Gases in Geothermal Fluids and Gas Emissions from Geothermal Power Plants

WORLD BANK GROUP
Energy & Extractives
ESMAP
Energy Sector Management Assistance Program

Thráinn Fridriksson

Global Geothermal Roundtable III: Reykjavík, April 26, 2016

Outline

1. Interim Technical Note Addressing Greenhouse Gas Emissions from Geothermal Power Projects – Key Findings and Recommendations
2. Gases in Geothermal Solutions
3. Global Emission Factors for Geothermal Power Plants
4. Processes Affecting GHG Emission Factors
5. Cost of GHG Capture and Treatment
6. Summary and Conclusions

Interim Technical Note

Addressing Greenhouse Gases from Geothermal Power Production

Prepared by ESMAP for World Bank teams preparing investment projects involving geothermal power

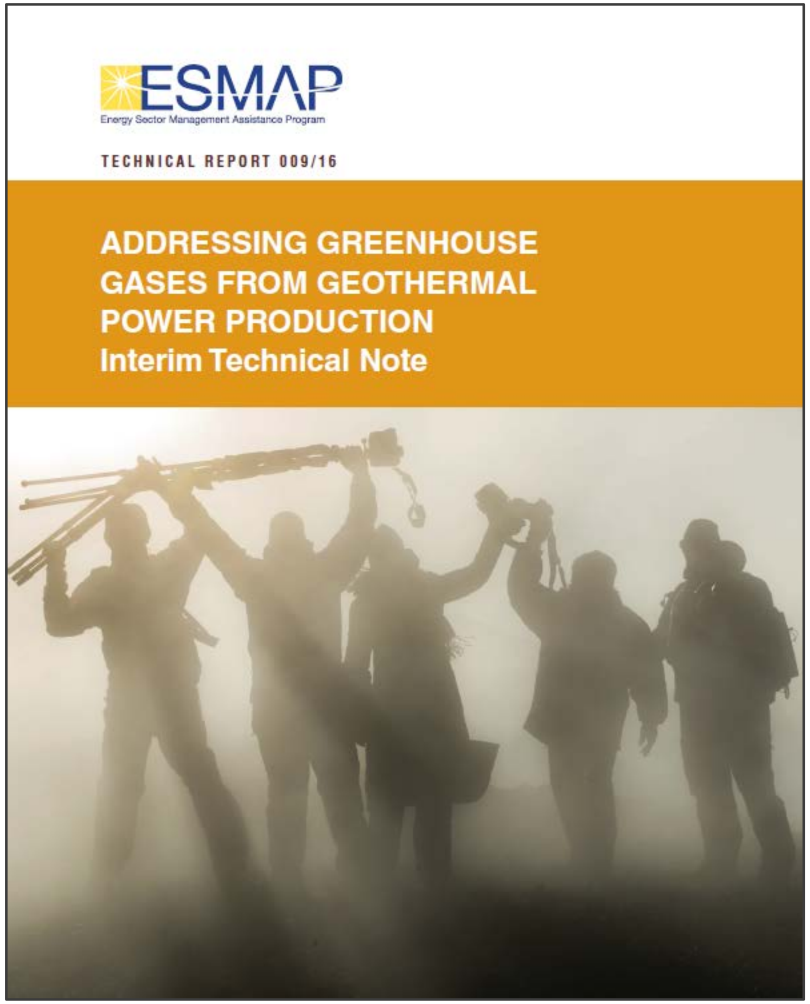
Extensive review by World Bank specialists and an external panel of sector experts

Two main sections:

Part 1 Review of Existing Knowledge of GHG Emissions from Geothermal Systems and Power Plants

Part 2 Guidance on Methods to Assess Emissions from Geothermal Power Projects

Formally released at the Global Geothermal Roundtable in Reykjavik



Interim Technical Note

Existing Knowledge of GHG Emissions from Geothermal Systems and Power Plants

Key Findings

- GHGs naturally present in geothermal fluids and geothermal power production generally leads to some GHG emissions
- Global average GHG emissions from geothermal power are small relative to emissions from fossil fuel
- In rare cases geothermal GHG emissions can be significant, specifically for resources in carbonate bearing reservoir rocks
- GHG emissions may change over time due to natural causes and in response to production
    - **Magmatic activity** can *increase* emissions
    - **Steam cap** formation may result in temporary *increase* or *decrease* in emissions depending on production strategy
    - ***Reinjection*** generally tends to *decrease* emissions
    - **Production** may *decrease* or *increase* emissions through natural pathways – very limited information available
- All technologies suitable for high temperature resources result in emissions unless capture facilities are installed
- Capture and treatment can be economically feasible where there is a market for CO_2 products

Interim Technical Note

Guidance on Methods to Address Emissions from Geothermal Power Projects

Systematic approach to estimate future emissions from geothermal projects is presented

Available information	Estimation of GHG emission factor
No information on geology or energy conversion technology OR volcanic rocks expected at reservoir level	As a default, assume GHG emission factors are equal to the global weighted average CO_2 emission factor, 128 gCO_2e/kWh
unless	
Carbonate rocks expected at reservoir level	Anticipate high GHG emission factors – 790 gCO_2e/kWh
or	
Existing geothermal power plants in analogous geological setting	Use GHG emission factors from neighboring / analogous power plants if available and if geological conditions are comparable
or	
Pumped binary technology anticipated	Assume emission factor of 0 gCO_2e/kWh
or	
Exploration wells drilled and discharge tested? Pumped binary not feasible	Detailed methodology provided to compute emission factors based on gas concentration in steam and energy conversion factor

Key Recommendations

- Collect GHG emission data from power plants to improve understanding on changes with time
- Promote studies of GHG emissions through natural pathways before and after commissioning of power plants to close a critical knowledge gap of this process
- Where GHG emissions from geothermal projects are above the national grid emission factor encourage feasibility studies of GHG capture and
- Provide financing for GHG capture where found to be economically feasible

Composition of Geothermal Gas and Potential Impacts

Wt% Dry Gas, Based on 15 Representative Analyses from Varied Geologic Settings[1]

	Median[1]	Maximum[1]	Minimum[1]	GHG	Toxic	Odor	Corrosive	Flammable
CO_2	95.4	99.8	75.7	Yes				
H_2S	3.0	21.2	0.1		Yes[2]	Yes[2]	Yes	Yes
CH_4	0.15	1.7	0.0045	Yes				Yes
H_2	0.012	2.2	0.001					Yes
NH_3	0.29	1.8	0.005		Yes	Yes		
N_2	0.84	3.0	0.17					
Ar	0.02	0.04	0.004					
Hg, B, Rn	Trace				Yes			

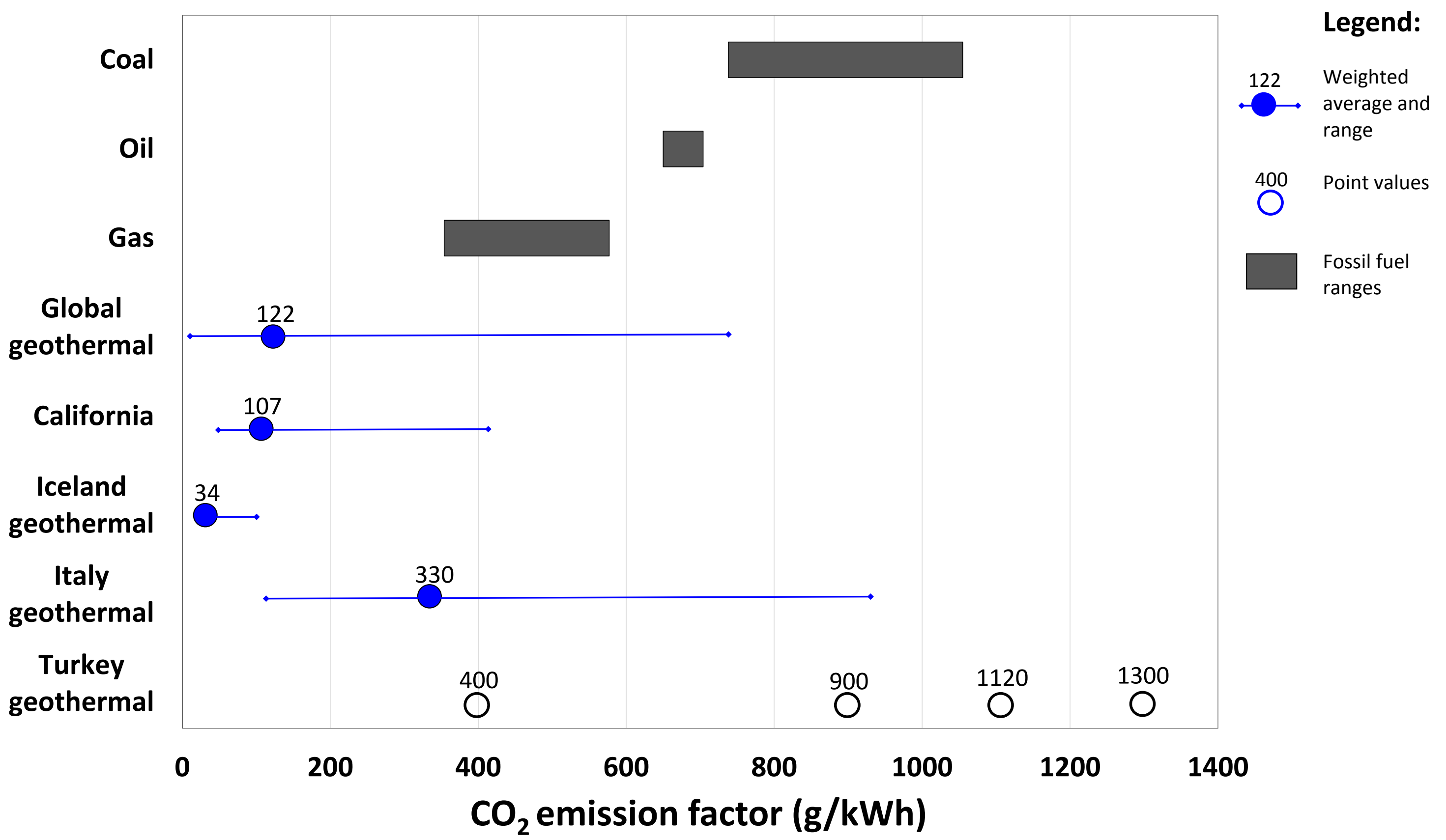
[1] Concentration Data from Arnorsson et al., (2007),

[2]H_2S is lethal at moderate concentrations (700 mg/kg) and an odor nuisance at low concentrations

CO_2 emission factors

FOR GEOTHERMAL POWER COMPARED TO FOSSIL FUEL POWER (ESMAP, 2016 AND REFERENCES THEREIN)

- Global average emission factors for geothermal plants is **122 g/kWh**[1] compared to **~450 g/kWh** for Gas Plants and **~1000 g/kWh** for Coal Plants
- High emission Geothermal Plants occur in regions dominated by carbonate bed-rock



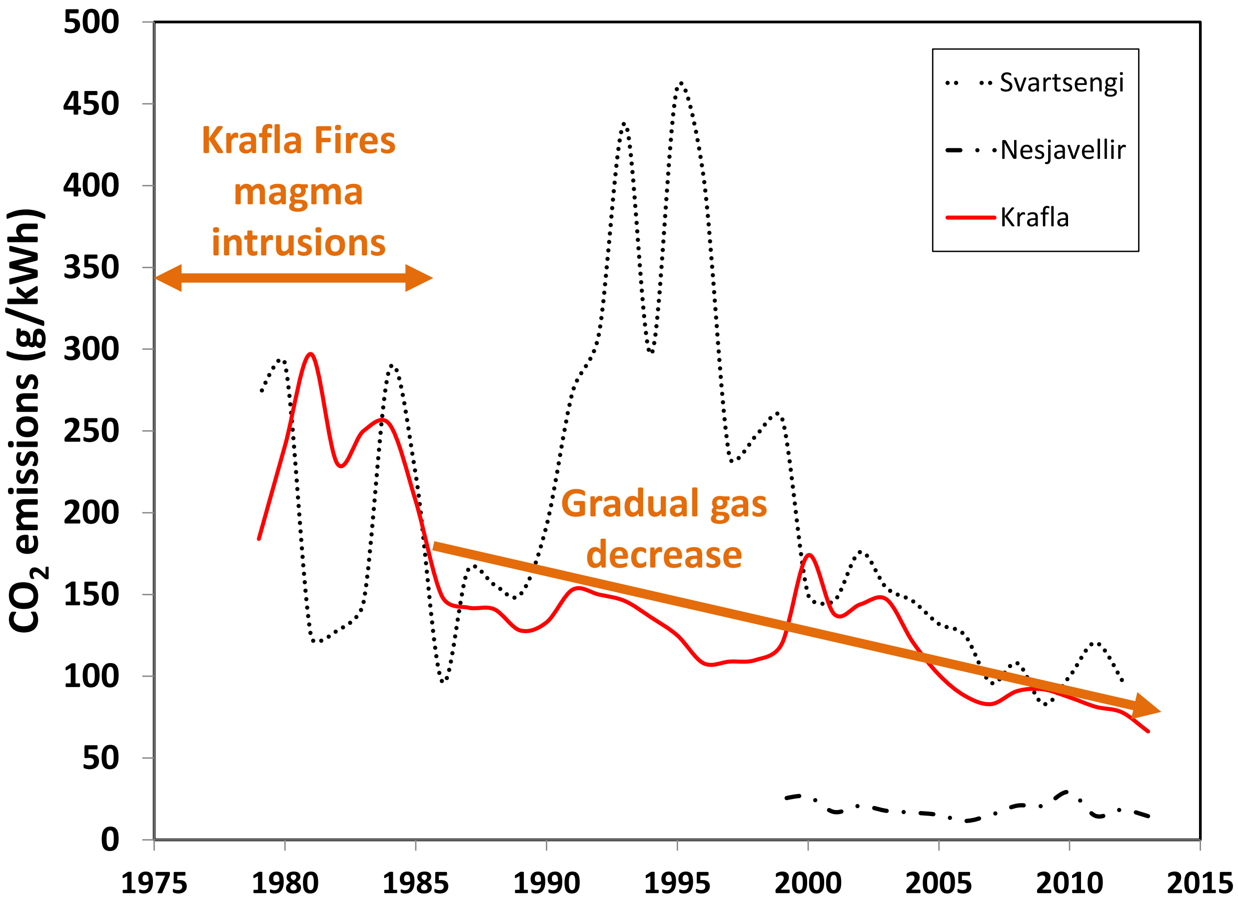
[1] Bertani and Thain (2002)

Processes Involving CO_2 in Geothermal Systems

Examples From Three Icelandic Geothermal Systems

Krafla

- Magma intrusions related to the Krafla-Fires 1975 to 1984 caused an early emission spike
- Overall decrease since 1985 as the system is gradually approaching mineralogical equilibrium
- Reinjection of gas free brine may also play a role in decrease
- Occasional spikes as new high gas wells were taken into production

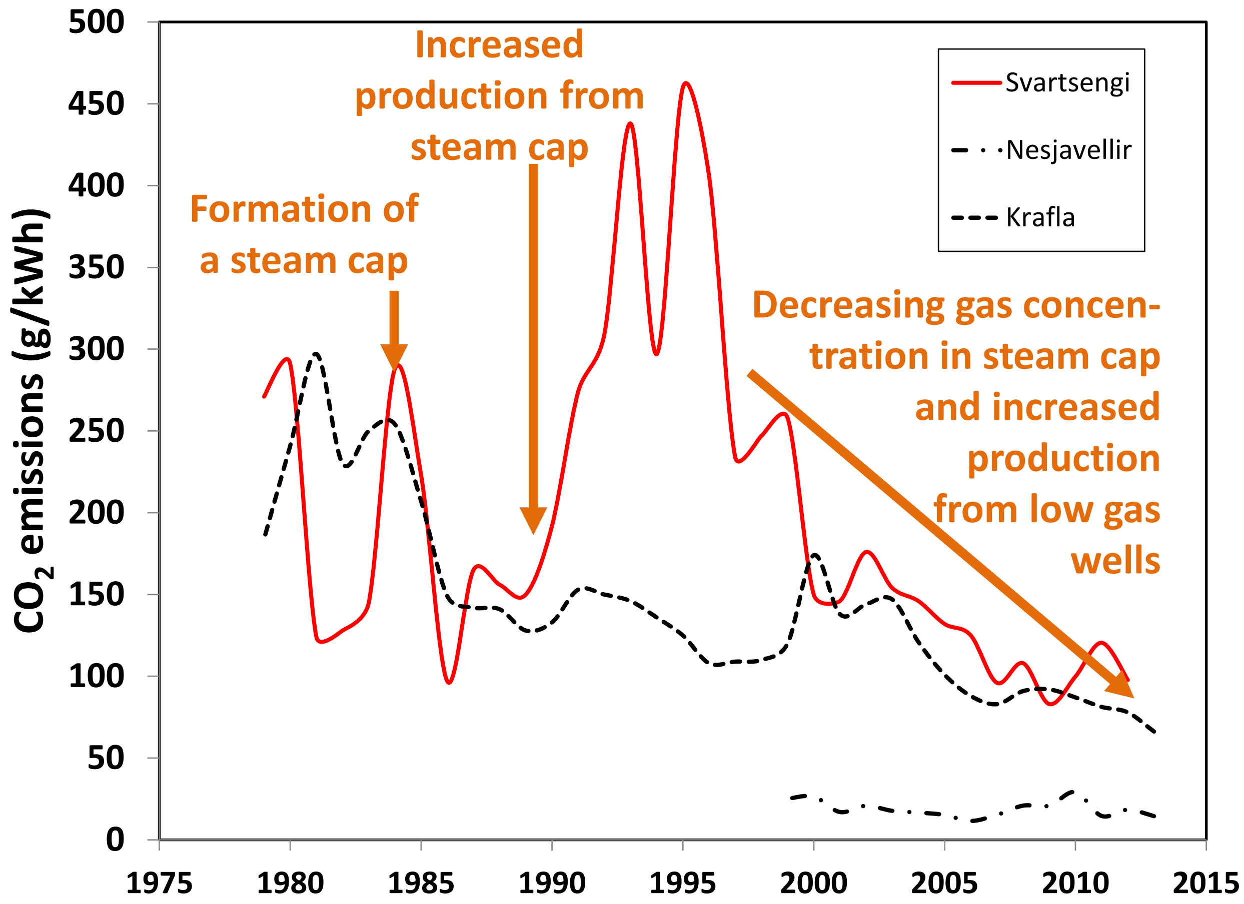


Processes Involving CO_2 in Geothermal Systems

Examples From Three Icelandic Geothermal Systems

Svartsengi

- Production resulted in formation of a gas rich steam cap over a part of the reservoir by mid 1980s
- In early 1990s production from steam cap increased
- Gas emission has decreased since late 1990s due to
  - **decreasing gas concentration in steam cap,**
  - **increased production from deep low-gas wells and**
  - **reinjection**

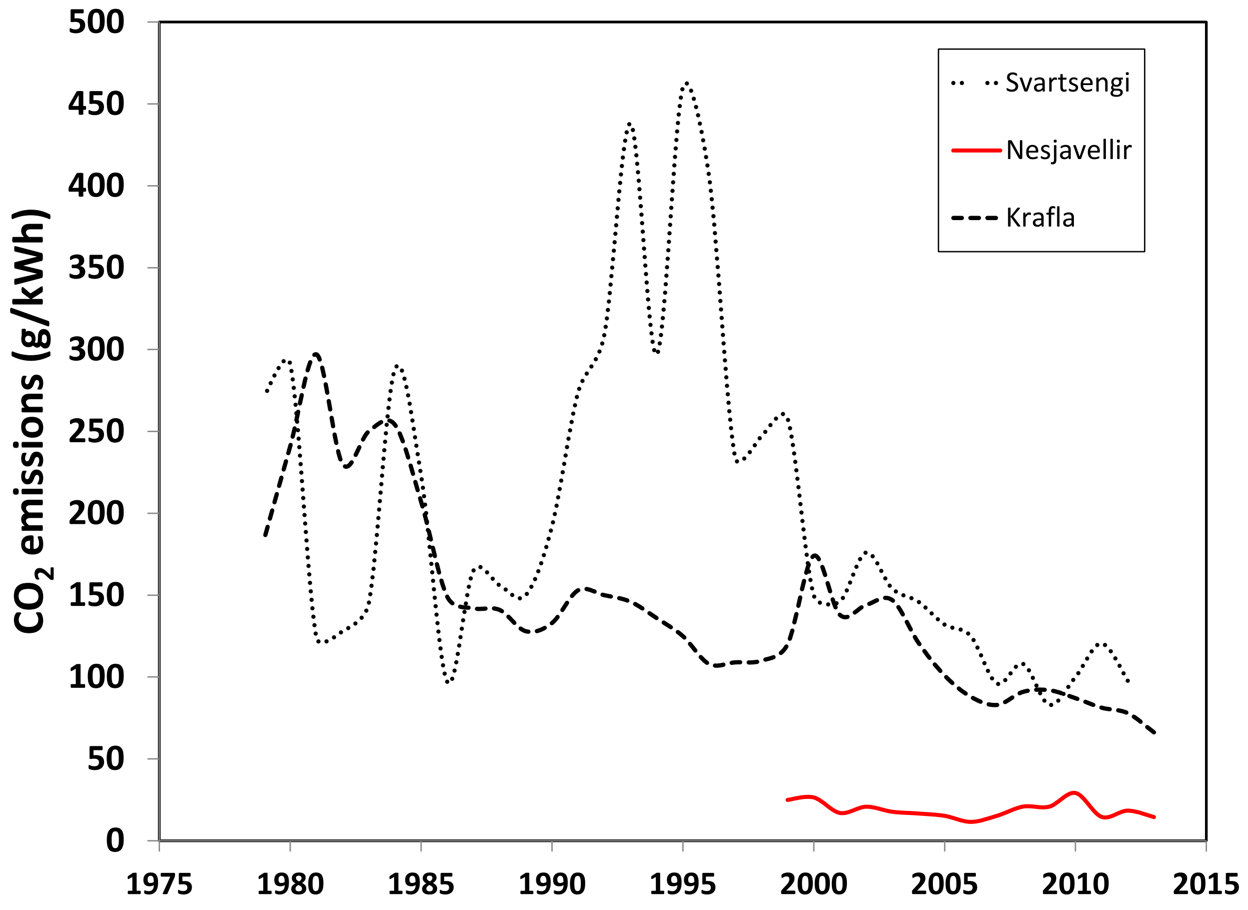


Processes Involving CO_2 in Geothermal Systems

Examples From Three Icelandic Geothermal Systems

Nesjavellir

- Consistently low gas emission
- Minor fluctuations due to new production wells
- Overall trend towards decreasing emissions

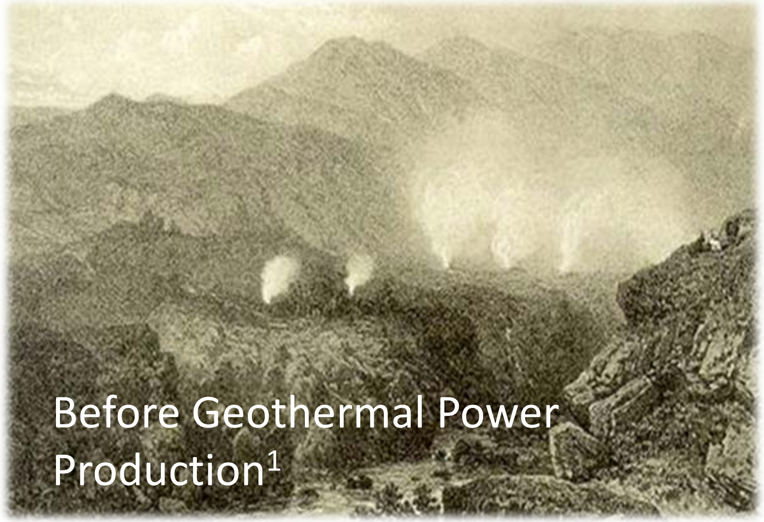


Effects of Geothermal Power Production on Natural Emissions

Larderello, Italy

Geothermal power production may result in **decreasing emissions of CO_2** through natural pathways, i.e. fumaroles and soil.

- The Larderello area, Tuscany, Italy, is an example of an area where surface activity, and by proxy CO_2 emission, greatly decreased in response to power production.
- As a result, in Italy emissions from geothermal power plants are not considered anthropogenic as they are offset by a reduction in natural emissions



References:
[1] G. Jervis (1868)
[2] Photo from ENEL Green Power

Effects of Geothermal Power Production on Natural Emissions

Reykjanes, Iceland

- A 100 MW geothermal power plant was commissioned at Reykjanes in 2006. The production resulted in pressure drawdown that **increased** surface activity and **CO_2 emission**
- Heat flow and CO_2 flux through surface has been monitored and is still increasing
- Emissions from geothermal power plants are considered anthropogenic in Iceland

: Before commissioning of 100 MW Plant

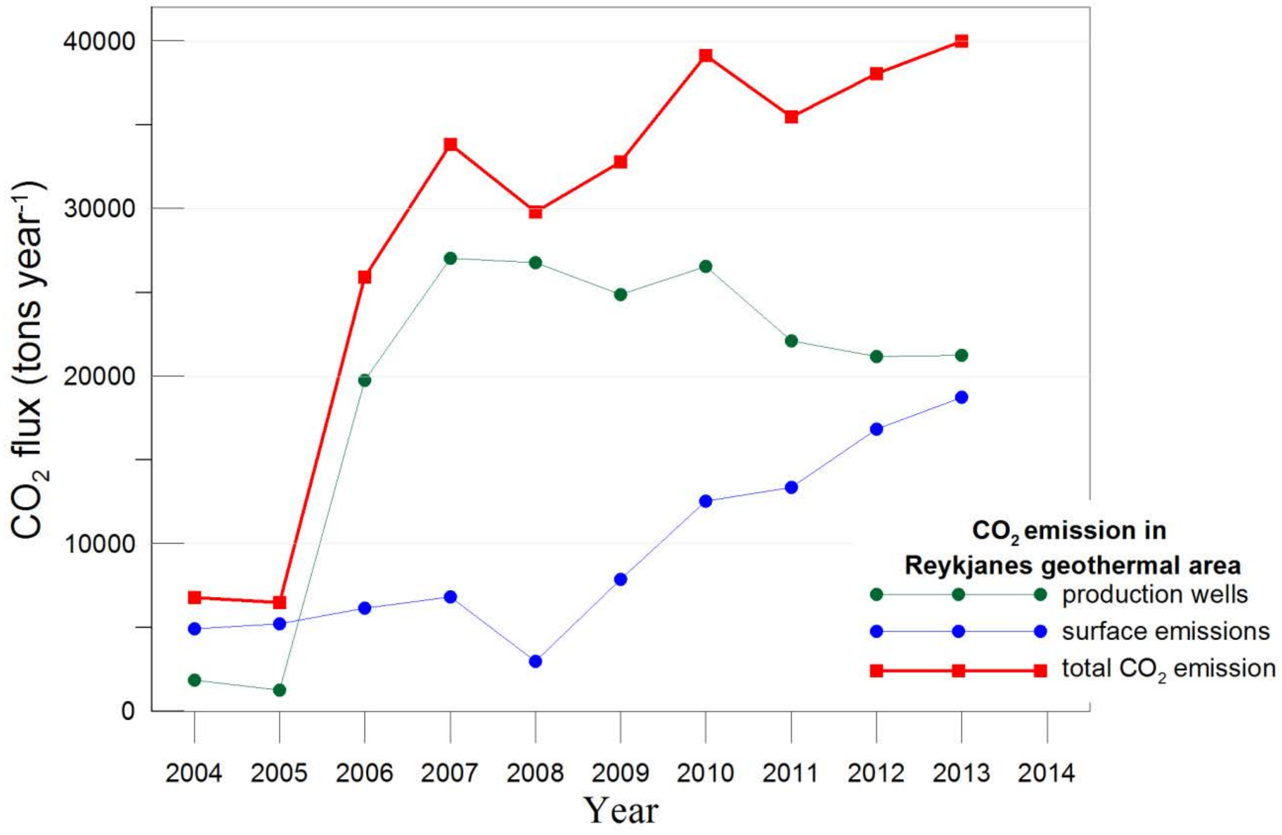
: After commissioning of 100 MW Plant

Source:
Iceland GeoSurvey

Effects of Geothermal Power Production on Natural Emissions

Reykjanes, Iceland

- A 100 MW geothermal power plant was commissioned at Reykjanes in 2006. The production resulted in pressure drawdown that **increased** surface activity and **CO_2 emission**
- Heat flow and CO_2 flux through surface has been monitored and is still increasing
- Emissions from geothermal power plants are considered anthropogenic in Iceland



Source:
Iceland GeoSurvey

Early Phase Cost Evaluation of CO_2 Capture and Treatment

ESMAP (2016), Trimeric Corporation (2015)

- Technologies to capture and treat geothermal CO_2 are commercially available
- Cost depends on a number of factors, including gas composition and gas supply (amount)
- Analysis conducted assuming supply of
  - 50 tonne/hour
  - Relatively pure CO_2
  - US labor and material cost
  - Power cost of 10.5 USc/kWh
- Market price for beverage grade CO_2 varies; can be 100 – 200 USD per tonne
- Local demand may limit the feasibility of CO_2 capture from high CO_2 systems

Product	Power usage (MW)	Treatment cost (USD per tonne CO_2)
Greenhouse CO_2 *Removal of H_2O, H_2S, NH_3, Hg*	0.21	5.24
Reinjection of CO_2 *Removal of NH_3*	3.2	10.3
CO_2 for EOR *Removal of H_2S, NH_3, H_2O*	3.7	15.4
Beverage grade CO_2 *Removal of H_2S, NH_3, H_2O, N_2, H_2, Ar, CH_4, COS, C_2H_6*	4.8	23.0

Summary and conclusions

- GHGs naturally present in geothermal fluids and geothermal power production generally leads to some GHG emissions
- Global average GHG emissions from geothermal power are small relative to emissions from fossil fuel
- In rare cases geothermal GHG emissions can be significant, specifically for resources in carbonate bearing reservoir rocks
- More data are needed to improve understanding of evolution of GHG emissions from geothermal systems under production, especially emissions through natural pathways
- Technologies for gas capture and treatment are commercially available
- GHG capture can be commercially viable
- Methodology to estimate future GHG emissions from geothermal projects has been proposed
- Critical knowledge gaps regarding evolution of emissions are identified recommendations have been made towards closing those gaps
- Feasibility studies for gas capture are recommended where emissions are significant
- It is recommended to provide additional financing for GHG capture investments where economically feasible

TFRIDRIKSSON@WORLDBANK.ORG

Thank You.

The World Bank
1818 H Street, NW | Washington DC, USA
www.esmap.org | esmap@worldbank.org

WORLD BANK GROUP
Energy & Extractives
ESMAP
Energy Sector Management Assistance Program