

Geothermal gas management at Hellisheidi Power Plant

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Benefits of geothermal in Iceland

Economic, environmental, social ...

- Households and companies
 - Affordable electricity and heating
 - Public health
- Economic
 - In 2010 Iceland's total economic benefit from geothermal was calculated to be about **\$600** million
- Environmental
 - Reduced carbon footprint by ≈ 4 million tons CO₂ equivalent



Not without challenges

Geothermal energy and geothermal gas emissions



- Emissions
 - CO₂, H₂S
 - H₂, N₂, CH₄, Ar
 - Environmentally significant
 - Greenhouse gases, corrosive, toxic, flammable, foul smell
- Origin
 - Magmatic
 - Meteoric/precipitation
 - Water rock reactions

Geothermal power plants by the Hengill central volcano

Nesjavellir



Commissioning 1990-2005
120 MW_e and 400 MW_{th}
H₂S: ≈ 9,000 tons
CO₂: ≈ 16,000 tons
30 km. from the Capital area

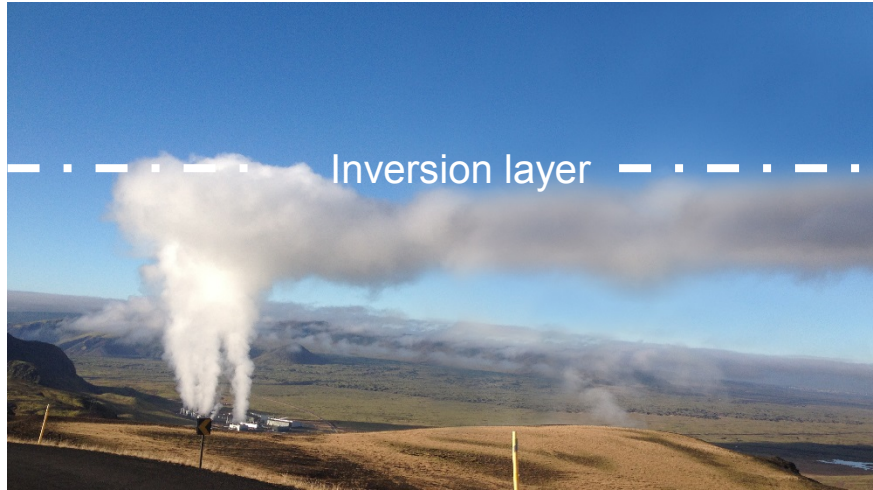
Hellisheidi



Commissioning 2006-2011
303 MW_e and 133 MW_{th}
H₂S: ≈ 11,000 tons
CO₂: ≈ 40,000 tons
20 km from the Capital area

Social acceptance

Geothermal utilization met its most serious challenge for decades



- In 2006 complaints and demands for cleaning the H_2S gas from the Hellisheidi Power Plant
- Plans were for new power plants in the Hengill area
 - Declared in EIAs the H_2S would be abated
- In 2007 a team of experts began the development of injecting H_2S into the basaltic bedrock

Complaints reflected in regulation

Icelandic regulation 514/2010 on atmospheric concentration of H₂S

- Stricter than WHO guidelines
- Requires the geothermal industry in Iceland to reduce atmospheric concentration
- Power companies obliged to conduct measurements in cooperation with authorities

Guidelines/ regulation on atmospheric H ₂ S concentration	Averaging period	Value µg/m ³
WHO Air quality guidelines, 2 nd Edition	24 hour	150
Icelandic regulation 514/2010	24 hour	50*
	3 hour	150
	1 year	5

* Allowed instances of surpassing limit is 3 times per year

United front against the challenge



- The largest environmental challenge OR was facing
- Formal collaboration between Iceland's three largest geothermal companies
 - OR
 - Landsvirkjun
 - HS Orka
- OR rightfully was in the driver's seat

Methods to reduce H₂S



For 20 years OR examined the possibility of reducing emissions of H₂S gas or since before the commissioning of Nesjavellir Power Plant

- Chemical methods
- Biological methods
- Physical methods
- Steam hood ejectors or chimneys

Traditional methods

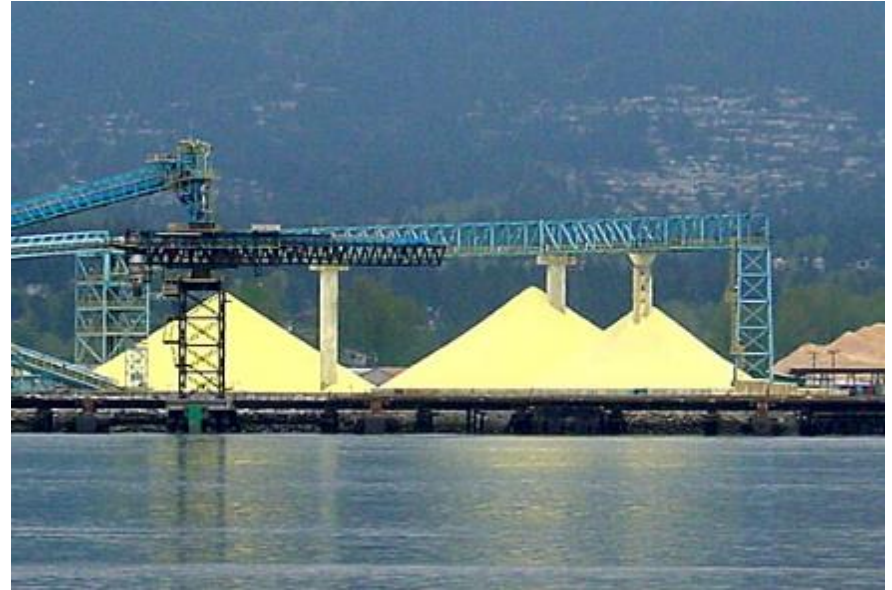
Pressure on OR to resolve to off-the-shelf solutions

Chemical and biological methods produce sulfur or sulfuric acid

- Market for sulfur and sulfuric acid is not lucrative
- Would have to be disposed of into sulfur deposits
 - Requires special attention, ground water and biota in the vicinity
 - Flammability

OR's main stressing point:

- Traditional methods don't solve the problem but merely relocate it



Methods to reduce H₂S



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- Biological methods
- **Physical methods**
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During the debate scientists had been working...

CO₂ abatement and subsurface sequestration

6 SUNNUDAGUR 15. JANÚAR 2006

FRÉTTIR

Íslendingar geta orðið frumkvöðlar í bindingu koltvíoíxíðs

Einn fremsti vísindamaður heims í rannsóknunum á umhverfisbreytingum, Wallace B. Broecker, fjallaði í fyrirlestri um glímunna við loftslagsbreytingar. **Andri Karl** kynnti sér hvernig mannkynið getur tekið á við hlýmun loftslags og hvernig Íslendingar geta komið að þeirri baráttu.



Á nekkern þíttvaru fjólkingsvægar hóu senn í með tölvagæðittum og kláun heitlingar um loftlagssvæði va loftlagi vörð grípið er til ka gæða. Síva eru hláttin einar áframtíttina og í komna máli og um hvernig þe

Kyrotokkum aðeins lífið se

Broecker seokuphlápa við ekki etli á að árun sem lífið jarðar líe kang laður aðar lífið hefta aðkítungu rímslóttina. Ke

sett í gang, einu áhrif í líft að þ Broecker og þe

á þau lífið seokúttinn stinnu sínar minni bonu aðrímmslóttíð íet vagna aðkítgnat og kolúm

Íttann neðr íkylkítríð að n vísóð sem heft vegrum en lítt rímslóttina ala

þjeðu. Undirbálavörðun líttu að þe etti að

áð þonna verbtírt rímslóttina ásamt líttírlög að ríkja samttítt

á millí ríkja he verktarar. Haa þegar se fyrtíttónna í Haaðaríð byggðinga fram gert ríttinn í

Meðal gesta voru forseti Íslands, Ólafur Ragnar Grímsson, og Kristín Ingólfsson, rektor IH.

Wallace B. Broecker er prófessor í jarðfræði við Columbia háskólann í New York og er hér á landi fyrir atvinnu jarðvísindaforsóknir Háskóla Íslands og Ólafur Ragnar Grímsson, forseta Íslands, sem ákveðið hefur að þetta sé fyrir því að vísindamenn, fræðimenn og fyrirtæki í Íslan, menningu og stjórnmálum sátt Íslan þetta og haldi hér fyrirlestra undir samheiti Nýr strömur. Fyrsti fyrirlestrarnir frá fram fyrir líttu hald í Óskju, Náttúruvísindaháskóla Háskóla Íslands, á föstudag og í morgun sagðir forsetinn m. a. stjórklaga árangur með að fá til haldinn gæðun vin til að hefta fyrirlestraróð sína.

Fyrirtætur Broeckers fjalltu um glímunna við loftlagssvæðinga, hvernig mannkynið getur tekið á við hlýmun loftslags af vísitum gróðurháaðrifa og hvern-

Broecker að breyttinn kolvísíðe frá andrímmslóttinu og bindung þess í þjeðu að einu mikilvægasta teftu til að takast á við loftlagssvæðinga.

Ólafur Ragnar tapti einnig á því í ávartí sínu að Broecker, ásamt forsetynni frá Columbia-háskóla í New York, yrð hér á landi næstu daga til að refta miðlungu rímslóttina, s. a. loftlagssvæðinga og bindingu kolvísíðna, við framkvæfa í Íslanaka vísindasamfélagi en þe myndir eru upp um að nýrða grunn að samrímmsvæðitítt Colvísíðna Háskóla Íslands og rannsóknarstöðanna. Þar yrð vísíttíttítt m. a. framhaldnir á mjúktíttinn að binda kolvísíð á Íslan, en íslanokur þe-grunnur yrðu stjórnmálaga til þess.

25 milljarðar tónna koltvíoíxíðs



- In 2006 Wallace Broecker was invited to Iceland by the President to give a talk on climate change
 - Removing CO₂ from the air and sequestering it in the subsurface
- CarbFix initiated in 2007
 - International experts investigate the feasibility of CO₂ sequestration in basalt
- Hellisheidi was an ideal laboratory
 - Stream of CO₂ and ample basalt





OR's pilot stations at Hellisheidi

-capture, transporting and re-injection 2007-2012

CarbFix and SulFix

Same basic processes



Basalt



CO₂ dissolved in water



Carbonates



Basalt



H₂S dissolved in water



Sulfur and Sulfides

CarbFix boosts SulFix



- An international group of scientists and PhD students
- Collaboration between OR, University of Iceland and universities in USA and Europe
- The findings of the CarbFix Project, methodology and technical equipment have been utilized directly in the SulFix project

CarbFix feasibility manifested

Important results in October 2014

- $\approx 90\%$ sequestration in mineral form within a year from re-injection
- Theory confirmed
- The project receives attention in the scientific community
- A boost for the ongoing SulFix project



Calcite from a core of ~ 420 m depth. The green color is calcite marked by tracer.

SulFix

Re-injection in full scale in June 2014

- Stable operation from beginning
- Re-injection of H_2S precipitates in the basaltic rock forming pyrite
- $\approx 2,500$ tons H_2S re-injected in 2015
- $\approx 25\%$ of the H_2S emissions
- 75-80% sequestration in mineral form within six months from re-injection confirmed in 2016

Doubling of capacity in 2016



Dissemination of knowledge

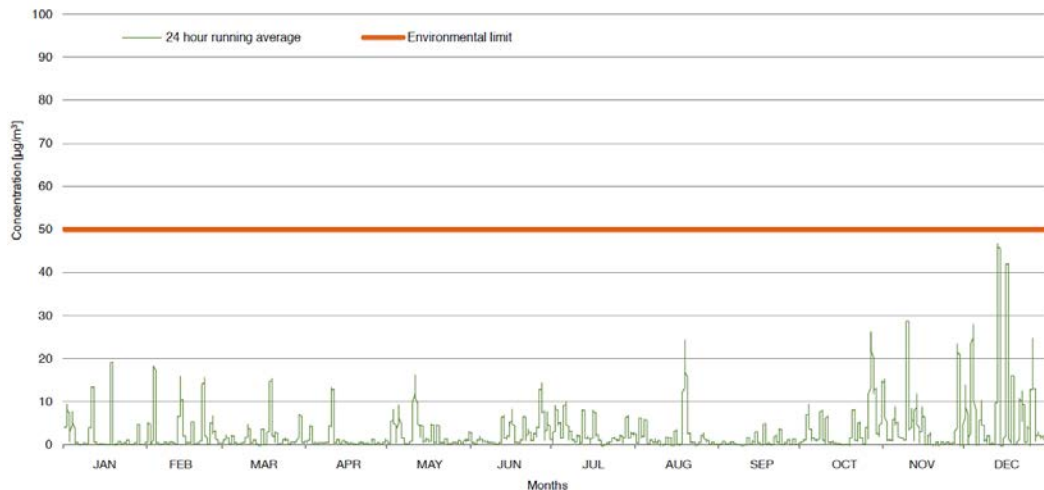


Ségolène Royal



Christiana Figueres

The daily concentration of H₂S in Reykjavik 2015



Year	Number of times environmental limits surpassed
2012	2
2013	1
2014	2
2015	0

* Allowed instances of surpassing limit is 3 times per year

Innovations past and present



- Challenges foster opportunities
- Current challenges have brought innovative solutions
 - Scientists
 - Engineers
 - Tradesmen and –women
 - Workers
 - **Managers**

Lessons learned and implications

Approaching

- Near zero gas emission geothermal power plants
- Acceptance, image and respect
- Diverse use of geothermal gases instead of re-injecting them
- A global alternative?



Photo: www.nasa.gov

