Pathways to Decarbonisation of the Fossil Fuel Cycle

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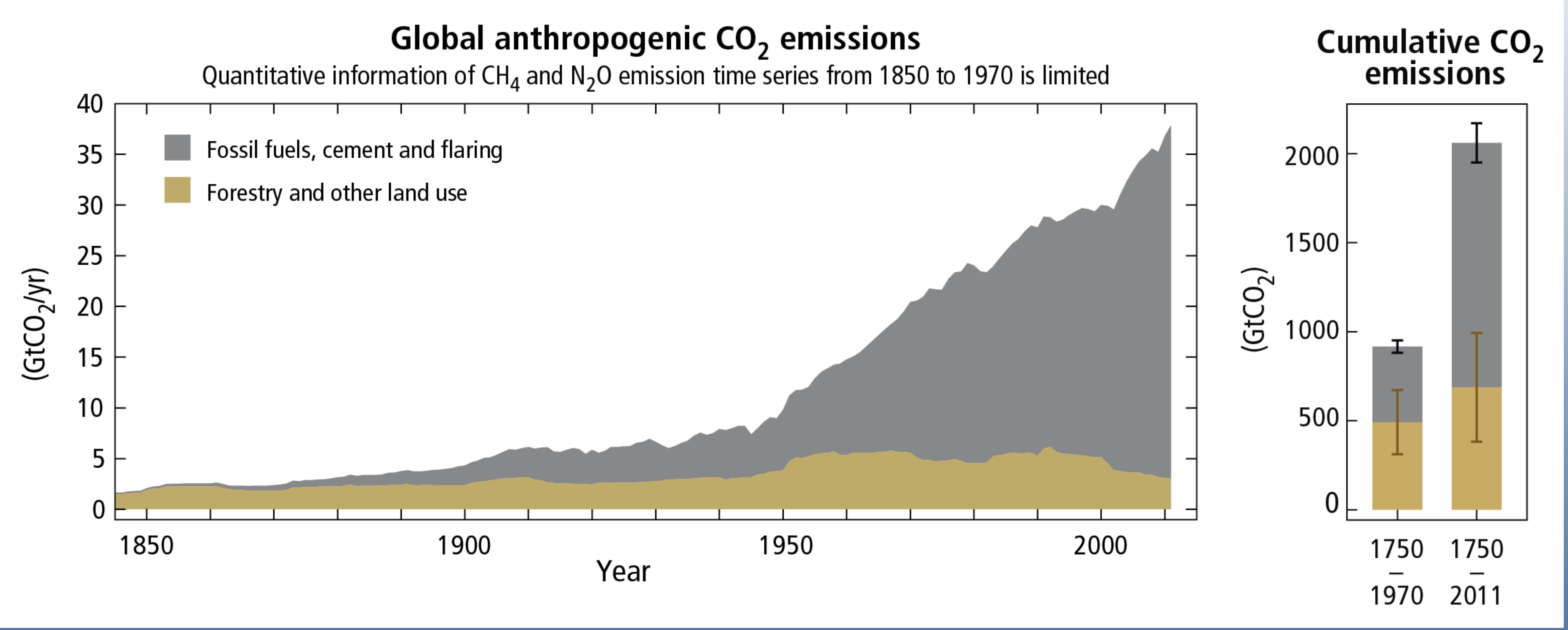
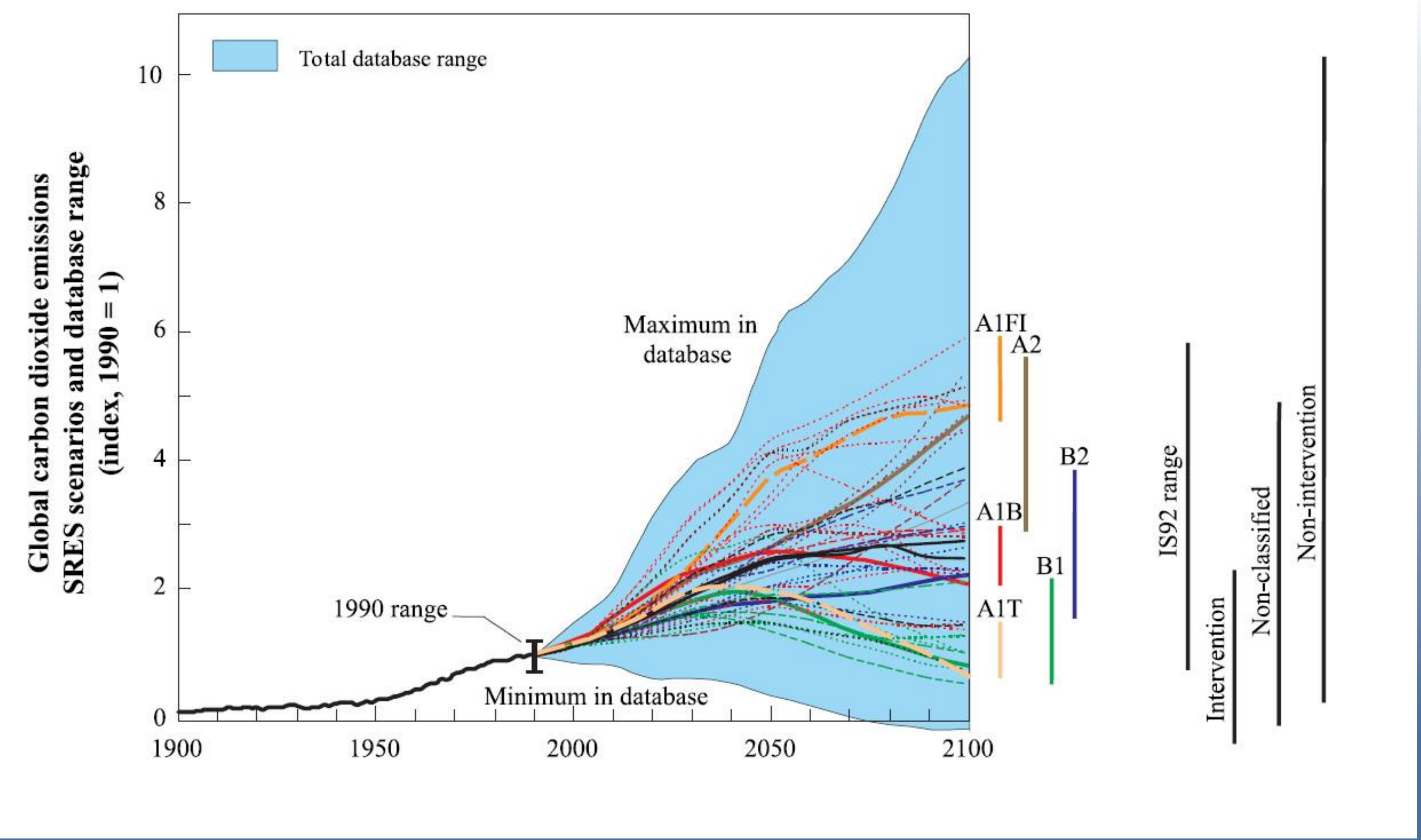
Anthropogenic CO_2 Emissions



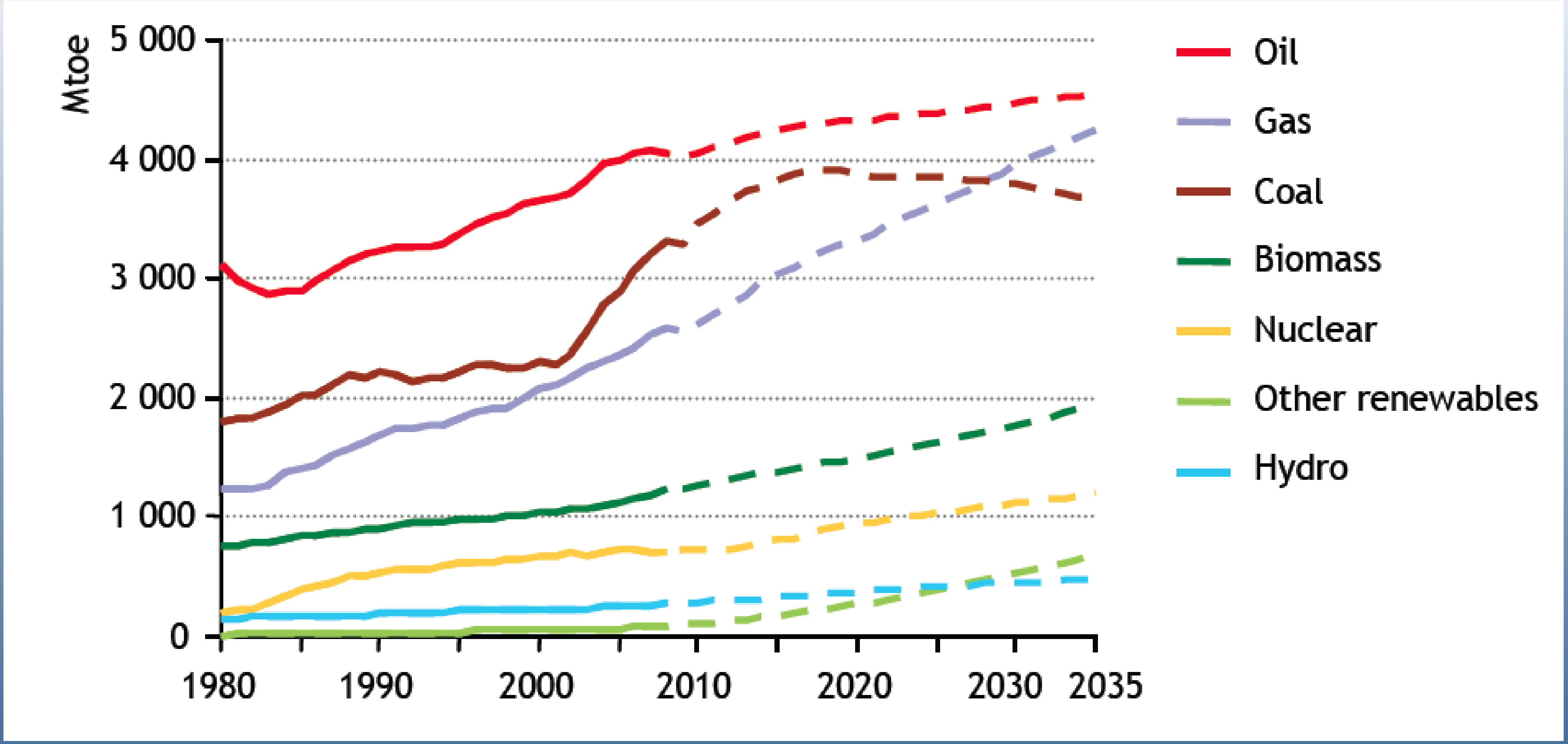
IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC Model Simulations of CO_2 Emissions



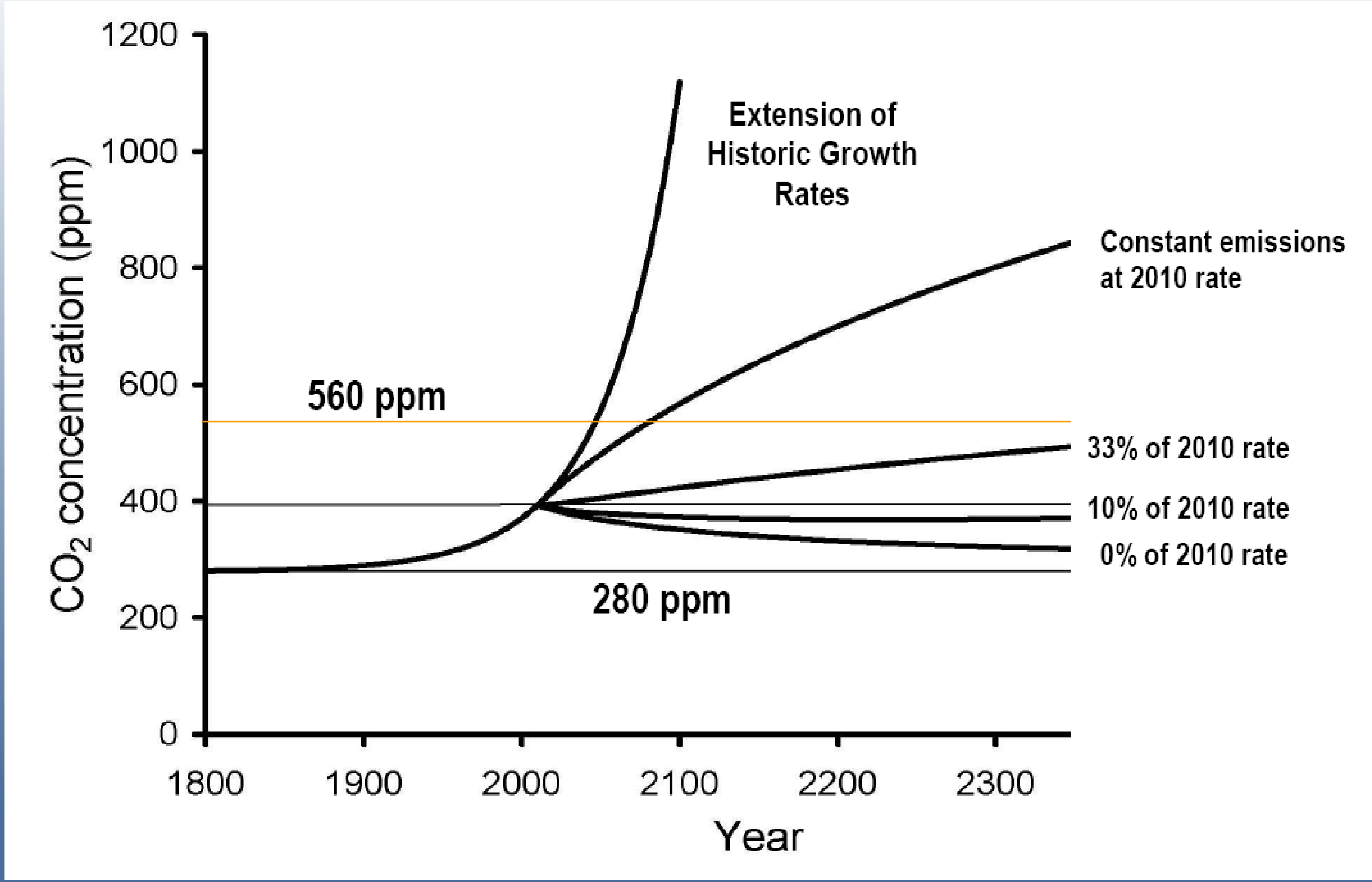
Source: IPCC Data Distribution Center

World Primary Energy Demand



World Energy Outlook – Special Report (2011)

Environmental Limits – Call for Mitigation



Carbon Capture and Storage

Without carbon capture and storage fossil fuels will have to be phased out

CO_2 from concentrated sources

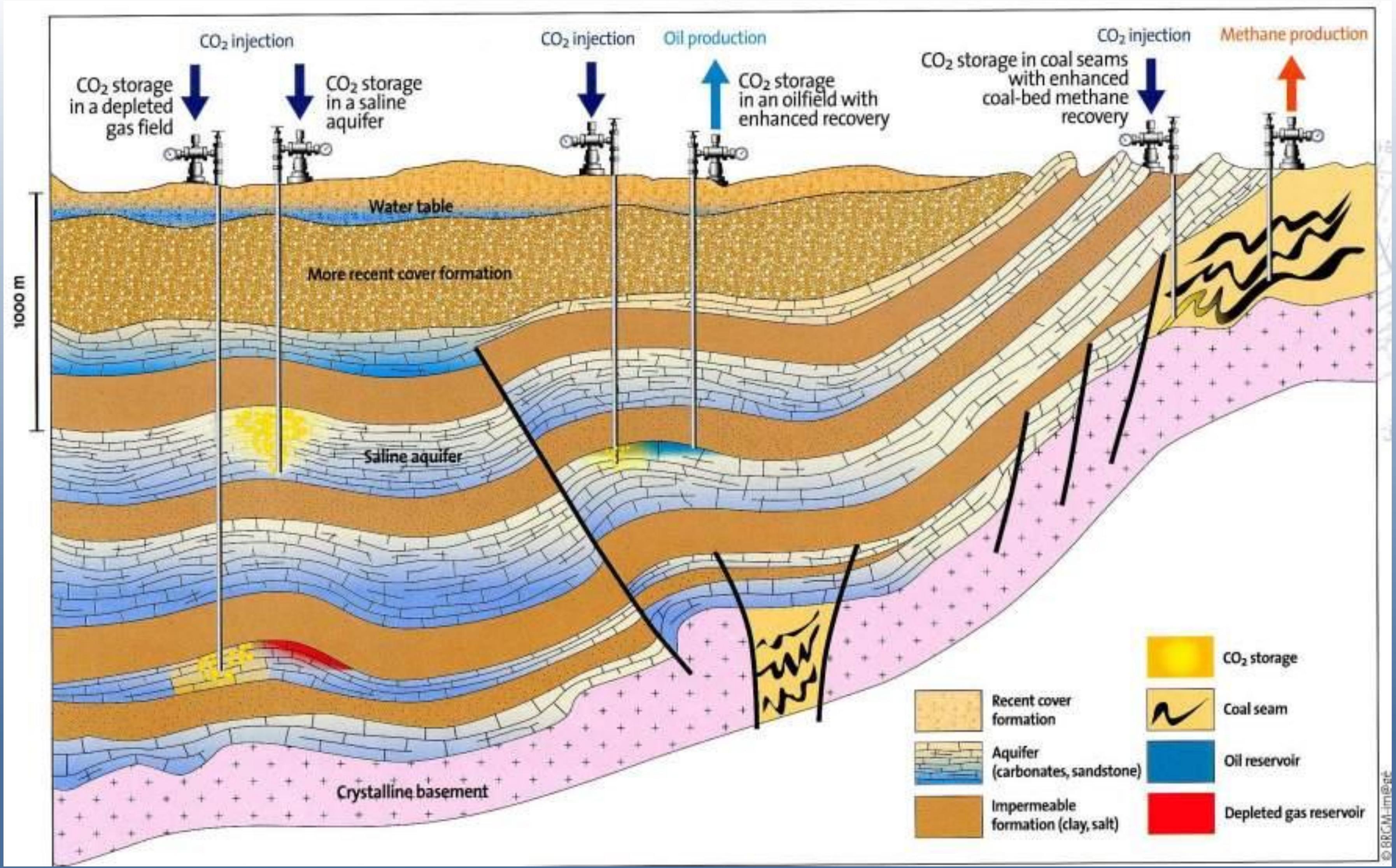
Capture from power plants, cement, steel, refineries, etc.

CO_2 extraction from air

Permanent & safe disposal

Geologic and mineral storage

Geologic CO_2 Storage

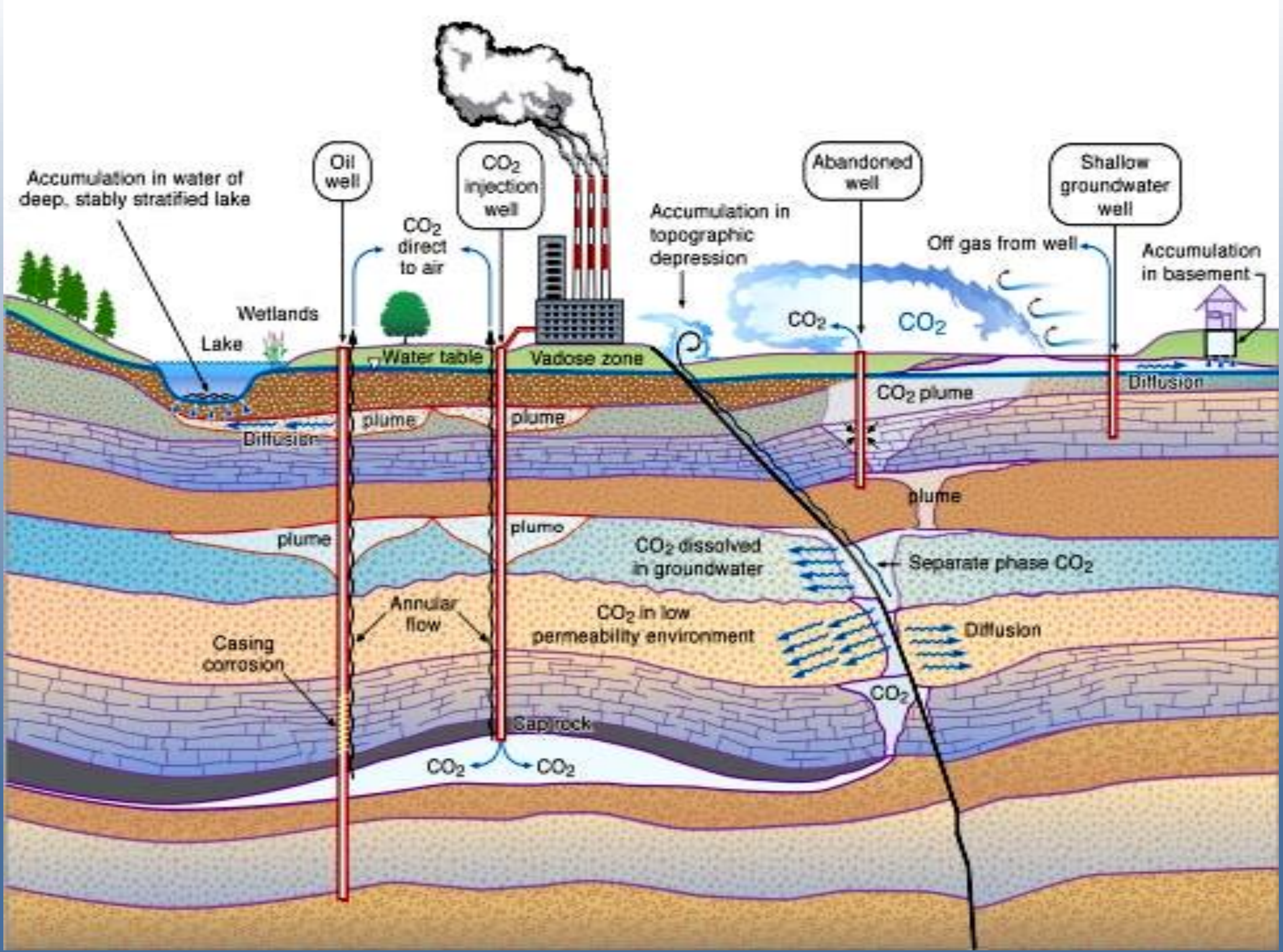


Problem of Scale

- 1,000 Mwe coal-fired power plant: 10 Mt CO_2/year -> 700 Mt CO_2
- Total CO_2 volume ~1 km^3 (density of 780 kg/m^3 at 40°C, 150 bar)
- CO_2 foot print in the subsurface could reach 100 km^2 (Pruess et al. 2001)
- US: 1,500 coal-fired generators, capacity of 335,830 MWe

➢ **CCS Scale Million – Billion Tons per year**

Risk of Leakage



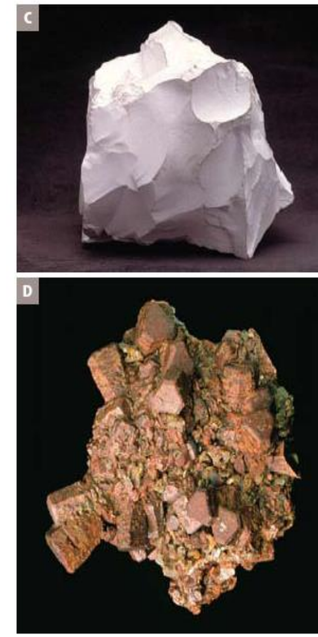
Source: www.westcarb.org

Mineral Carbonation

basalt

$SiAl_{0.36}Ca_{0.30}Mg_{0.25}Fe_{0.17}O_{3.35}$

$+ CO_2 =$

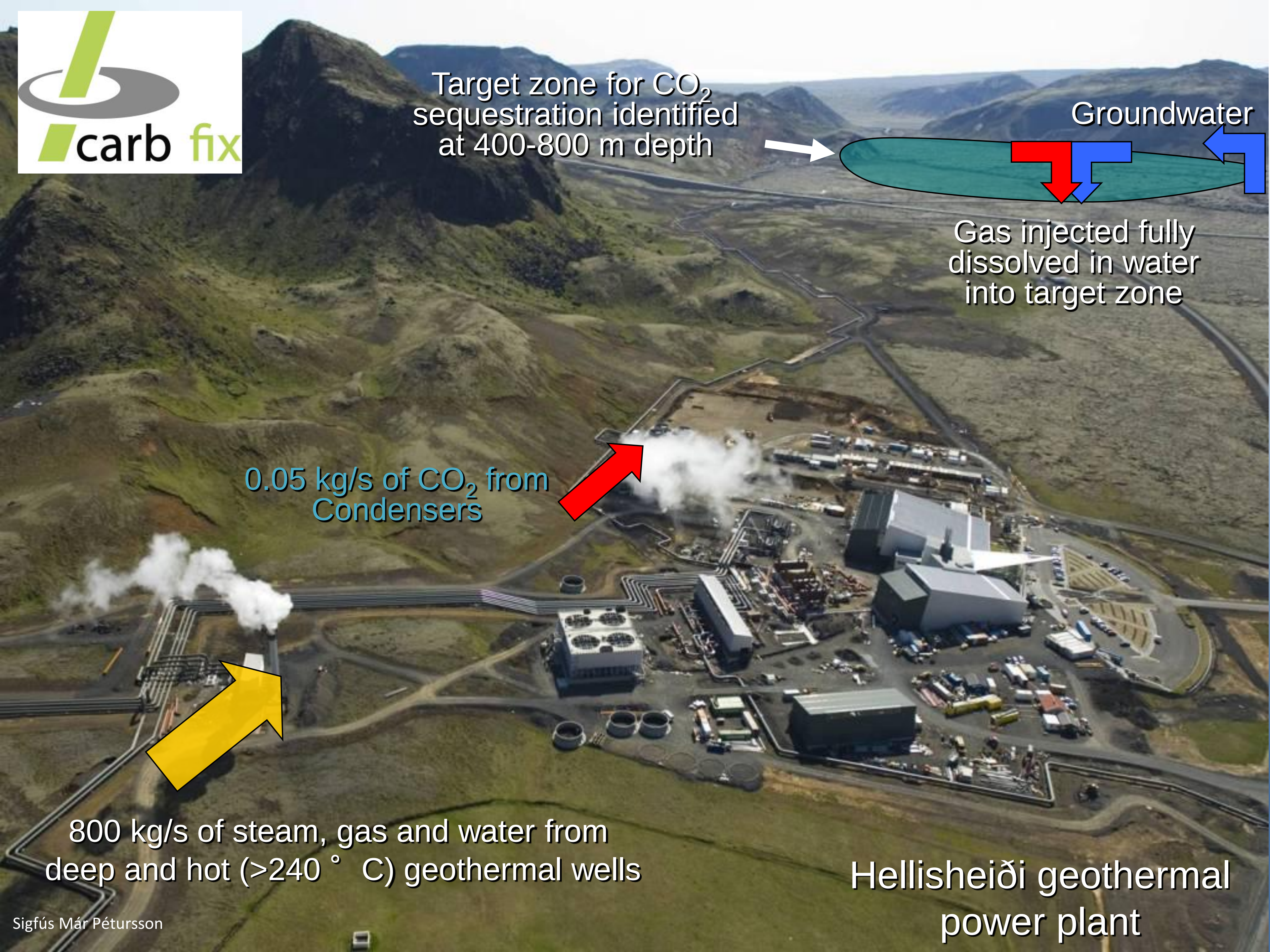


peridotite

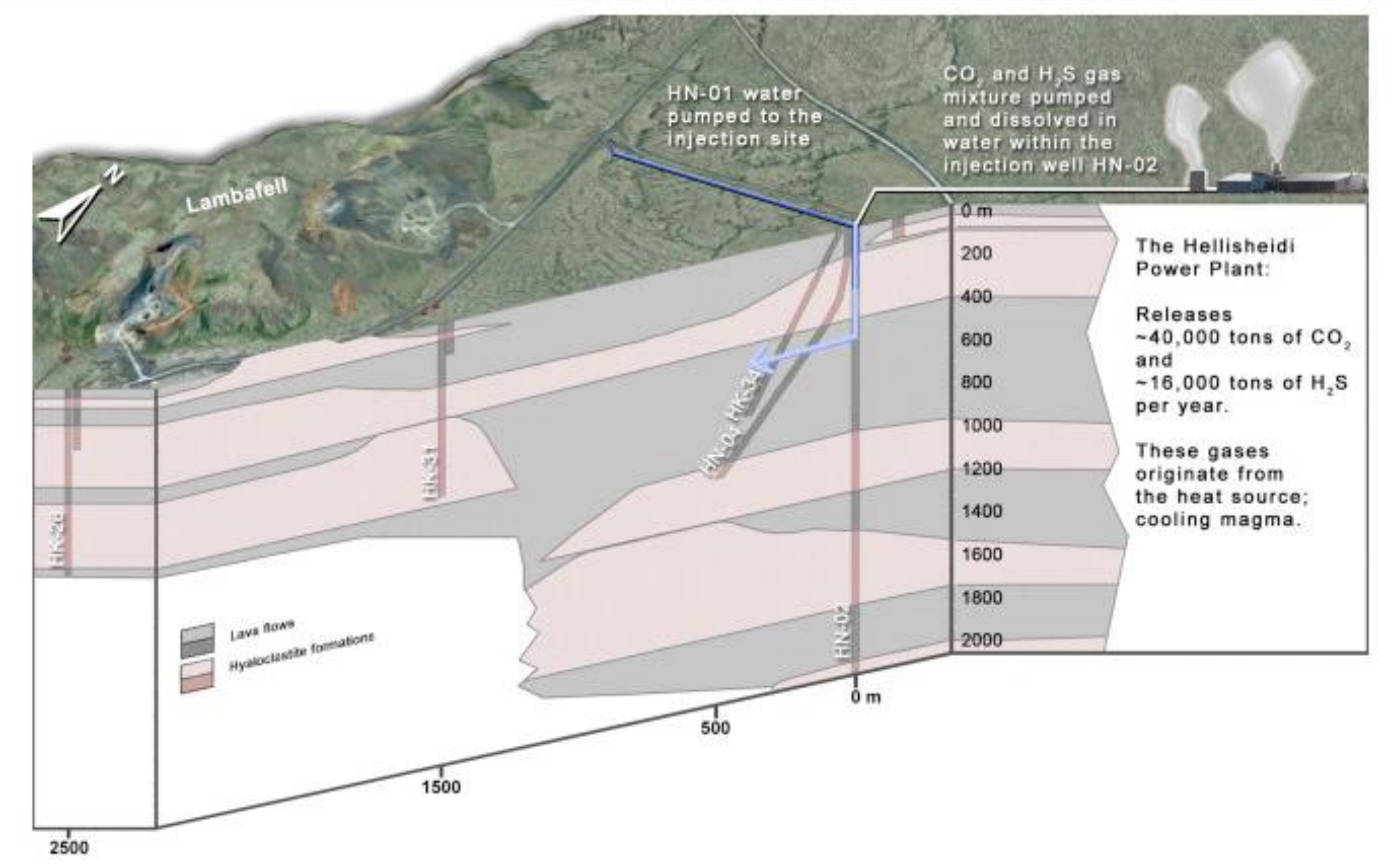
$SiAl_{0.08}Mg_{1.32}Fe_{0.14}O_{3.42}$

$+ CO_2 =$

Calcite
Magnesite
siderite

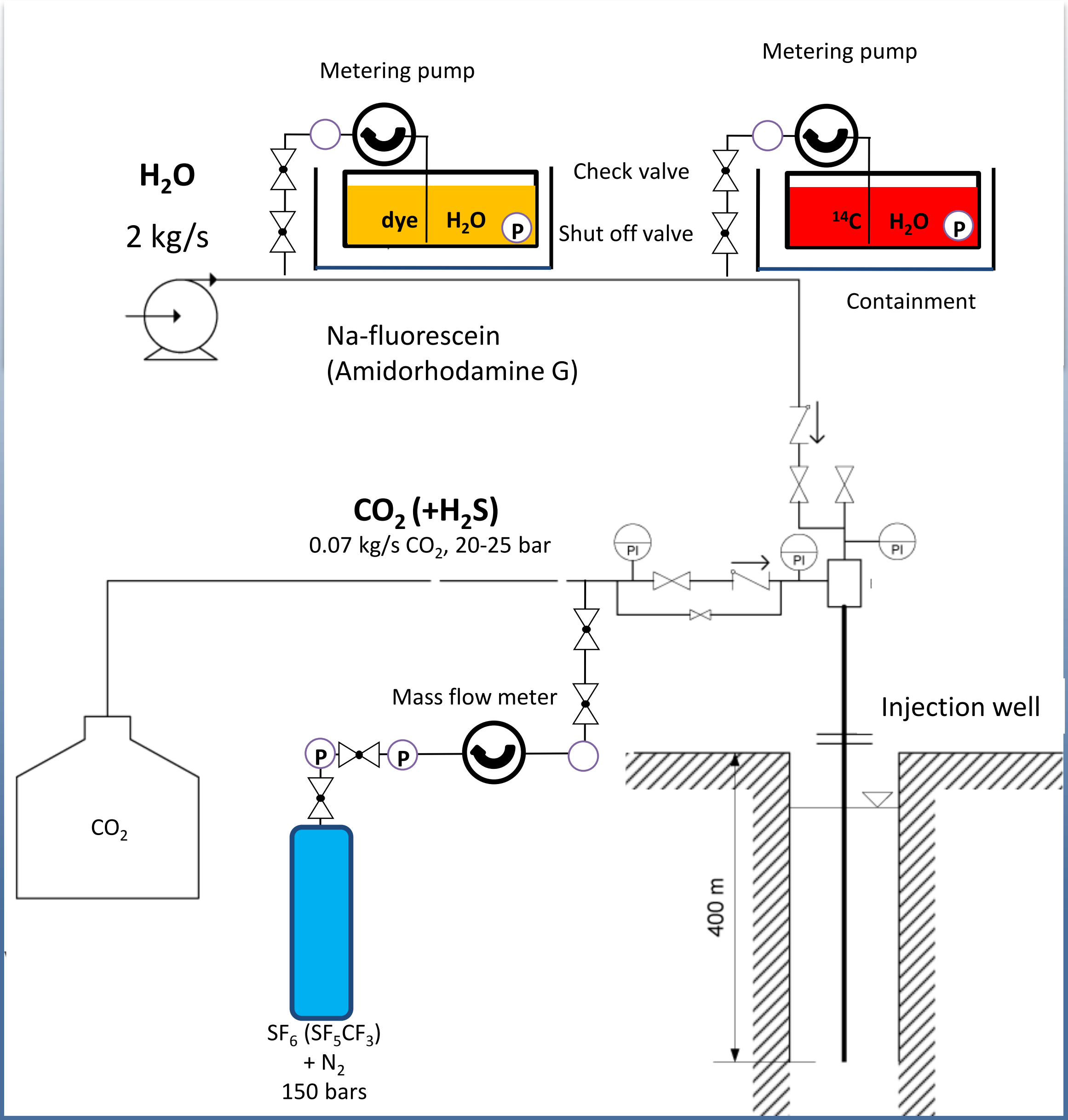

carb fix
Target zone for CO_2 sequestration identified at 400-800 m depth
Groundwater
Gas injected fully dissolved in water into target zone
0.05 kg/s of CO_2 from Condensers
800 kg/s of steam, gas and water from deep and hot (>240 ° C) geothermal wells
Hellisheiði geothermal power plant
Sigfús Már Pétursson

CarbFix Pilot Injection Site



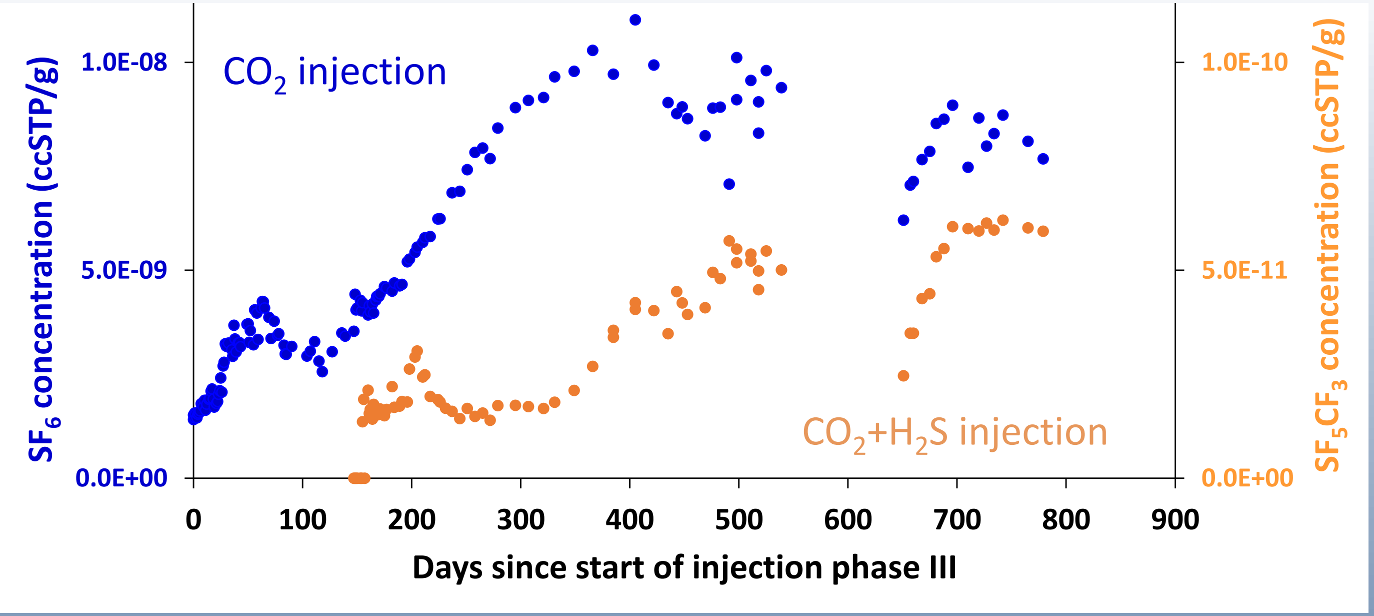
Alfredsson et al., IJGGC, 2013

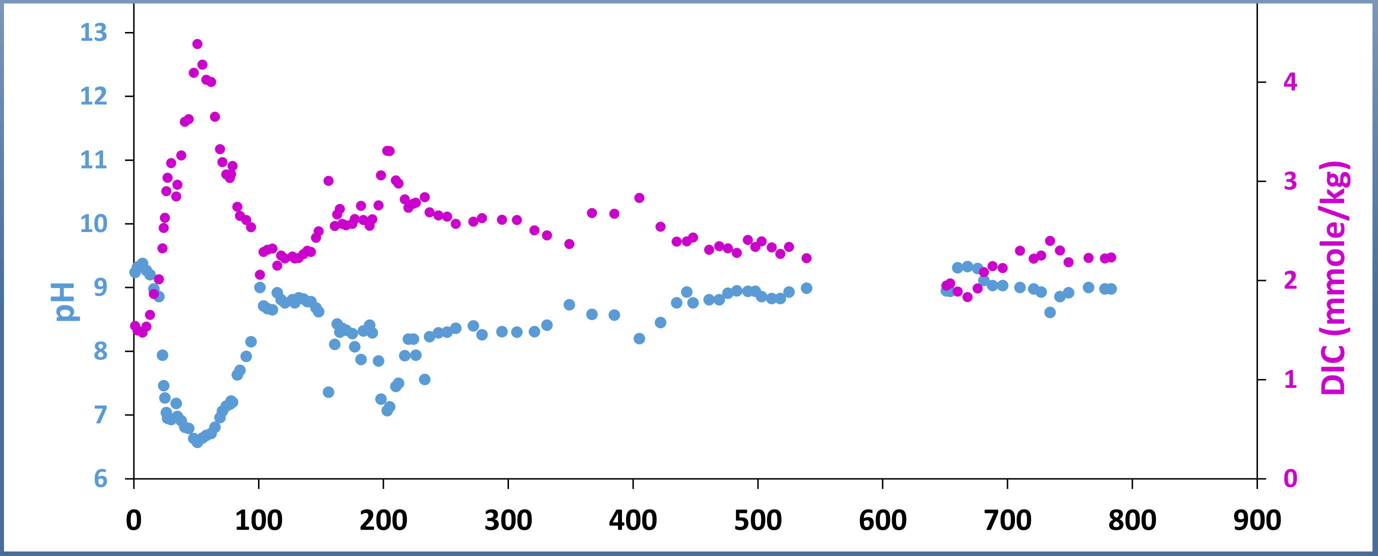
Tracer injection system



SF_6, SF_5CF_3, DIC & pH monitoring

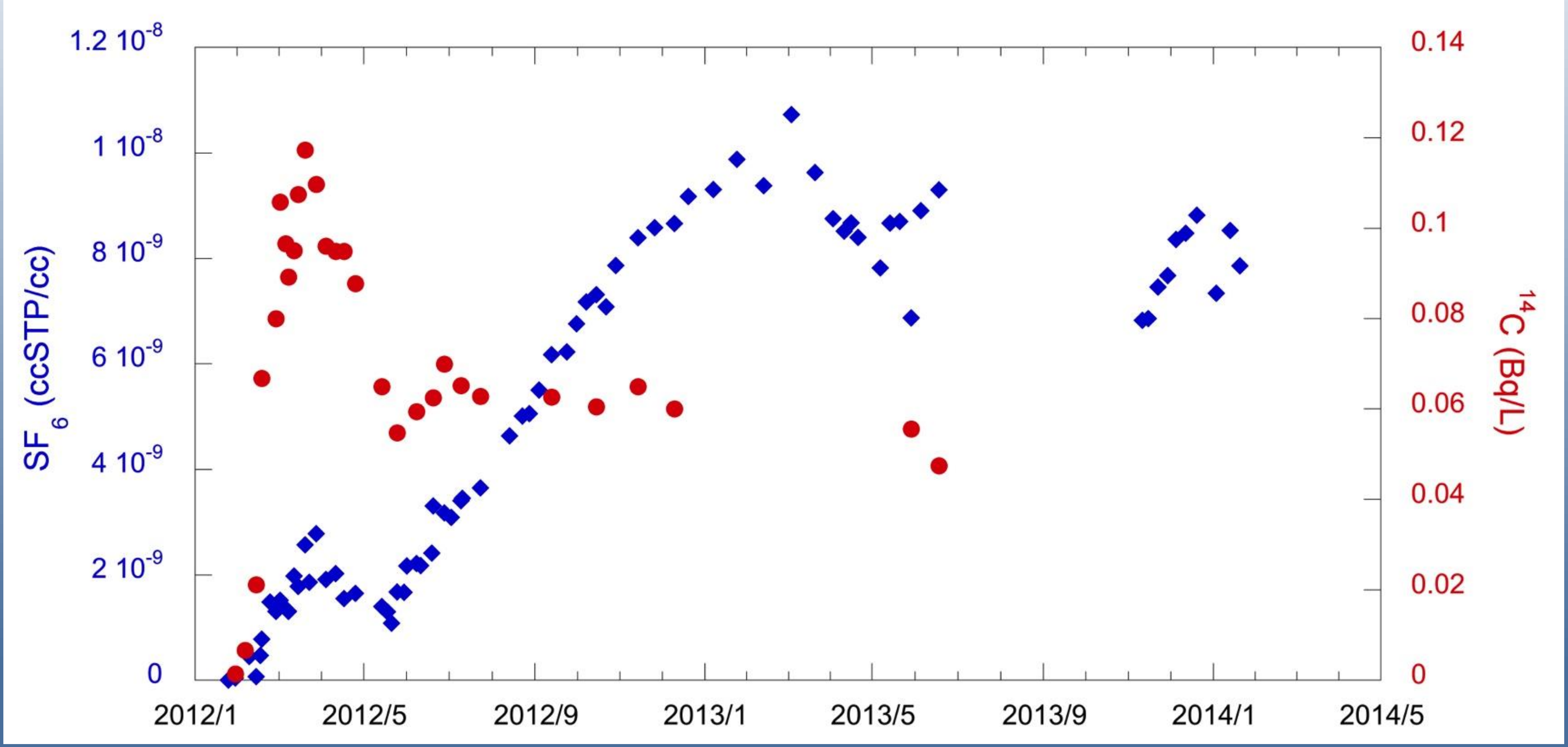
- Goal: Monitor solute transport in subsurface





^{14}C monitoring

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



Carbon mass balance

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

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

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

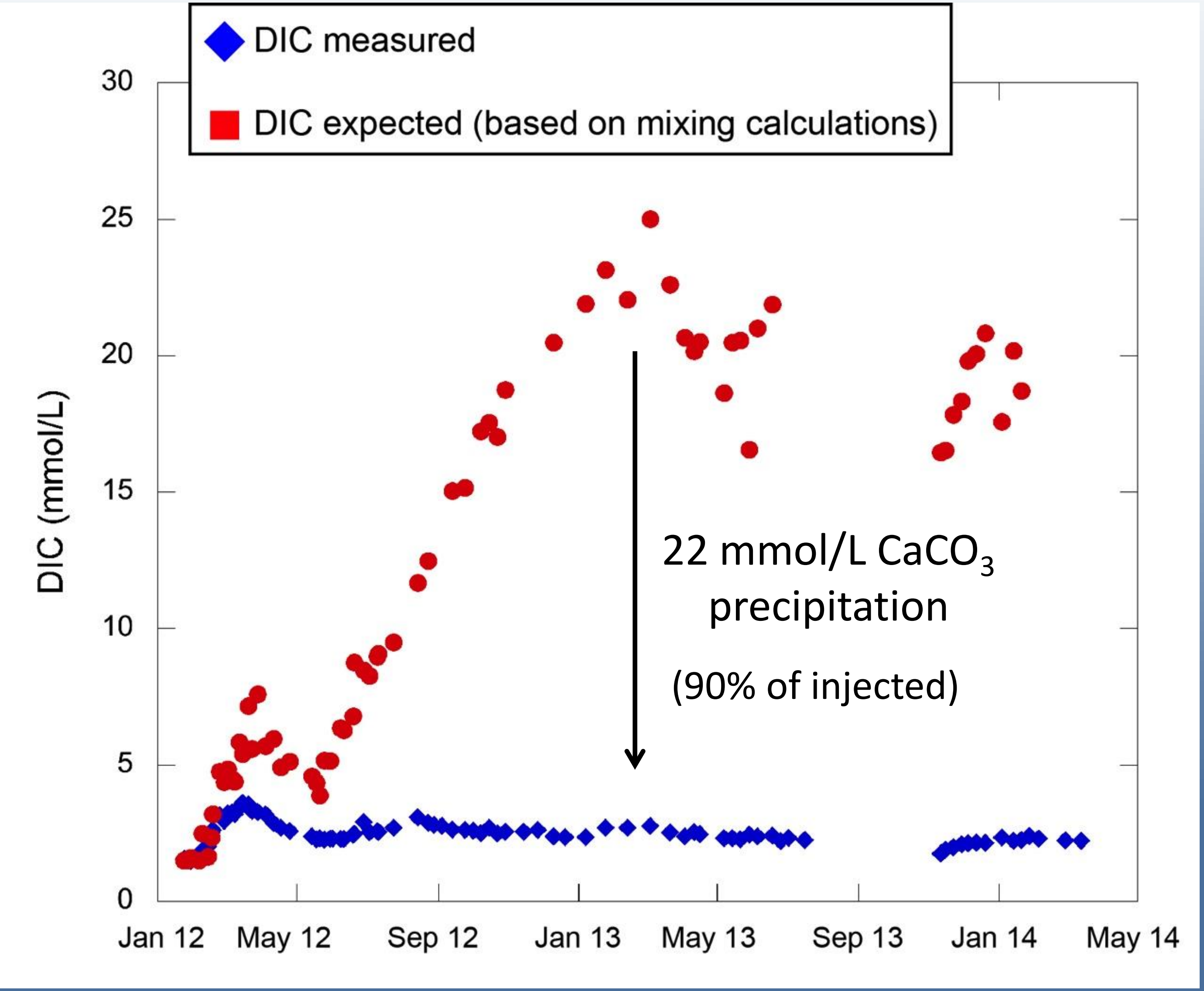
$$DIC_{mix} = X_{SF6} \times DIC_{IS} + \left(1 - X_{SF6}\right) \times DIC_{BW}$$

3. Calculating difference between measured and theoretical DIC

$$\mathrm{D}DIC = DIC_{sample} - DIC_{mix}$$

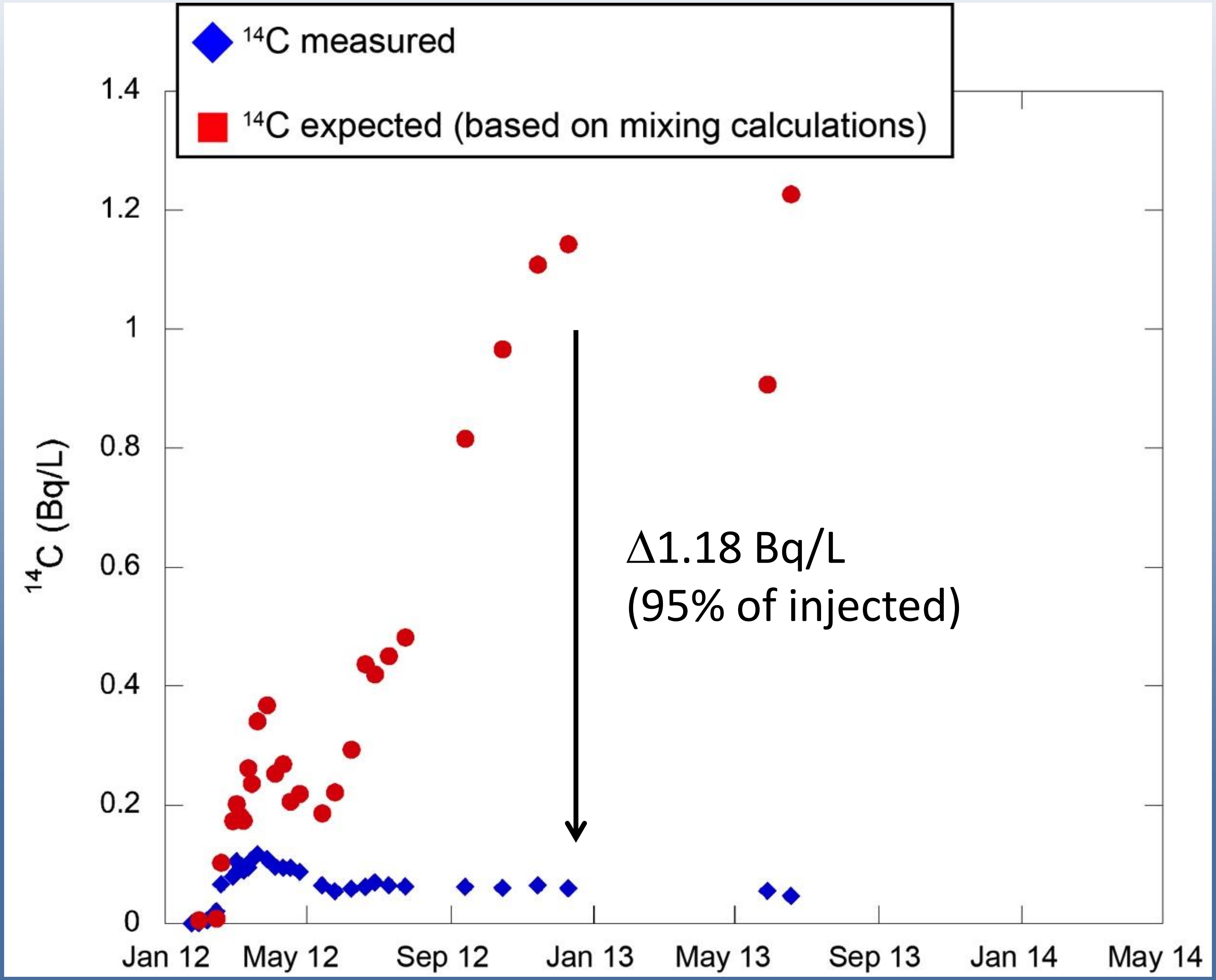
Carbon mass balance

expected vs. measured DIC concentration



^{14}C mass balance

expected vs measured ^{14}C concentration



Future Opportunities at CarbFix Test Site

- Study effect of gas composition (impurities) injected into subsurface on geologic carbon storage efforts on industrial scale
- Improvement and optimization of gas separation techniques
- Develop new and refine existing chemical and geophysical monitoring and verification techniques
- Study practical tolerance levels of injected gas composition (impurities) with regard to pipeline and well design and separation capabilities
- Definition and evaluation of environmental safety risks associated with impure CO_2 injections
- Develop best practices for geologic storage of impure CO_2

Oman Drilling Project
Sultanate of Oman

Project Sponsors

icdp

DEEP CARBON OBSERVATORY

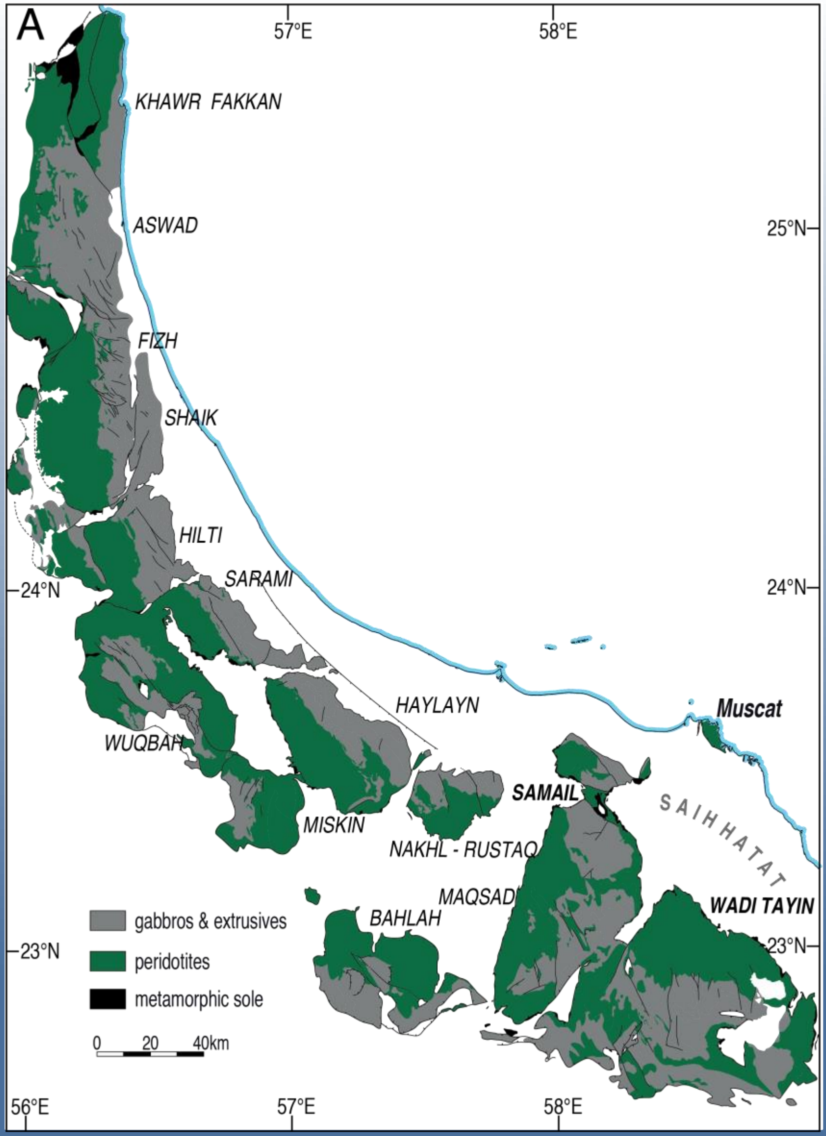
NASA

DFG Deutsche Forschungsgemeinschaft

IODP INTEGRATED OCEAN DRILLING PROGRAM

NSF

Mineral Carbonation in Mantle Peridotite



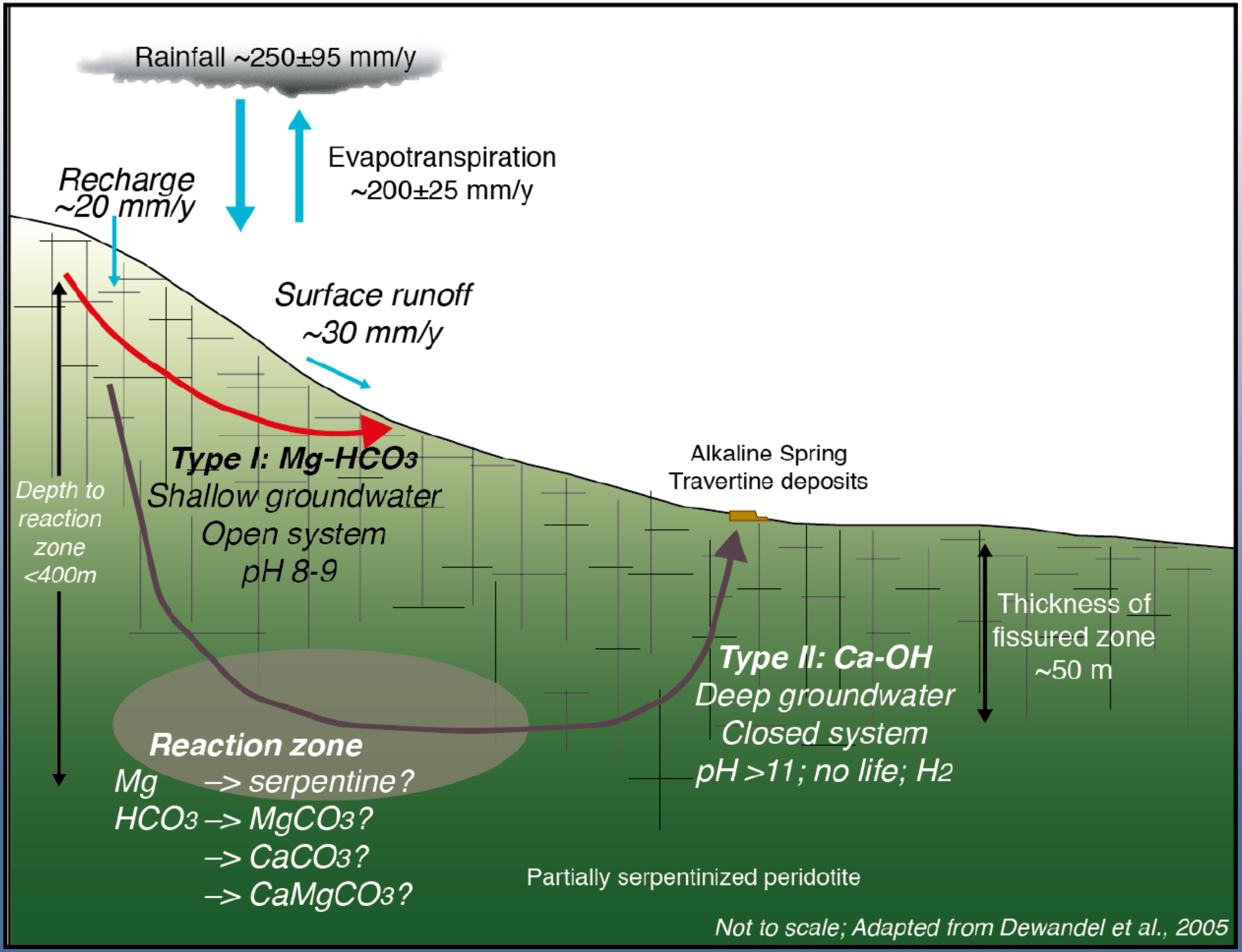
Map of Samail Ophiolite, Oman

Carbonation on surface

Carbonation in subsurface

H_2 and CH_4 production

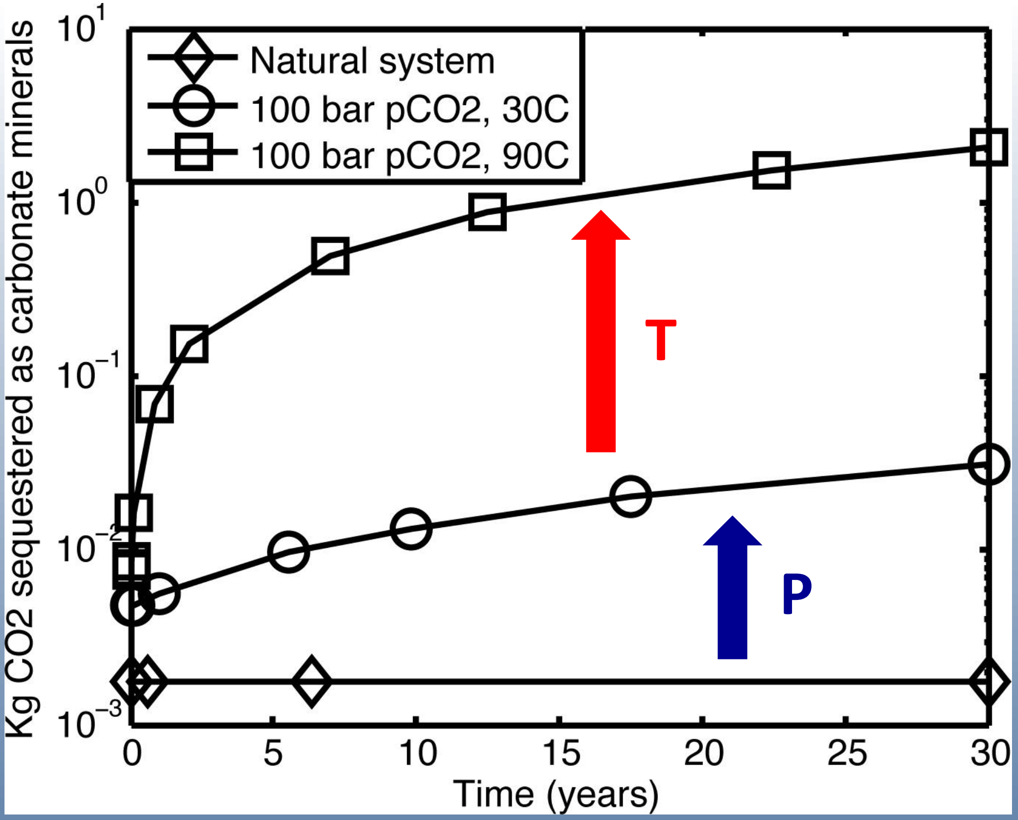
Hydrogeological Model – Carbonation Flow Path



Natural Mineral Carbonation Rate

- rate of solid carbonate formation in Oman is ~10^4 to 10^5 tons CO_2/year
- 1000 tons CO_2/km^3/year in actively carbonating upper 15 m of mantle peridotite
- 4 tons C/km^2/year (CO_2 consumed by weathering: global average is 2 tons C/km^2/yr; Hartmann et al. 2009)

Engineered Carbonation System



- Reaction path modeling using mineral dissolution and precipitation kinetics

- Total amount of CO_2 mineralized in the 90°C scenario is ~1200 x the amount sequestered in the natural system over the same time frame.
- The kg CO_2/kg peridotite ratio in the 90°C scenario is 0.61, which indicates almost complete mineralization (complete forsterite mineralization -> 0.63 ratio)

Paukert et al. 2012

Research Opportunities Oman Drilling Project

- Oman Drilling Project will provide a subsurface laboratory to study CO_2-rock-water interactions relevant for CO_2 storage, to evaluate feedback mechanism between CO_2-rock-water reactions and geomechanics, and to test novel chemical and geophysical monitoring techniques related to geologic carbon storage
- Study feedback mechanism between CO_2-rock-water interaction and geomechanics
- Understand generation of abiotic methane and hydrogen
- Study role of deep subsurface biosphere in carbon storage