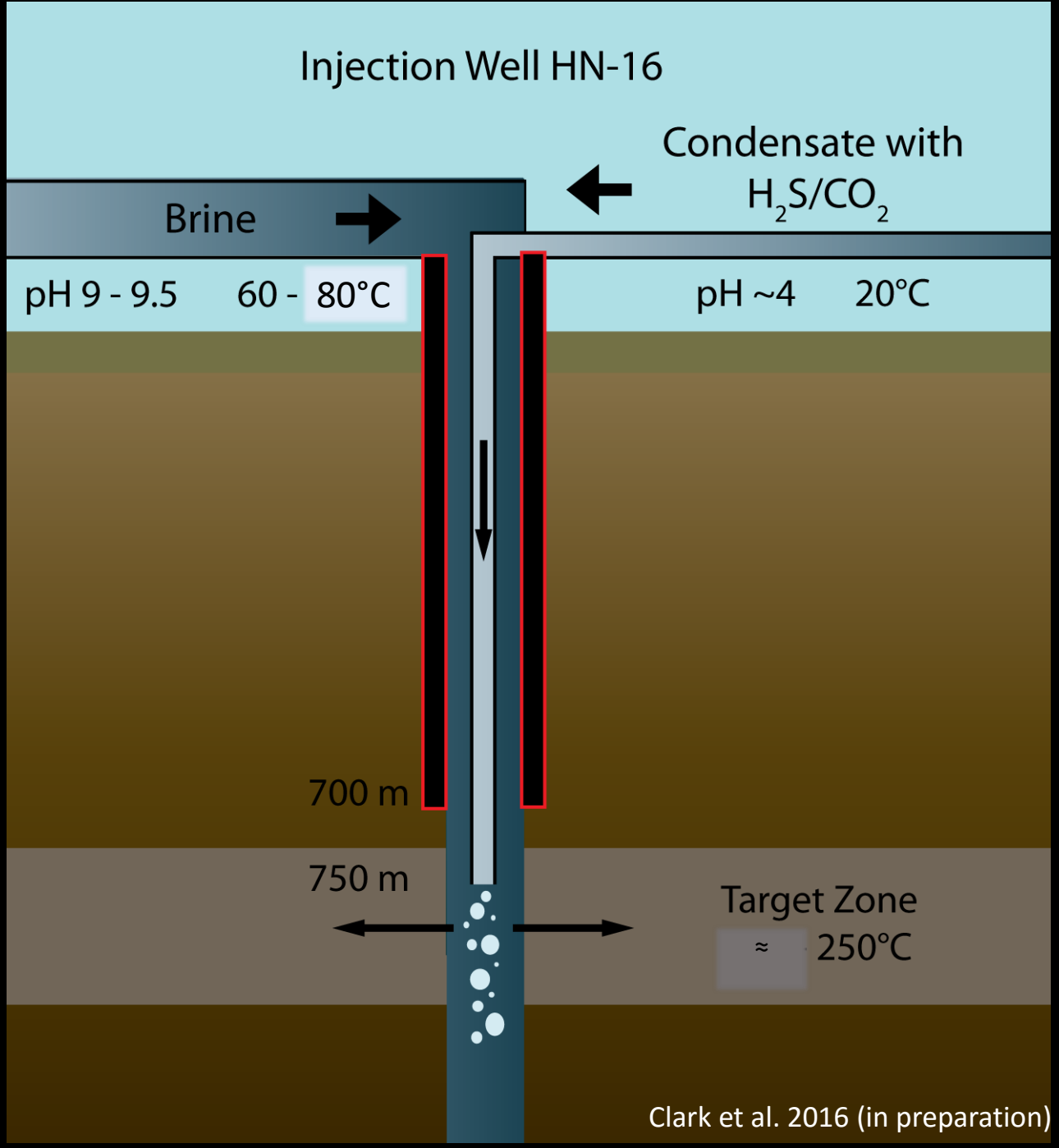
Gas and condensation water are taken from one of the turbines at Hellisheiði


“Insoluble gases” out
“Pure” condensate “shower”
“Pure” condensate “shower” at 20°C
In-going gases at 5 bars
Out-going gas-charged condensate water at ≈ pH 4, 20°C and pressurised to 8 bars before injection


"Insoluble gases" out: H_2, N_2, O_2, CH_4, Ar…
"Pure" condensate "shower" at 20 ¨C
Dissolution reactions:
$CO_{2(g)} + H_2O = H_2CO_3$
$H_2CO_3 = HCO_3^- + H^+$
$HCO_3^- = CO_3^{2-} + H^+$
$H_2S_{(g)} = H_2S_{(aq)}$
$H_2S_{(aq)} = HS^- + H^+$
$HS^- = S^{2-} + H^+$
In-going gas stream at 5 bars
Out-going gas-charged condensate water at ≈ pH 4, 20°C and pressurised to 8 bars before injection



Gunnarsson et al. 2016 (in preparation)



Clark et al. 2016 (in preparation)

Dissolution reactions in the gas "scrubber":

$CO_{2(g)} + H_2O = H_2CO_3$

$H_2CO_3 = HCO_3^- + H^+$

$HCO_3^- = CO_3^{2-} + H^+$

$H_2S_{(g)} = H_2S_{(aq)}$

$H_2S_{(aq)} = HS^- + H^+$

$HS^- = S^{2-} + H^+$

Dissolution reactions:

Basalt + xH^+ ..... → $Mg^{2+} + Ca^{2+} + Fe^{2+} + ...$

Precipitation reactions:

$(Ca, Fe, Mg)^{2+} + CO_3^{2-} \rightarrow$ **$(Ca,Fe,Mg)CO_{3(s)}$**

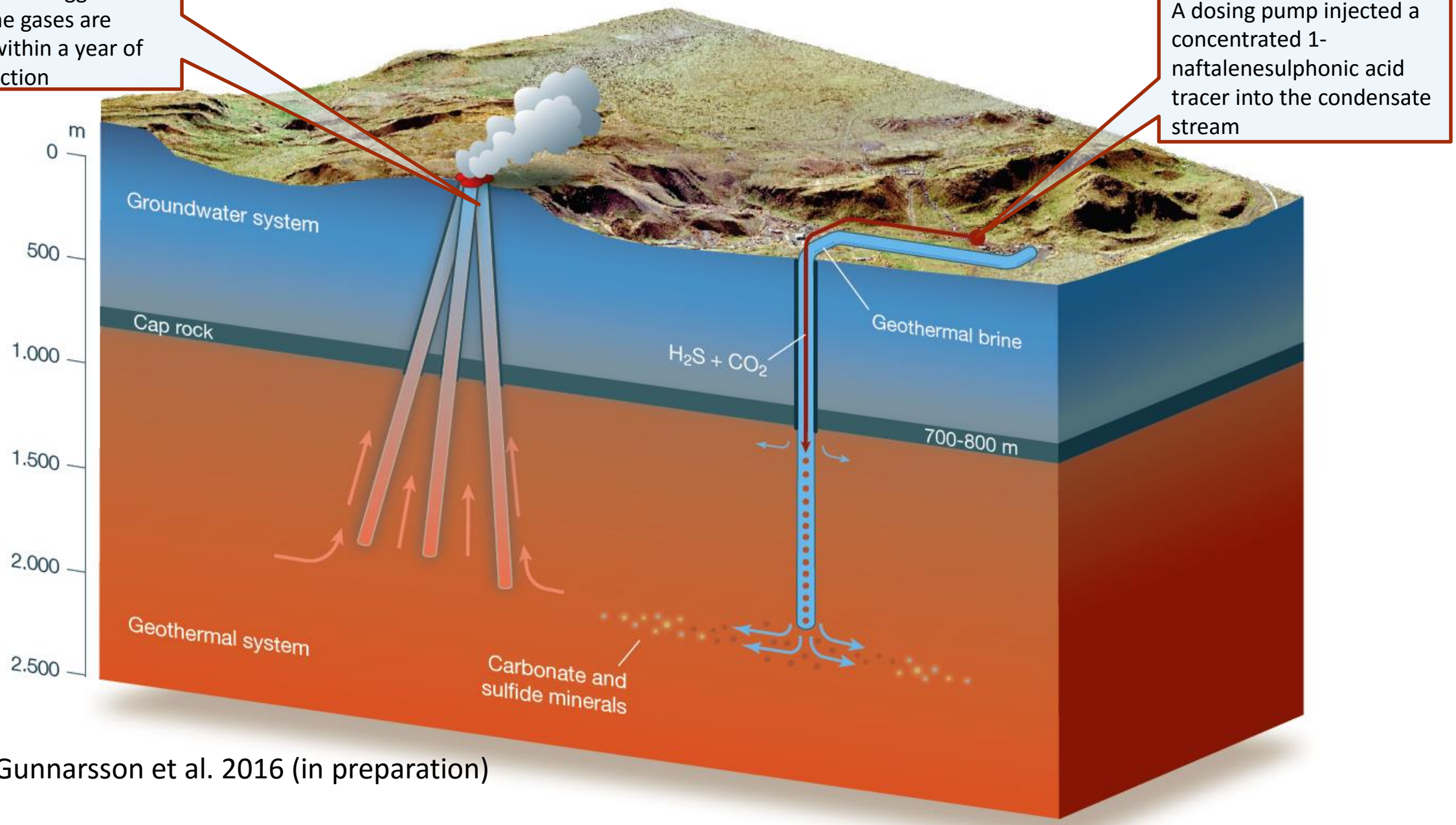
calcite, siderite, magnesite, and mixture thereof

$Fe^{2+} + S^{2-} \rightarrow$ **$FeS_{(s)}$** $+ 2H^+$

pyrite (FeS_2) – pyrrhotite ($Fe_{1-x}S_x$) simplified reaction

Mass balance on the injected and observed tracer, CO_2 and H_2S concentrations suggest that most of the gases are mineralised within a year of injection

A dosing pump injected a concentrated 1-naftalenesulphonic acid tracer into the condensate stream



Gunnarsson et al. 2016 (in preparation)