Operational issues in Geothermal Energy in Europe

Annex II: Presentations

October 2016

Table of Contents

Geothermal ERA-NET Workshop "OpERA"

Operational Issues of Geothermal Installations in Europe

Program (status: 28/09/2015)

Thursday, 1st of October 2015:

Moderator: Dario Frigo (Plinius Chemical Consulting)

12:00 - 12:45 ***Registration and Welcome Snack***

12:45 - 13:30 ***Welcome & Introduction***

Netherlands Enterprise Agency (RVO.nl) / Ministry of Economic Affairs Netherlands

Geothermal Era-NET Coordination Office

OpERA Steering Committee

13:30 - 15:10 ***Session I: Country overviews***

13:30 - 13:50 Hungary - Annamária Nádor (MFGI)

13:50 - 14:10 Italy - Adele Manzella (CNR)

14:10 - 14:30 Netherlands - Martin van der Hout (DAGO)

14:30 - 14:50 Slovenia - Andrej Lapanje (GeoZS)

14:50 - 15:10 Germany - Florian Eichinger (Hydroisotop GmbH)

15:10 - 15:30 ***Coffee break***

15:30 - 17:10 ***Session I: Country overviews (continued)***

15:30 - 15:50 Iceland - Hjalti Páll Ingólfsson (Orkustofnun)

15:50 - 16:10 Switzerland - Bernd Frieg (Nagra)

16:10 - 16:30 France - Christian Boissavy (AFPG)

16:30 - 16:50 Denmark - Søren Berg Lorenzen (DGDH)

16:50 - 17:10 Austria - Gregor Götzl (GBA)

17:10 - 18:15 ***Summary, Conclusions and Follow up***

Dario Frigo (Plinius Chemical Consulting)

Paul Ramsak (RVO)

Stephan Schreiber (PtJ)

19:00 - 22:00 ***Dinner at Kasteel Vaalsbroek (incl. reception)***

Geothermal ERA-NET Joint Activity “OpERA”

Operational Issues of Geothermal Installations in Europe

Friday, 2^{nd} of October 2015:

Moderator: Dario Frigo (Plinius Chemical Consulting)

09:00 - 10:15 ***Session II: Scaling***

09:00 - 09:15 Netherlands - Radboud Vorage (Aardwarmtecluster 1 KKP BV)

“Experience with scaling in Geothermal wells, especially on lead scaling in Slochteren reservoirs in the Netherlands”

09:15 - 09:30 Hungary - Janos Szanyi (Szeged University)

“Thermal Decomposition of Barite scale by laser”

09:30 - 09:45 Italy - Giordano Montegrossi , (CNR)

“Solute precipitations in geothermal reservoirs: Modelling examples of a SPA project with high precipitating fluid”

09:45 - 10:15 Discussion - Dario Frigo (Plinius Chemical Consulting)

10:15 - 10:35 ***Coffee break***

10:35 - 11:50 ***Session III: Scaling & Gas content***

10:35 - 10:50 Germany - Andreas Rauch (gec-co GmbH)

“PRV-GT - Avoidance of scaling and outgassing with a downhole pressure retention valve”

10:50 - 11:05 Netherlands - Niels Hartog (KWR)

“Carbonate Scaling and the Role of Degassing in Geothermal Systems in The Netherlands: Causes, Effects and Remedies”

11:05 - 11:20 Iceland - Bjarni Már Júlíusson (Reykjavik Energy)

“Tackling the Challenge of GEO Emissions”

11:20 - 11:50 Discussion - Dario Frigo (Plinius Chemical Consulting)

11:50 - 13:00 ***Lunch at venue***

13:00 - 14:15 ***Session IV: Corrosion***

13:00 - 13:15 Iceland - Ingólfur Örn Þorbjörnsson (ISOR)

“Materials for high temperature geothermal utilisation”

13:15 - 13:30 Germany - Simona Regenspurg (GFZ)

“Corrosion monitoring - Experience from the in situ geothermal research platform Groß Schönebeck (Germany)“

13:30 - 13:45 Netherlands - Hans Veldkamp (TNO)

“Identification of corrosion risk in geothermal wells in the Netherlands”

13:45- 14:15 Discussion - Dario Frigo (Plinius Chemical Consulting)

14:15 - 14:35 ***Coffee break***

14:35 - 16:05 ***Session V: Reinjection***

14:35 - 14:50 Netherlands - Wart van Zonneveld (Floricultura)

“Injectivity of gas containing medium in a closed loop geothermal system”

14:50 - 15:05 Hungary - Miklós Hlatki (GW Technology Consulting Ltd.)

“Rock mechanical and formation damage aspects of reinjection into soft Upper-Pannonian sandstones”

15:05 - 15:20 Germany - Marion Schindler & Ludger Küperkoch (BESTEC GmbH)

“Fluid-injection induced seismicity at Insheim geothermal site (Pfalz/Germany)”

15:20 - 15:35 Slovenia - Evgen Torhač (Petrol Geoterm d.o.o.)

“Geothermal district heating with reinjection in Lendava, Slovenia”

15:35- 16:05 Discussion - Dario Frigo (Plinius Chemical Consulting)

16:05 - 17:00 ***Final Discussion, Conclusions and Next steps***

Dario Frigo (Plinius Chemical Consulting)

Paul Ramsak (RVO)

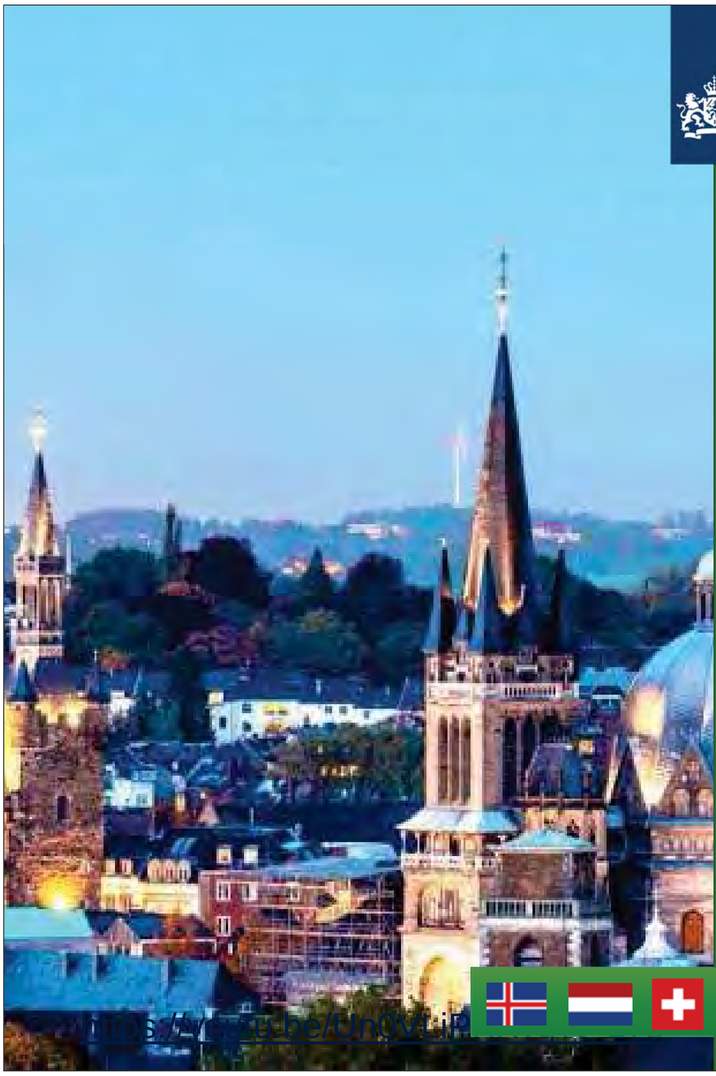
Stephan Schreiber (PtJ)

Venue ***Kasteel Vaalsbroek, Vaalsbroek 1, Vaals, NL***
www.bilderberg.nl/en/vaals/castle-vaalsbroek
(about 7 km from Aachen Central Station)

Netherlands Enterprise Agency

Geothermal ERA-NET

OpERA
welcome



Paul Ramsak
Netherlands Enterprise Agency
OpERA steering committee

OpERA Expert workshop
Vaals (NL/D/B/(M))
1 oct 2015

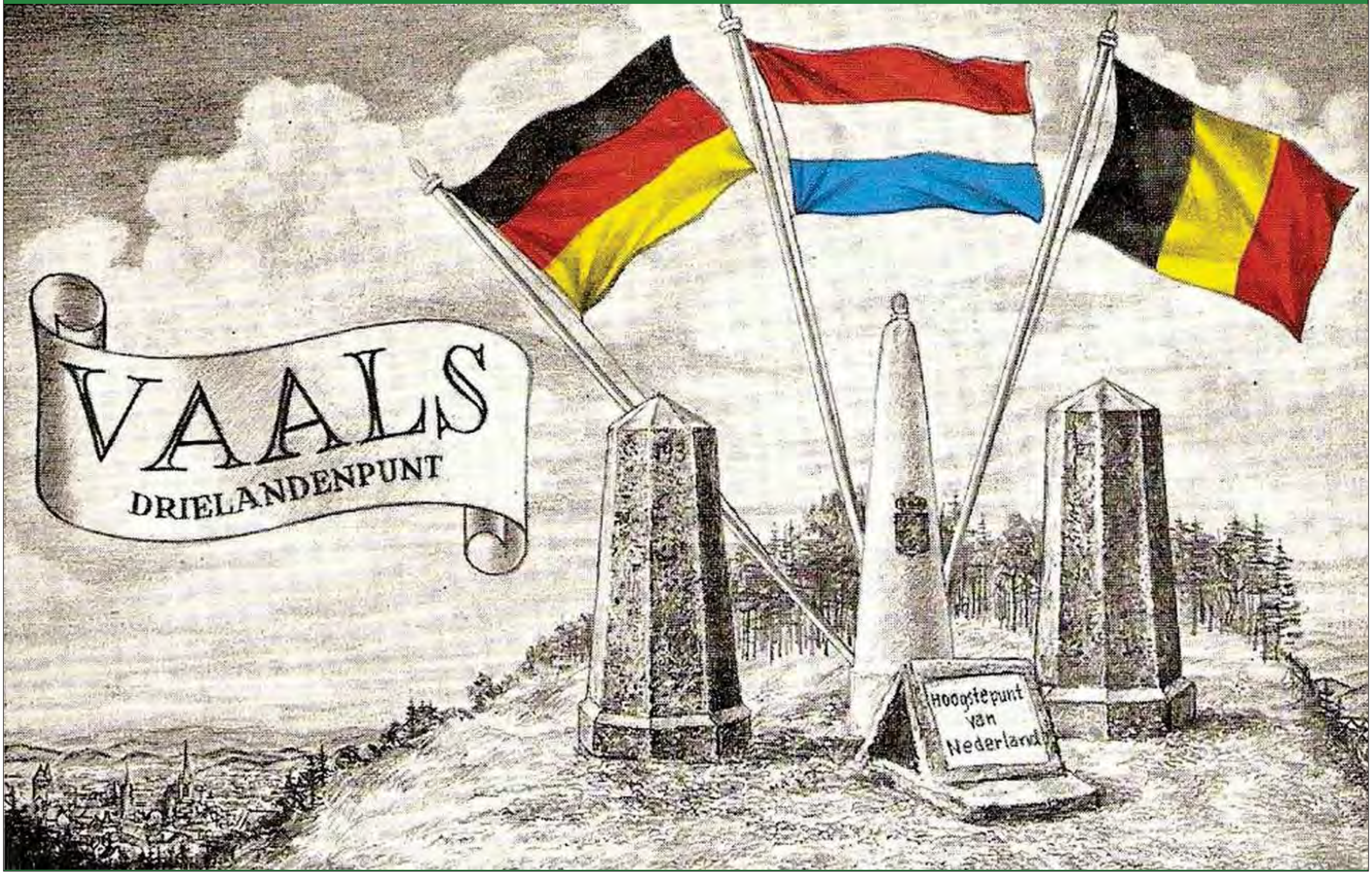
https://youtu.be/Un0VLiP

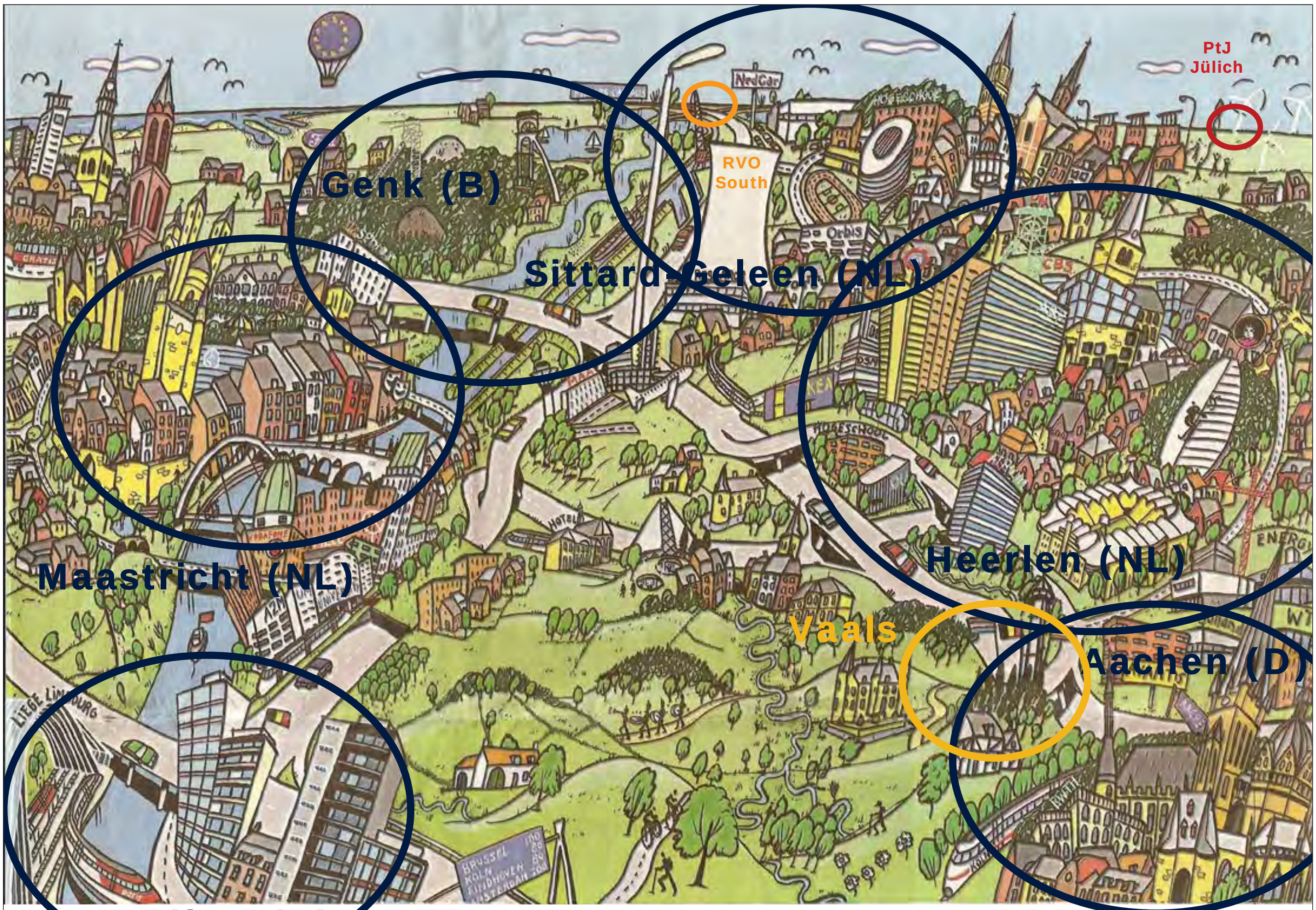

Welcome to Vaalsbroek


Skiing in the Dutch Mountains

Almhütte in the Dutch Mountains

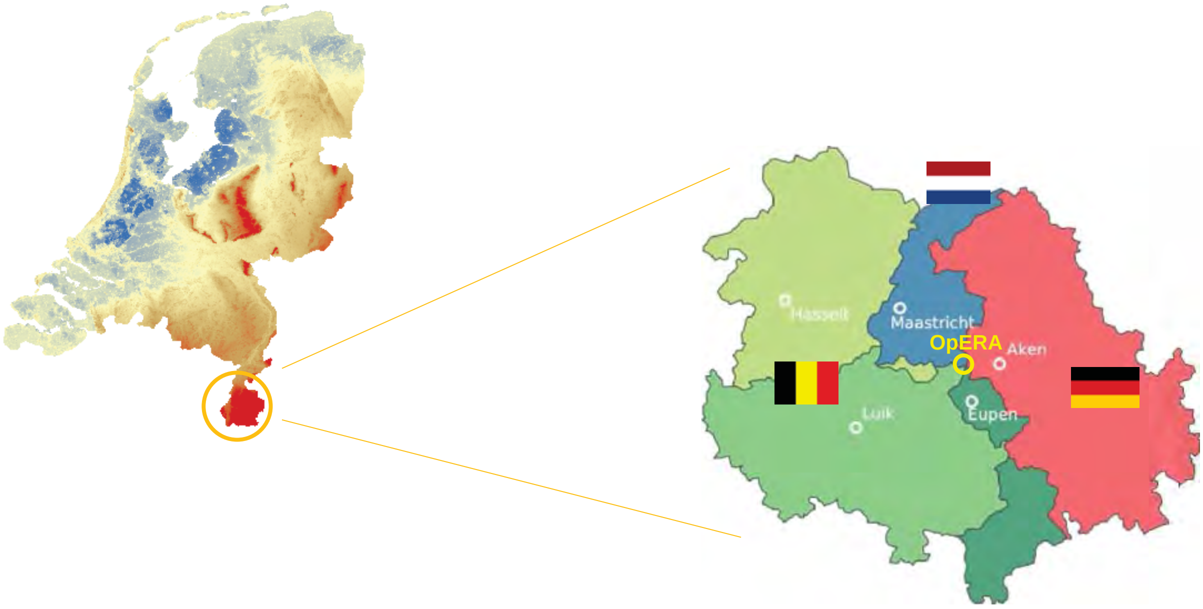
Wine from the Dutch Mountains

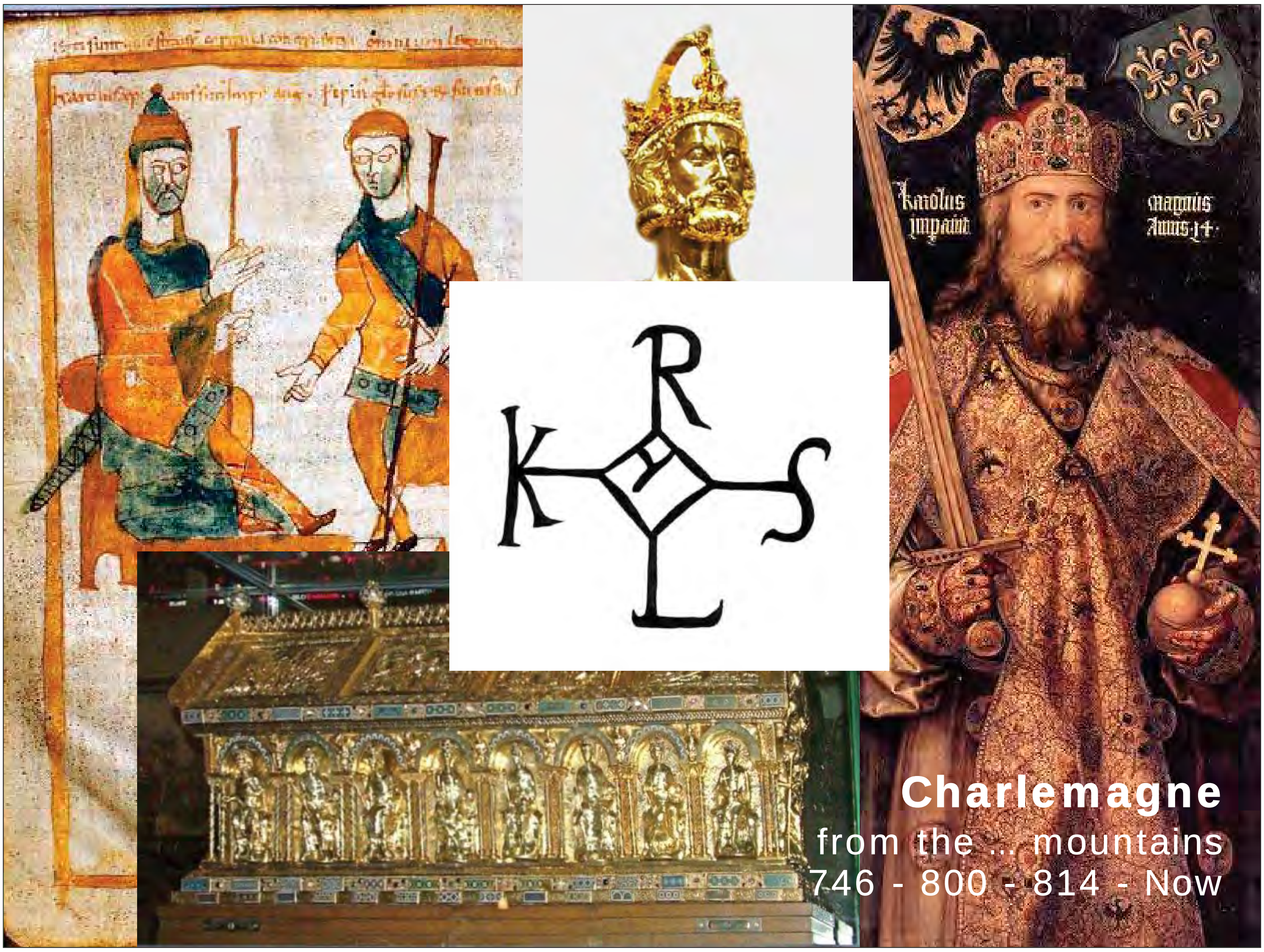




The greater Dutch Mountains

Over 3 ½ Million people…
living in the greater Dutch Mountains





Geothermal wells in Aachen

Aachen-Innenstadt

Name	Temperatur	Förderung	Nutzung
Kaiserquelle	52° C	12 m³/h	Mineralwasser
Rosenquelle AC	47°C	43 m³/h	Carolus Thermen, Quellenhof
Nikolausquelle	31°C		ungenutzt
Großer Monarch	26°C		ungenutzt
Komphausbadquelle			ungenutzt

Burtscheid

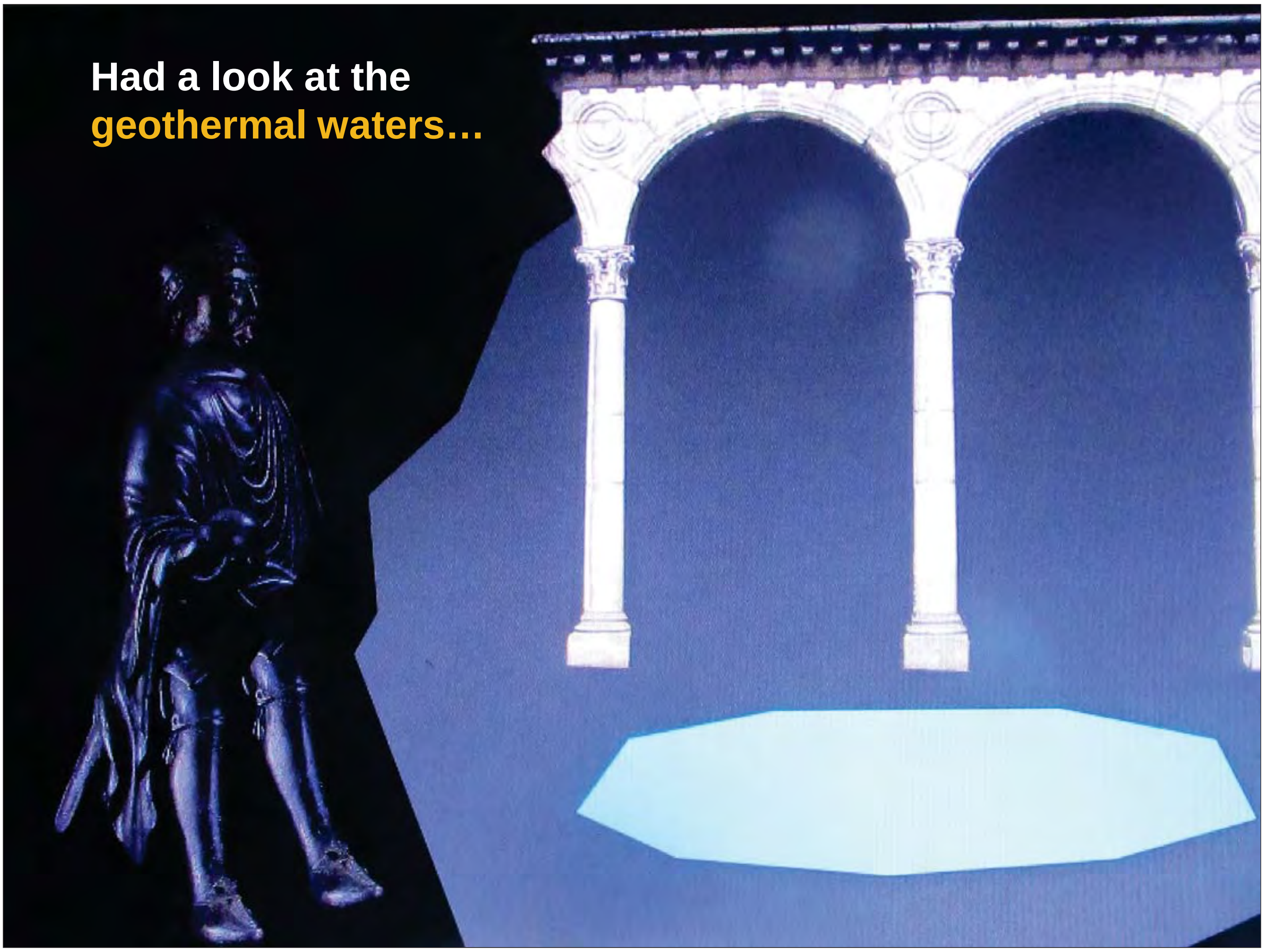
Name	Temperatur	Förderung	Nutzung
Landesbadquelle	70°C	69 m³/h	Kurklinik
Schwertbadquelle	67°C	2 m³/h	Kurklinik
Rosenquelle BS	62°C	14 m³/h	Kurklinik
Schlangenbadquelle	50°C		ungenutzt
Kochbrunnen	44°C		ungenutzt
Mephistoquelle	39°C	6 m³/h	Mineralwasser
Gartenquelle	34°C		ungenutzt
Michaelisquelle	32°C		ungenutzt
Pockenpützchen, Pockenbrünnchen und Schlangenquellchen	28°C		ungenutzt


Landesbadquelle


Gartenquelle


Quellkammer Rosenquelle AC


Charlemagne came…


Had a look at the
geothermal waters…


…and decided to stay


Geothermal naturally !
The last renewable capital of Europe …
below the Dutch Mountains

One of the best states ever… including the Dutch Mountains

Treaty of Meerssen 870

The start of the trouble…decided in the Dutch Mountains


Karel de Grote
Charlemagne
Karl der Große
Carolus Magnus
Geothermal
ERA-NET
Aken
Aix-la-Chapelle
Aachen
800 AD
European
Geothermal


takk fyrir
ORKUSTOFNUN
National Energy Authority
rannís
dank u
NL Agency
Ministry of Economic Affairs
merci
ADEME
grazie
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
teşekkürler
TÜBİTAK
Geothermal
ERA-NET
danke
PtJ
Projektträger Jülich
Forschungszentrum Jülich
ďakujem
Ministerstvo školstva, vedy, výskumu a športu Slovenskej republiky
hvala
Welcome to
OpERA
obrigado
EDA
köszönöm
MFGI
www.geothermaleranet.eu

Contact Geothermal Energy NL Agency

coordinator WP2 Information Exchange Geothermal ERA-NET

www.agentschapnl.nl/aardwarmte

Paul Ramsak
+31-88-602 2275
paul.ramsak@agentschapnl.nl

NL Agency
NL Energy & Climate Change - Sittard
Geothermal Energy

Swentiboldstraat 21
P.O. Box 17
6130 AA Sittard, The Netherlands

www.geothermaleranet.eu

Geothermal ERA-NET

OpERA

Operational Issues of Geothermal Energy Installations in Europe

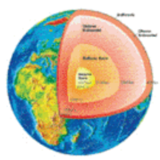
Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

Hjalti Páll Ingólfsson
Project Manager
Geothermal ERA NET Coordination Office

The Geothermal ERA NET is supported by the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 291866

Geothermal energy contributes to the Energy Union

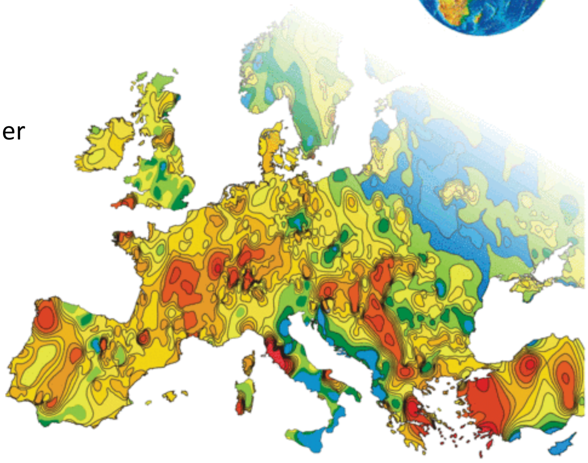
Geothermal ERA-NET



Geothermal energy is environmentally friendly.

It produces reliable baseload **power** and **heat** – all the more important to balance intermittent supplies from other renewable energy sources

Geothermal is a renewable energy source and independent of weather conditions.



Geothermal energy is indigenous and contributes to Europe's security of supply.

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

The Geothermal ERA-NET Consortium

IS	Orkustofnun (National Energy Authority),
NL	Rijksdienst voor Ondernemend Nederland
CH	Swiss Federal Office of Energy (SFOE)
I	National Research Council of Italy (CNR)
D	Jülich (PTJ)
F	ADEME (BRGM as third party)
IS	Icelandic Centre for Research (RANNÍS)
TR	TÜBITAK (Scientific and Technological Research Council of Turkey)
SVK	Slovak Ministry of Education, Science, Research and Sport
MFIG	Hungarian Geological and Geophysical Institute
SED	Slovenian Energy Directorate
EAD	Electicidade dos Acores

Lead partner is Orkustofnun
operating the
Geothermal ERA NET
Coordination Office

Started 2012 for 4 years
Budget 2 millj. €

Good geographical balance (North-West to South-East Europe) Partner countries chosen a.o. on basis of their 2020/2050 geothermal ambitions

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

The three Pillars of the EU Geothermal Policy

ERA NET vision is to

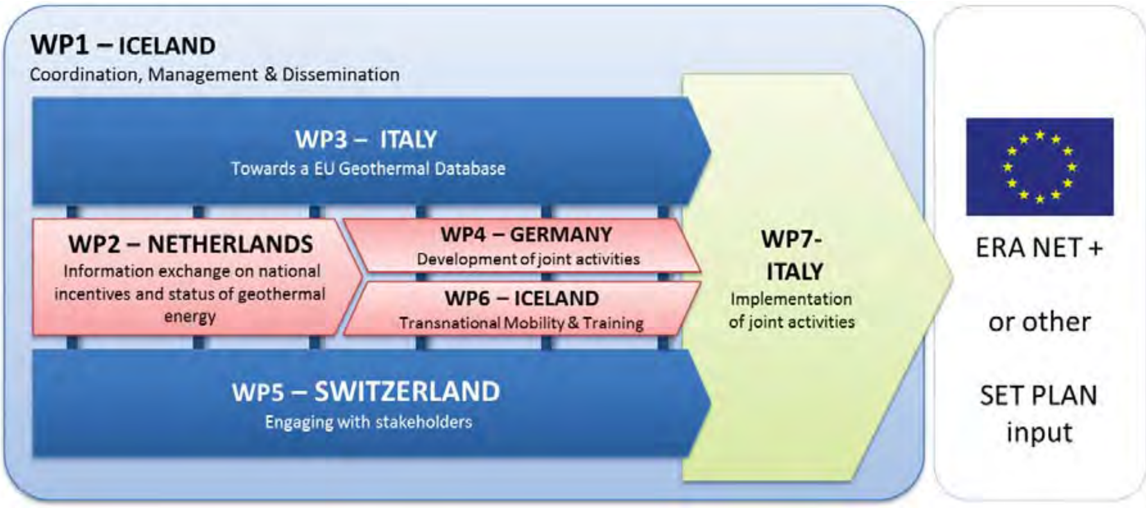
- *<u>minimize the fragmentation</u> of geothermal research,*
- *<u>build on European know-how</u> and know-who to utilize geothermal energy*
- *<u>structure large opportunities</u> in the utilization of geothermal energy through **Joint Activities (JAs)**.*

One important element of the Geothermal ERA NET is to

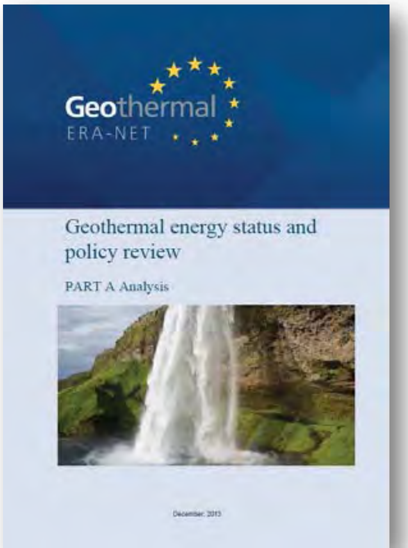
- *<u>link together</u> the geothermal industry pillar, the research pillar and the policy pillar*
- *<u>increasing cooperation</u> and consultation between those pillars and stakeholders*
- *<u>strengthen geothermal assessment and policy recommendation</u>.*

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

Organisational structure / work packages



Task 2.1 Initial Information Exchange



D2.1
December 2013
>ready

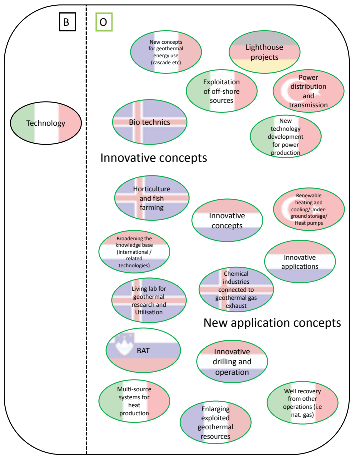
D2.2
October 2013
>ready

Technical & non-technical barriers & opportunities (task 2.2a)


Shortlist of barriers and opportunities for geothermal development
Technical and non-technical issues
Country:

10-bullet lists
(per country)

clustering
workshop



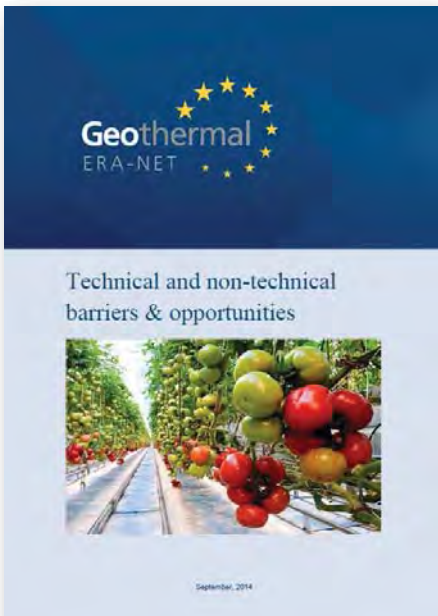
Report
(barriers &
opportunities)

Technical/non-technical barriers & opportunities

7 B&O clusters

A1 Regulations	
A2 Economics & risk-mitigation	a investment
	b operational support
	c risk mitigation
A3 New / innovative concepts and applications	
A4 Operational issues	
A5 Sub-surface knowledge / data	
A6 Structuring the geothermal sector	
A7 Public and education	a public acceptance
	b visibility & dissemination
	c education and training

report
> ready
sep'14



Future RD&D needs for geothermal development (task 2.2b PTJ/RvO)


Shortlist of RD&D needs for geothermal development

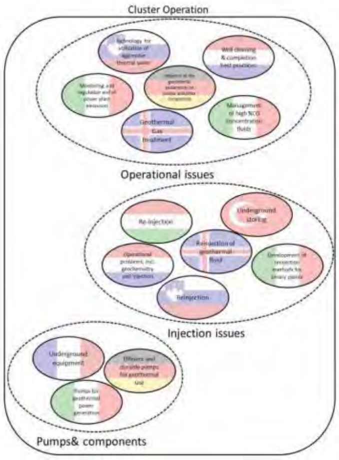
From first idea to field tests and demos; from subsurface to utilisation issues; supply and demand side; long and short term

Country:

	Title	Short description	Keywords	R&D or DM	U	I	S
6							
7							
8							
9							
10							

10-bullet lists
(per country)

clustering
workshop



report

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

RD&D needs

RD&D clusters

B1 Reservoirs	A reservoirs (general)
	B reservoir modelling
	C reservoir exploration
B2 Operation	A operational issues
	B injection issues
	C pumps & components
B3 PR & data	A dissemination
	B acceptance
	C reporting code/statistics
B4 New concepts	A innovative concepts
	B heat
	C power cycle
B5 Anthropogenic influence	A reservoir creation
	B seismicity
B6 Drilling	

report
> ready
sep'14

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

Propose (joint) actions

> ready nov '14

> basis for wp4:
development of joint activities

> All reports available on: www.geothermaleranet.eu

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

Common Challenges in Geothermal EraNet countries

Barriers & Opportunities clusters		*RD&D needs clusters*
A1 Regulations	...	
A2 Economics & risk-mitigation	...	
A3 New/innovative concepts and applications	↔	B4 New concepts
A4 Operational issues	↔	B2 Operation
A5 Sub-surface knowledge/data	↔	B1 Reservoirs
A6 Structuring the geothermal sector	...	
A7 Public and education	↔	B3 PR & data
	...	B5 Anthropogenic influence
	...	B6 Drilling

9 clusters

1. Regulations (A1)
2. Economics & Risk-mitigation (A2)
3. New/innovative concepts & applications (A3/B4)
4. Operation (A4/B2)
5. Subsurface/reservoir knowledge (A5/B1)
6. Structuring the geothermal sector (A6)
7. Public & Education (A7/B3)
8. Anthropogenic Influence (B5)
9. Drilling (B6)

All clusters are relevant for the progression of geothermal energy in Europe

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

How to collaborate?

JA1 Information exchange (groups)

regular meetings, workshops, visits, idea factories, etc.:

JA2 Joint work

Joint assignment: detailed study on specific issue

JA3 Joint call

Jointly developing new insights, new systems

- Appropriate (and feasible) JA-type should be chosen for a specific challenge
- JA's can evolve from JA1 > JA2 > JA3
- Effectiveness/Impact more important than amount of €'s

How to start/organise joint activities ?

- Bottom-up
- Bi- or multilateral
- Based on countries preferences (within the clusters)

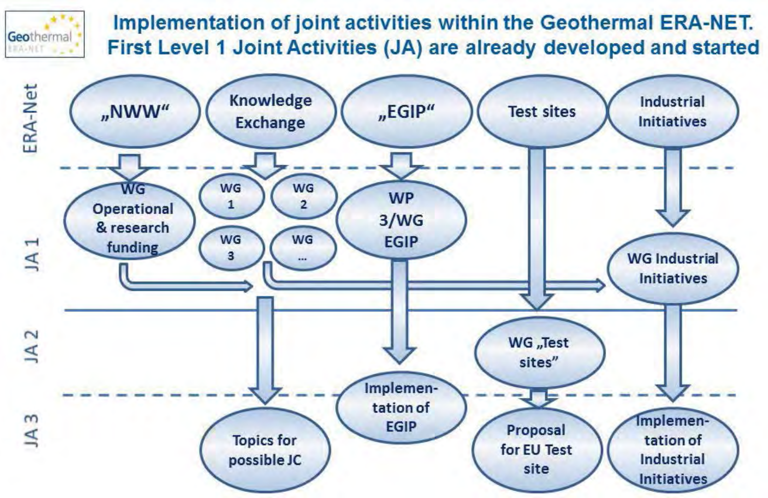
At least two countries to take the initiative

The Geothermal Era Network as a continuing vehicle to launch JA's !

Joint Activities

As a result 7 Joint Activities (JA) on different topics were proposed:

- **NWW** – New ways of working: Financial Instruments and Funding of RD&D and Geothermal Projects
- **OpERA** – RD&D Knowledge Exchange on operational issues of geothermal installations in Europe
- **PRGeo** - RD&D Knowledge Exchange on public relations for geothermal energy
- **New Concepts** for geothermal energy production and usage
- **ReSus** - RD&D Knowledge Exchange on reservoir sustainability
- **Tuning EGIP** (European Geothermal Information Platform) for target users
- **Geostat** - Towards Consistency of geothermal data



Geothermal ERA NET Cofund Action – continued cooperation

creating a European research and innovation framework

- The objective is to organize and pool national financial and human resources as well as national research infrastructures, **to accelerate research and innovation**.
- Building on relationships with industry and researchers and bridge the gap between research and the market with **innovative solutions**.
- Focus on what is often called “deep” geothermal energy.
  - The scope includes the integration of geothermal reservoirs into novel energy system concepts (e.g. use of reservoirs for energy storage, CO2 storage, integration with near-surface geothermal applications).

Next steps towards the
Geothermal ERA NET Cofund Action

Action	Finished by
Identification of relevant contacts in potentially participating countries	September 2015
Invitation letters to potential participants & flyer	September 2015
Distribute first draft proposal	September 2015
Preparatory meeting 1	November 2015
2nd draft proposal	December 2015
Deadline for letters of commitment	February 2016
Preparatory meetings 2, 3, teleconferences and subsequent drafts	First quarter 2016
Submission of the proposal	5 April 2016 (provisional)

Geothermal ERA NET
Coordination Office
Orkustofnun, Iceland

www.geothermaleranet.eu

Netherlands Enterprise Agency

Geothermal ERA-NET

OpERA
an introduction

Paul Ramsak
Netherlands Enterprise Agency
Geothermal ERANet KnowlEx leader
OpERA steering committee

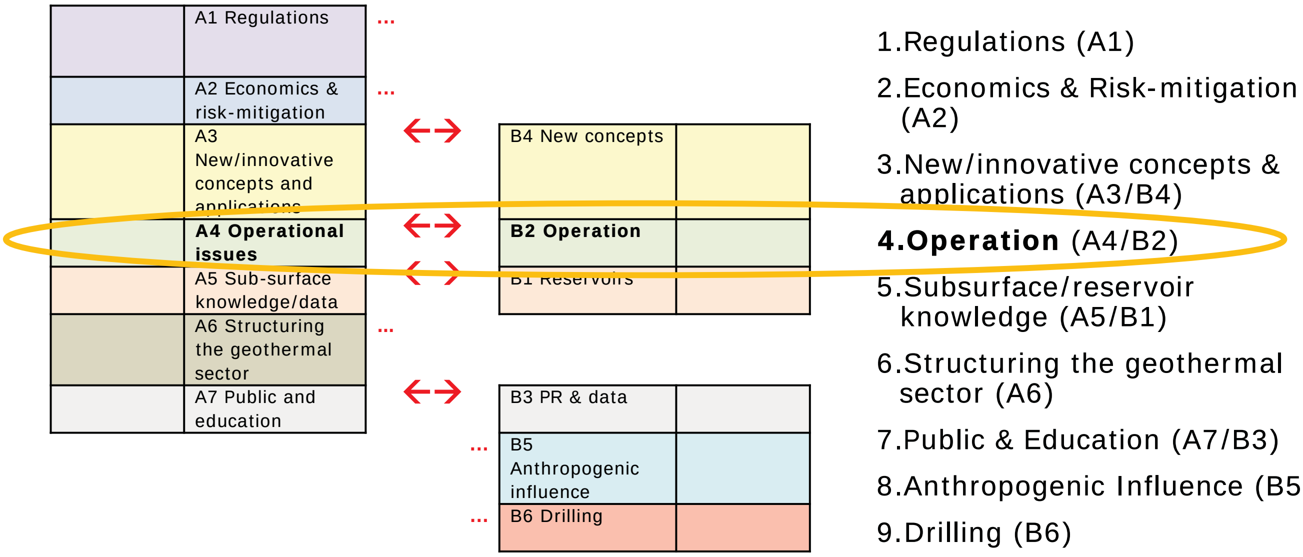
OpERA Expert workshop
Vaals (NL/D/B)
1+2 oct 2015

Geothermal ERA-NET

OpERA

Operational Issues of Geothermal Installations in Europe

Common Challenges in Geothermal EraNet countries

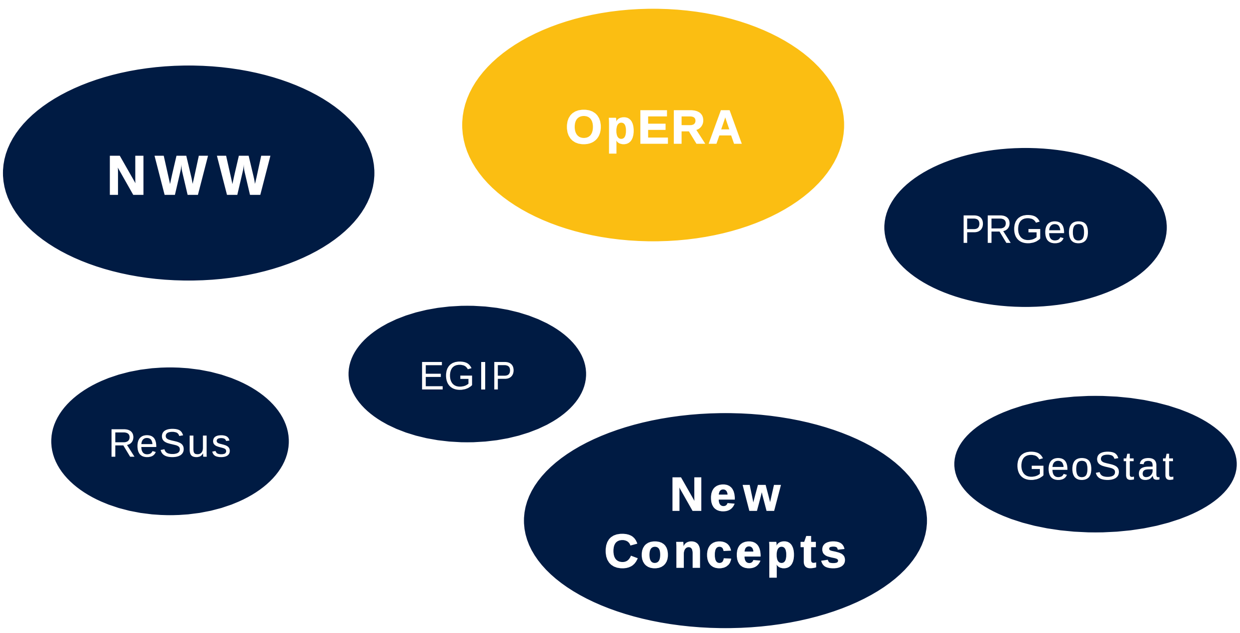


9 clusters

1. Regulations (A1)
2. Economics & Risk-mitigation (A2)
3. New/innovative concepts & applications (A3/B4)
4. **Operation** (A4/B2)
5. Subsurface/reservoir knowledge (A5/B1)
6. Structuring the geothermal sector (A6)
7. Public & Education (A7/B3)
8. Anthropogenic Influence (B5)
9. Drilling (B6)

All clusters are relevant for the progression of geothermal energy in Europe

7 Joint Activities



Why OpERA?

WP2 identified several barriers and RD&D-needs related to operation of geothermal installations

Crucial for LT performance of Geothermal Installations

- Barriers:
  - Resource exploitation
  - Operational issues
  - Environmental impact
  - Geochemistry & injectivity
  - Reinjection

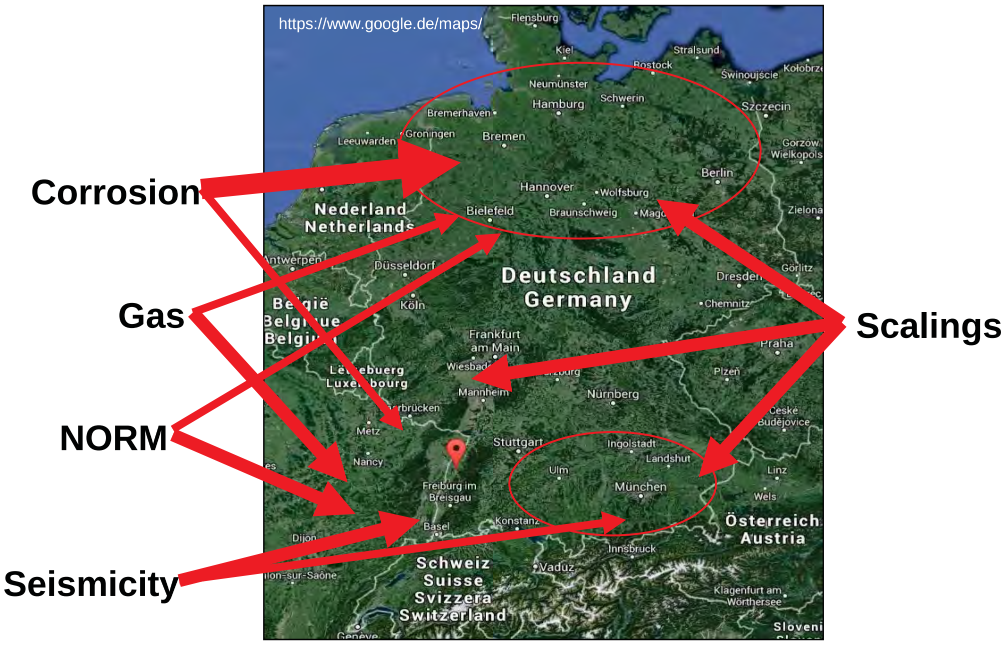
- RD&D-Needs:
  - Operational Issues
    - Aggressive thermal water
    - Pumps & components
    - Well cleaning & completion
    - High NCG concentrations
    - Power plant Emmissions
    - Gas treatment
  - Injection Issues
    - Re-injection (mentioned 3x)
    - Underground storage
    - Re-injection methods (binary)
    - Geochemistry during re-injection
  - Pumps & Components
    - Underground equipment
    - Efficient & durable pumps
    - Pumps

Why OpERA?

- Mentioned by:

- Therefore: Knowledge exchange on operational issues can help to:
  - Use knowledge on already solved problems European-wide
  - Cluster research efforts
  - Merge budgets for a higher output

Why OpERA? Example Germany



How to collaborate?

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regular meetings, workshops, visits, idea factories, etc.:

JA2 Joint work

Joint assignment: detailed study on specific issue(s)

JA3 Joint call

Jointly developing new insights, new systems

- Appropriate (and feasible) JA-type should be chosen for a specific challenge
- JA's can evolve from JA1 > JA2 > JA3
- Effectiveness/Impact more important than amount of €'s

The Concept of **OpERA**

Overview of Operational Issues in participating countries

Trans-national **knowledge and information Exchange**

First approach for **trans-national cooperation** on specific topic

*Building the **base for further cooperation**,*

if the benefit of this approach is proven

First Joint Activity: **OpERA**

- **OpERAtional issues** of geothermal installations
- **workshop – october 2015**
  - Scaling
  - Corrosion
  - Gas content
  - Reinjection

- **follow-up**
  - Expert group > solved/unsolved issues/best practices (JA1)
  - Joint studies (JA2/JA3)
  - ...

OpERA – the EuRopeAn team

Coordination

D + NL

EraNet Partners

IS + SLO + H + I + F + CH

Extra Partners

DK + A

OpERA Participants

- Selected group of experts
- Invitation only
- Operators, hands-on consultants & researchers

37 participants from 11 European countries. 27 speakers

- Building a network
- OpERA as a platform to solve Operational Issues on a European scale
- You're part of that network!

We need to solve operational problems for Geothermal Energy to flourish

OpERA Program

DAY 1 oct 2015 12:00-22:00

Registration & Welcome Snack

Welcome & Introduction

Ia Country overviews

Break

Ib Country overviews

Summary, Conclusions & Follow up

Dinner

DAY 2 oct 2015 9:00-17:00

II Scaling

Break

III Scaling & Gas content

Lunch

IV Corrosion

Break

V Reinjection

Final discussion, Conclusions & Next Steps

Geothermal ERA-NET Workshop “OpERA”

Operational Issues of Geothermal Installations in Europe

Preliminary Program (status: 09/09/2015 update)

Thursday, 1st of October 2015:

Moderator: Dario Frigo (Pilnius Chemical Consulting)

12:00 - 12:45	**Registration and Welcome Snack**
12:45 - 13:30	**Welcome & Introduction** Era-NET Coordination Office OpERA Steering Committee Ministry of Economic Affairs Netherlands Rijksdienst voor Ondernemend Nederland
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15:10 - 15:30	**Coffee break**
15:30 - 17:10	**Session I: Country overviews (continued)** 15:30 - 15:50 Iceland - Guðni A Jóhannesson (Orkustofnun) 15:50 - 16:10 Switzerland - Bernd Frieg (Nagra) 16:10 - 16:30 France - Christian Boissavy (AFPG) 16:30 - 16:50 Denmark - Søren Berg Lorenzen (DGDH) 16:50 - 17:10 Austria - Gregor Götzl (GBA)
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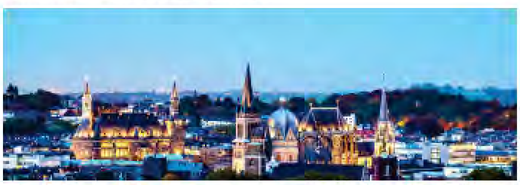
19:00 - 22:00	Dinner at Kasteel Vaalsbroek



Geothermal ERA-NET Joint Activity “OpERA”

Operational Issues of Geothermal Installations in Europe

Friday, 2nd of October 2015:

Moderator: Dario Frigo (Pilnius Chemical Consulting)

09:00 - 10:15	**Session II: Scaling** 09:00 - 09:15 Netherlands - Radboud Vorage (Aardwarmtecluster 1 KKP BV) 09:15 - 09:30 Hungary - Janos Szanyi (Szeged University) 09:30 - 09:45 Italy - Giordano Montegrossi (CNR) 09:45 - 10:15 Discussion - Dario Frigo (Pilnius Chemical Consulting)
10:15 - 10:35	**Coffee break**
10:35 - 11:50	**Session III: Scaling & Gas content** 10:35 - 10:50 Germany - Andreas Rauch (gec-co GmbH) 10:50 - 11:05 Netherlands - Niels Hartog (KWR) 11:05 - 11:20 Iceland - Bjarni Már Júlíusson (Reykjavik Energy) 11:20 - 11:50 Discussion - Dario Frigo (Pilnius Chemical Consulting)
11:50 - 13:00	**Lunch at venue**
13:00 - 14:15	**Session IV: Corrosion** 13:00 - 13:15 Iceland - Ingólfur Örn Þorbjörnsson (ISOR) 13:15 - 13:30 Germany- Simona Regenspurg (GFZ) 13:30 - 13:45 Netherlands - Hans Veldkamp (TNO) 13:45- 14:15 Discussion - Dario Frigo (Pilnius Chemical Consulting)
14:15 - 14:35	**Coffee break**
14:35 - 16:05	**Session V: Reinjection** 14:35 - 14:50 Netherlands - Wart van Zonneveld (Floricultura) 14:50 - 15:05 Hungary - Miklós Hlatki 15:05 - 15:20 Germany - Marion Schindler (BESTEC GmbH) 15:20 - 15:35 Slovenia - Evgen Torhač (Petrol Geoterm d.o.o.) 15:35- 16:05 Discussion - Dario Frigo (Pilnius Chemical Consulting)
16:05 - 17:00	**Final Discussion, Conclusions and Next steps** Dario Frigo (Pilnius Chemical Consulting) Paul Ramsak (RVO) Stephan Schreiber (PtJ)
Venue	Kasteel Vaalsbroek, Vaalsbroek 1, Vaals, NL www.bilderberg.nl/en/vaals/castle-vaalsbroek (about 7 km from Aachen Central Station)

OpERA Moderator

Dario Frigo

125
Ah!
[275]

Consult your PC
& avoid the element
of surprise

PLINIVS CHEMICAL CONSVLTING

Contact Geothermal Energy coordinator WP2 Information Exchange

NL Enterprise Agency Geothermal ERA-NET

www.rvo.nl/aardwarmte
www.rvo.nl/topsector-energie

Paul Ramsak
+31-88-602 2275
paul.ramsak@rvo.nl

Netherlands Enterprise Agency
Energy Department
Geothermal Energy

Slachthuisstraat 71
P.O. Box 965
6040 AZ Roermond, The Netherlands

www.geothermaleranet.eu

» Focus on energy and climate change

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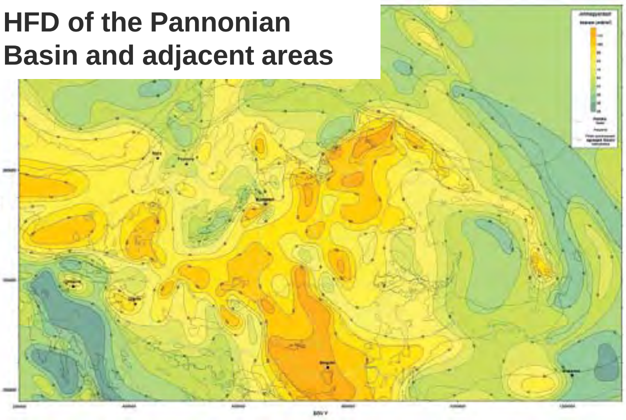
Operational Issues
of Geothermal Energy Installations in Europe

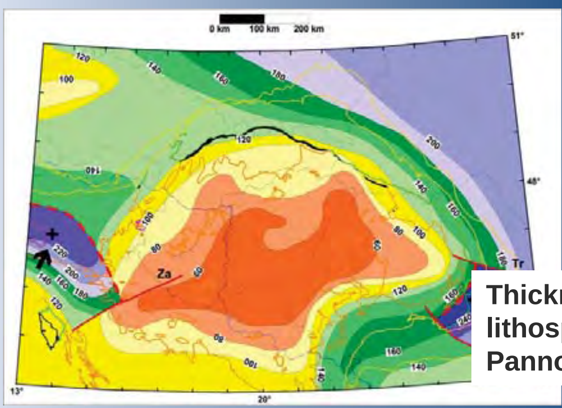
Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

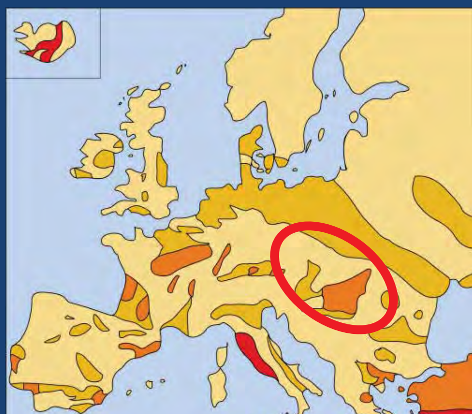
Country Overview
Hungary

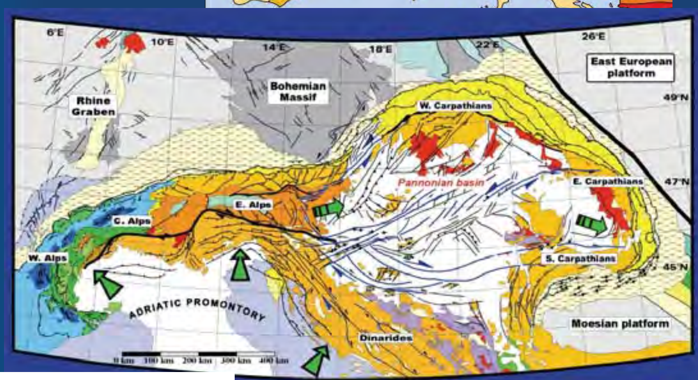
Annamária Nádor

Geothermal conditions of the Pannoninan Basin


HFD of the Pannonian Basin and adjacent areas

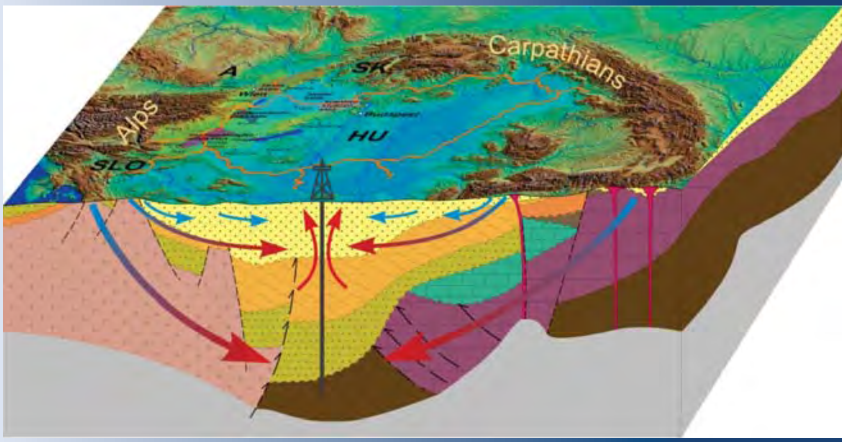






Thickness of the lithosphere in the Pannonian Basin

Pannonian basin: HSA play (convectional flow system)



- high heat flux
- thermal „insolation" of basin fill sediments
- regional groundwater flows driven by hydraulic potential between recharge and discharge areas
- many transboundary aquifers/reservoirs – joint management

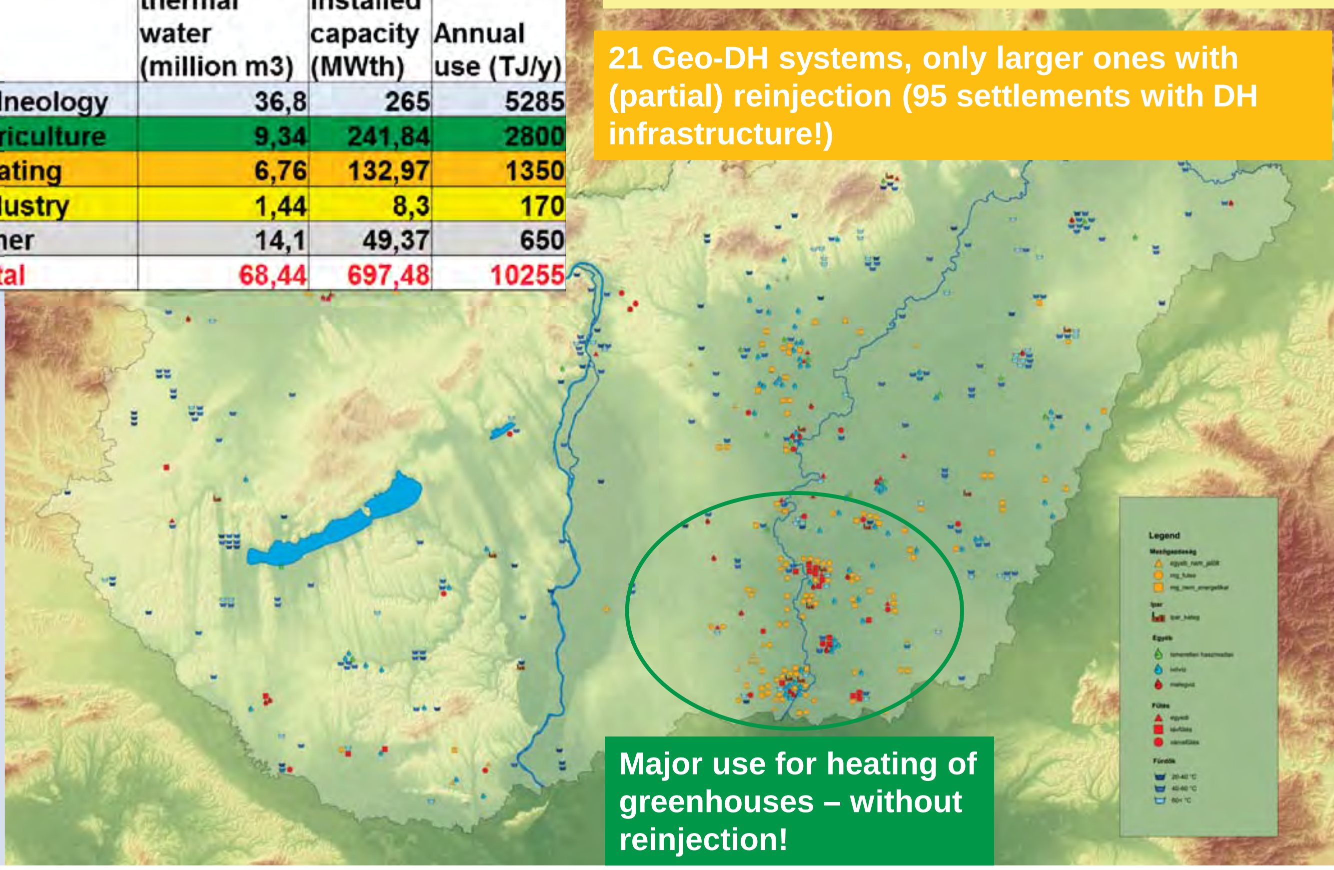
Main geothermal reservoirs	Paleo-Mesozoic fractured, karstified basement rocks	Miocene porous and carbonate reservoirs	Mio-Pliocene porous basin fill: multi-layered sandstones, shales
depth (top)	>2-3000 m	Basement highs	600-1500 m
temperature	>100-150 °C	50-150 °C	50-100 °C
prospect	CHP	CHP, direct use	direct use, balneology

Thermal water utilization in Hungary (93 000 km²)

~ 950 thermal wells (outflow T > 30 °C)
Annual production: 68,44 million m³ (2011)

	Abstracted thermal water (million m3)	Installed capacity (MWth)	Annual use (TJ/y)
Balneology	36,8	265	5285
Agriculture	9,34	241,84	2800
Heating	6,76	132,97	1350
Industry	1,44	8,3	170
Other	14,1	49,37	650
Total	68,44	697,48	10255

21 Geo-DH systems, only larger ones with (partial) reinjection (95 settlements with DH infrastructure!)



Major use for heating of greenhouses – without reinjection!

Energy strategy of Hungary 2011-2030

Import dependency:

- ~ 83% of hydrocarbons
- Security supply, focus on own resources

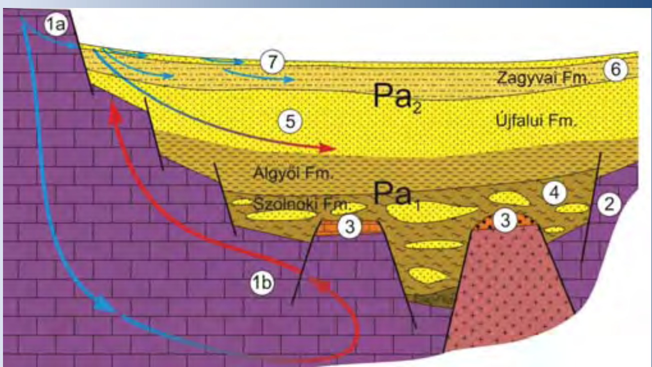
Main aim: ensure the longterm sustainability, security, and economic competitiveness of energy supply in Hungary

3 pillars: nuclear, coal, RES

RES Directive (2009/28/EC): 13% RES for Hungary→ 14,65% RES by 2020 (120,57 PJ)

Contribution of geothermal energy	2010 9% of total RES	2020 17% of total RES
Direct heat (PJ)	4,23	14,95
Electricity production (MW)	0	57

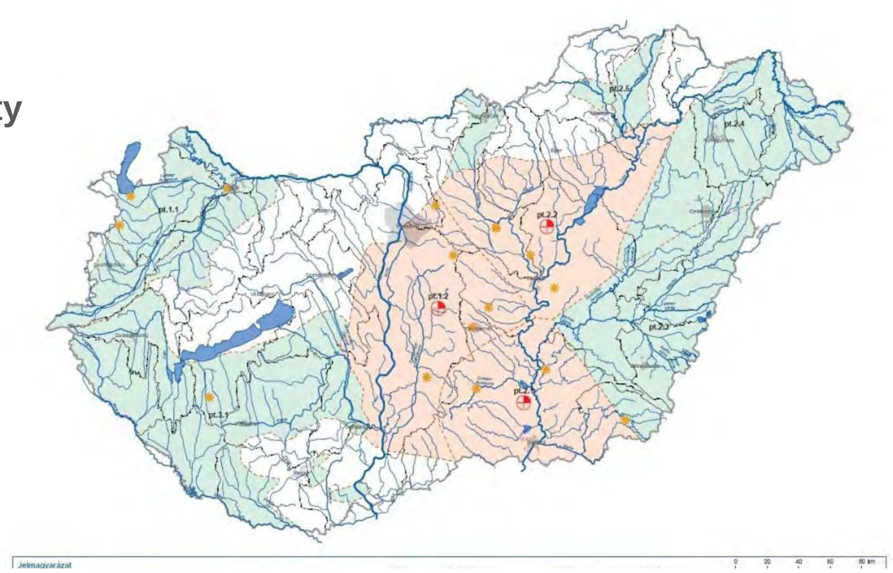
Operational issues in Hungary - reinjection



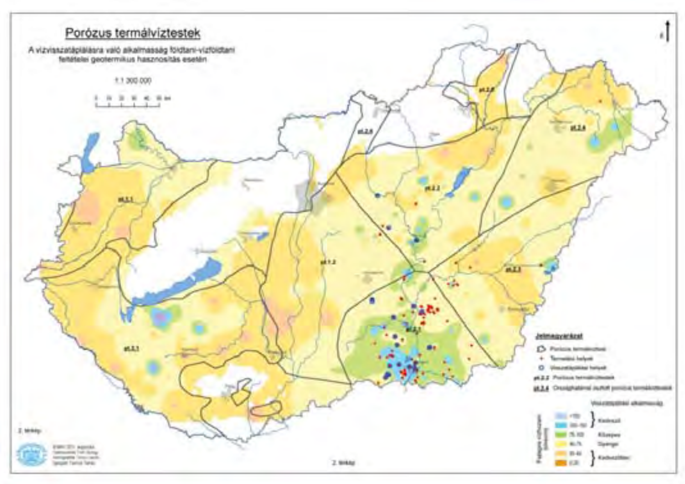
Re-injection operates into basement carbonates, but needs more R&D into heterogenous sandstone reservoirs

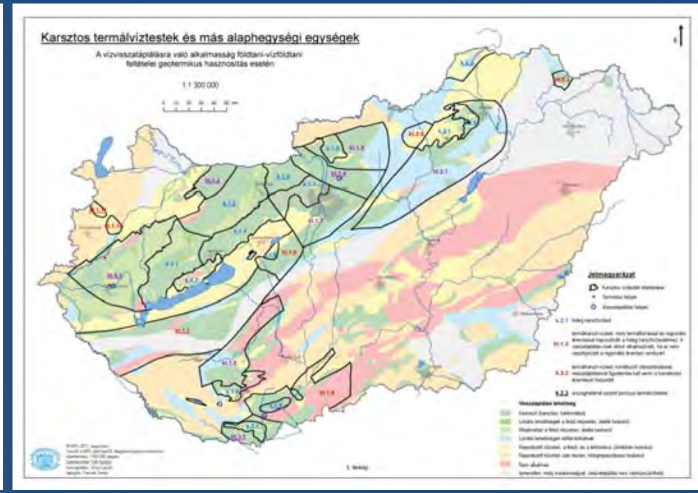
After many debates and changes in legislation now regulation is permissive: optionally licensed in individual grants.

Basis for re-injection: water management aspect: quantity status of aquifers
River Basin Management Plans (Water Framework Directive)



Operational issues in Hungary - reinjection





Re-injectivity potential of porous and karstic aquifers (Tóth, 2011)

For technical discussion with examples see presentation of M. Hlatki

Operational issues in Hungary – gas content

Thermal water wells – hydrocarbon wells: water with high gas contents vs. gas with high water content

Many Hungarian wells produce thermal water with significant dissolved gas content (methane, nitrogen, CO_2, H_2S)

Degasifiation units next to the production wells → Methane : separated and used in auxiliary equipments

Case study: Túrkeve: 74 C thermal water wih high gas content feeding local spa
Gas separated, collected and driven to 2 gas motors: 413 MWh/yr electricity and 12.866 GJ/yr hetat energy: additional heating of spa buildings

Operational issues in Hungary – gas content

Fábiánsebestyén
Steam blowout from HP / HT fractured dolomite reservoir at a depth of 3800 m

360 bar overpressure, 189 C wellhead temperature, blowout lasting for 47 days

Operational issues in Hungary – scaling

High dissolved content of some thermal water

Hungarian „Pammukale”: Egerszalók

For technical discussion with examples see presentation of J. Szanyi

Summary matrix

	solved		unsolved
	Issue	Solution	
Scaling	Carbonate scaling	Inhibitors (acids)	Baryte scale removal
Corrosion	No major issues reported		
Gas content	CH4 – safety issues	Gas separator	Separated gas treatment or utilization
Reinjection	Low injectivity of sandy aquifers	Proper well design, back-washing, microfiber iron and send filters	Further RD&D needed
	Surface disposal of waste water	Thermal lakes	High temperature and high TDS of waste water

Geothermal ERA-NET

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Country Overview
Italy

by Adele Manzella

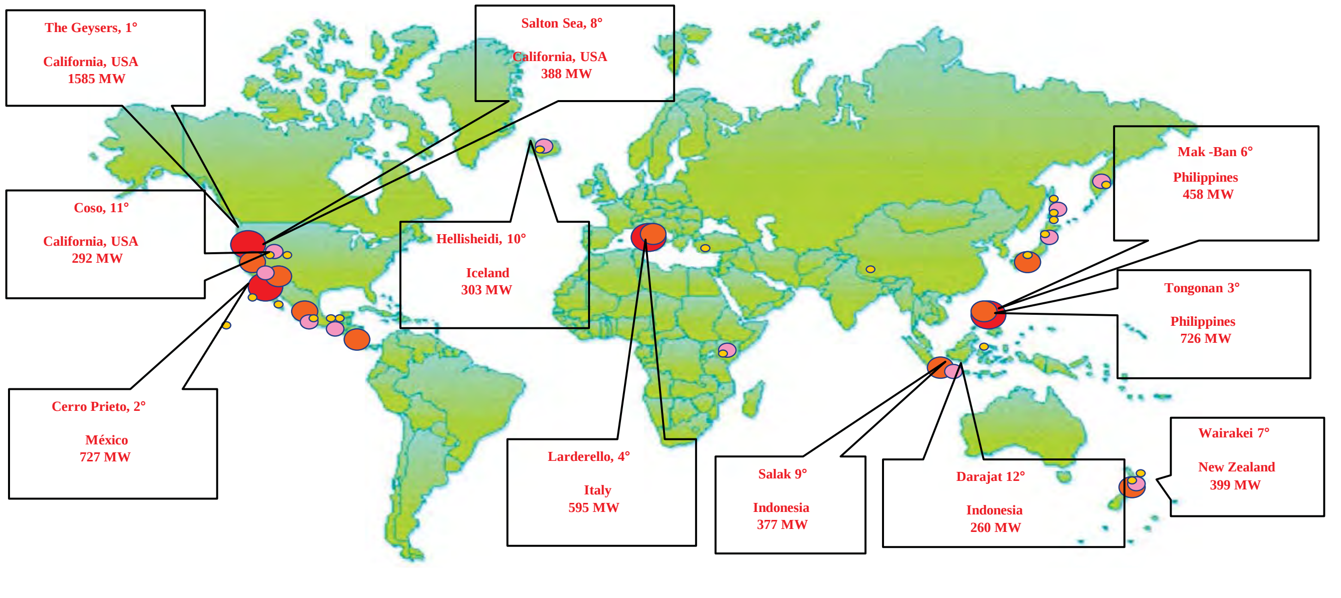
Consiglio Nazionale delle Ricerche

Enel Green Power

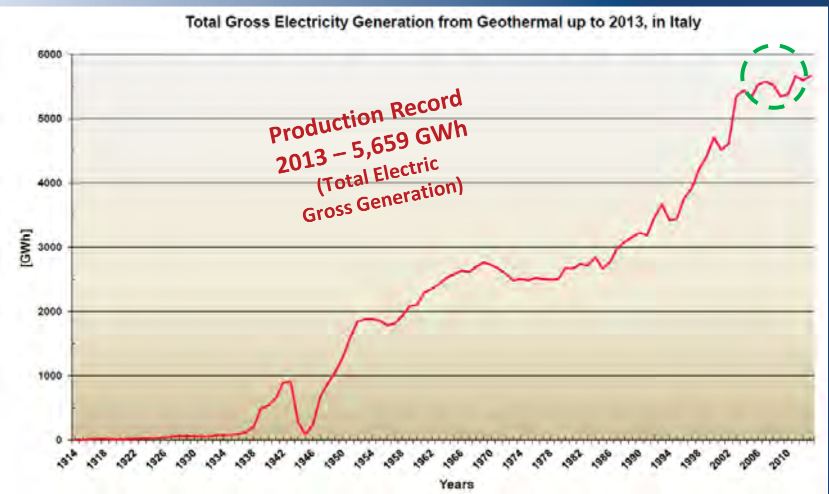
Images and topics are courtesy of Enel GP

Overview Geothermal Energy in Italy: Power production

Italy is the 6th country in the world for installed power capacity, with two main geothermal fields, Larderello and Mt. Amiata. Larderello is the 4° geothermal field in the world. 916 MW of the 2.13 GW of European installed capacity comes from Italy



Overview Geothermal Energy in Italy: Power production



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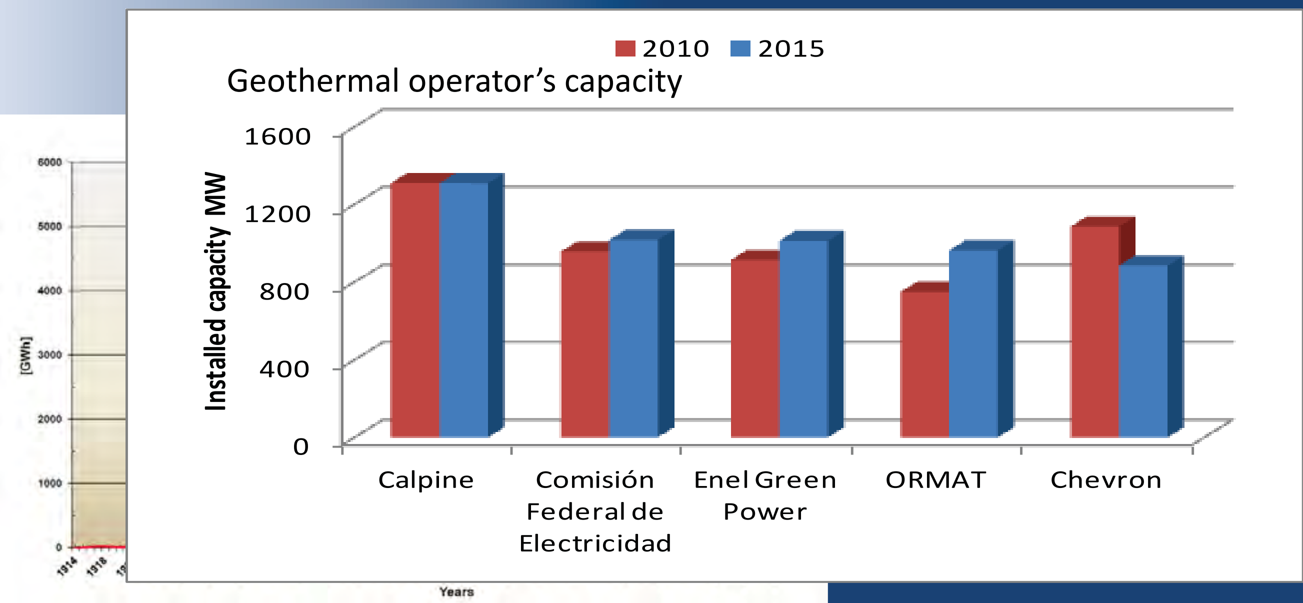
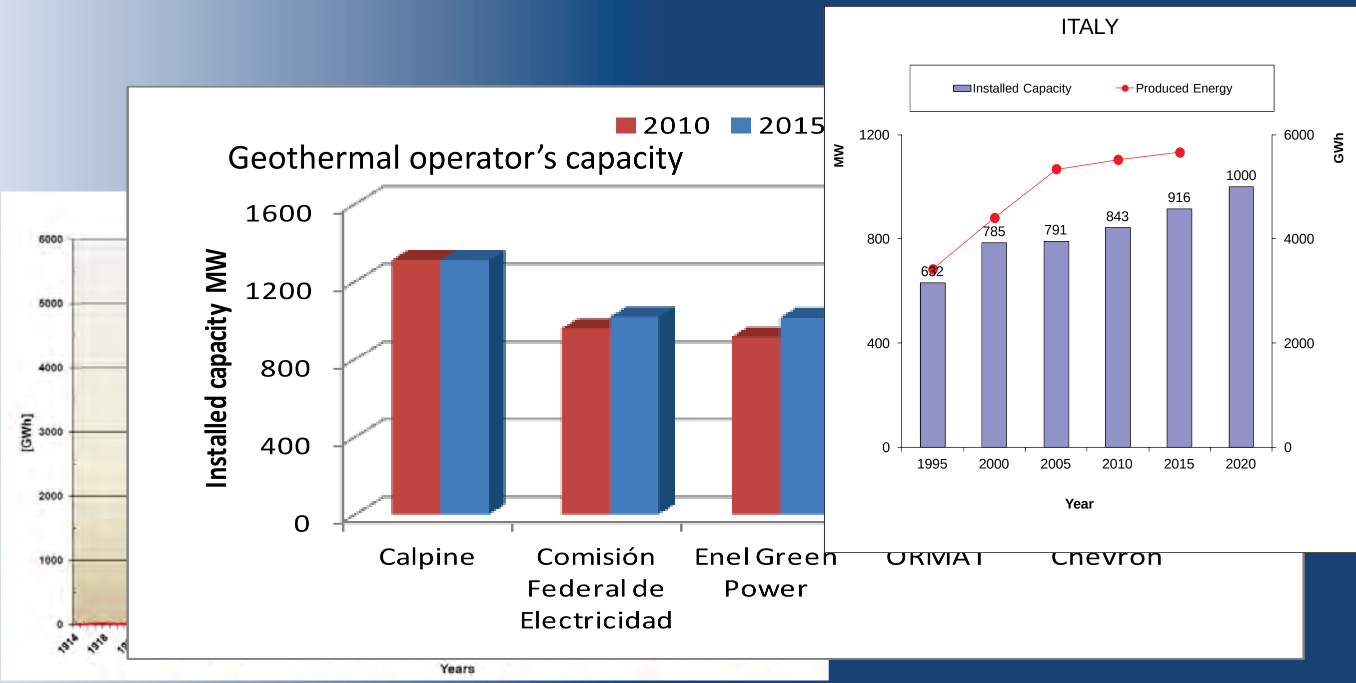


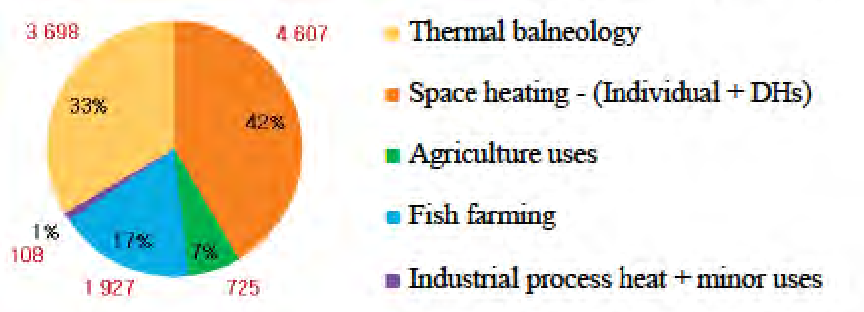
Overview Geothermal Energy in Italy: Power production



Overview Geothermal Energy in Italy: Heat production

Sector of application	Capacity (MW$_t$)			Energy (TJ/yr)		
	Total	GSHPs	DHs	Total	GSHPs	DHs
Space heating	725	550	78	4 607	3 211	683
Thermal balneology	421	-	-	3 698	-	-
Agriculture uses	69	14	-	725	82	-
Fish farming	122	-	-	1 927	-	-
Industrial process heat + minor uses	18	4	-	108	25	-
TOTAL	**1,355**	**568**	**92**	**11,065**	**3,318**	**683**

Total energy use: 11,065 TJ/yr



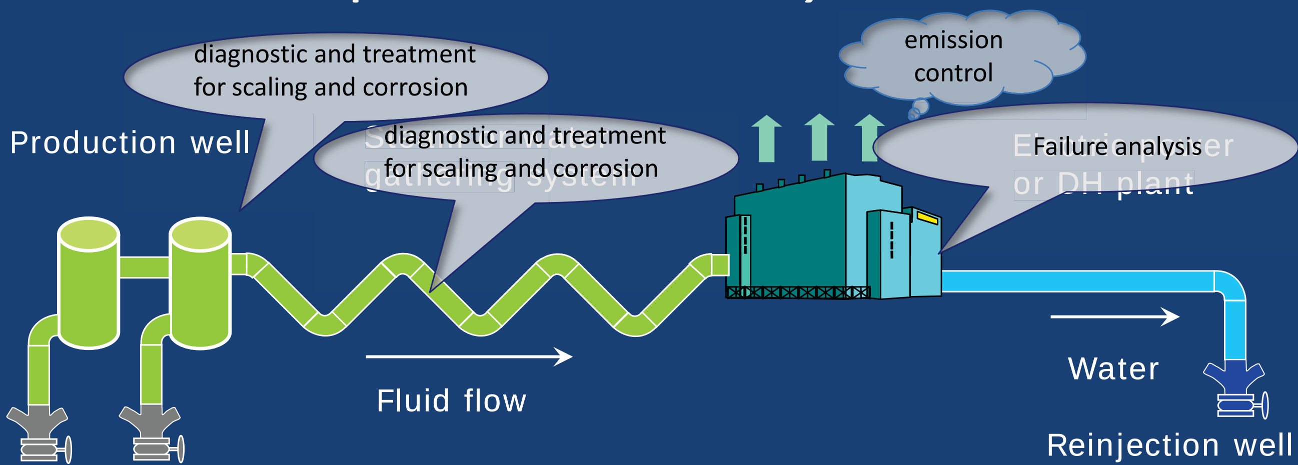
Overview Geothermal Energy in Italy: Heat production

Space heating is in rapid expansion, in particular GSHP systems (increase of 120% in four year for GSHP and 16% by DH)

Most DHs are in geothermal power production areas.

Geothermal DH in large towns are:
- Ferrara DH is in expansion
- Grado DH is under development
- Vicenza DH is proposed

Overview Operational Issues in *Italy*



Overview Operational Issues in *Italy*

Scaling Issues

Deposit from single flushing fluids, deposit on reinjection wells, pipelines, separators

This problem is usually tackled with:

monitoring and diagnostic

chemical (washing) and physical (pressure/temperature management) operations

Overview Operational Issues in *Italy*

Corrosion Issues

The steam produced by deep wells is often characterized by the presence of aggressive elements (O, H_2S, CO_2, NH_3, H, sulfates, Hg) and Chlorine, which accelerates corrosion.

Pressure decrease in-well or in pipes produces acid steam condensation, inducing localized corrosion on casing, pipes and turbine parts.

This is a **main issue**

Enel GP operates fields having aggressive fluids that are considered unmanageable by most operators

Overview Operational Issues in *Italy*

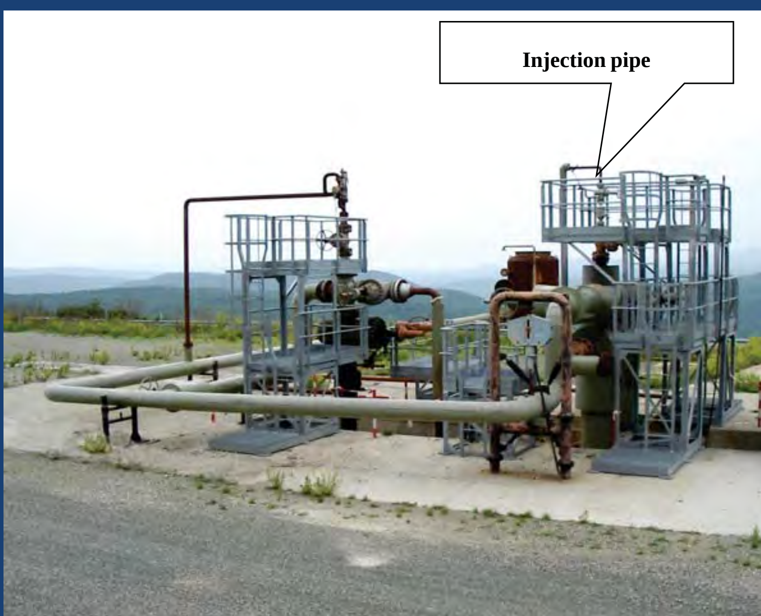
Corrosion Issues

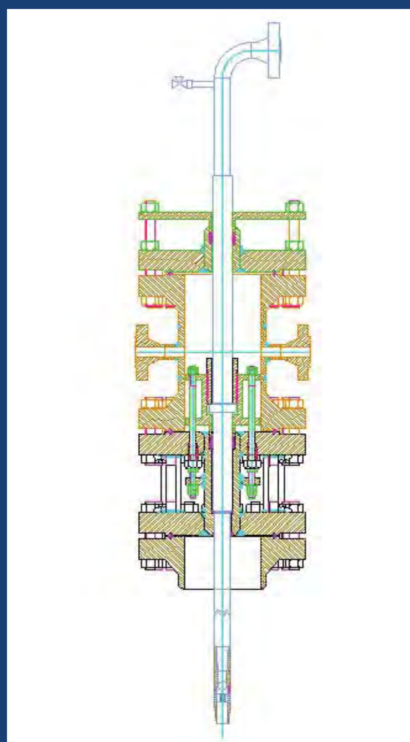
Solutions:

- monitoring systems
- steam washing to break down the pH of the fluid
- temperature and pressure management
- special coating and materials

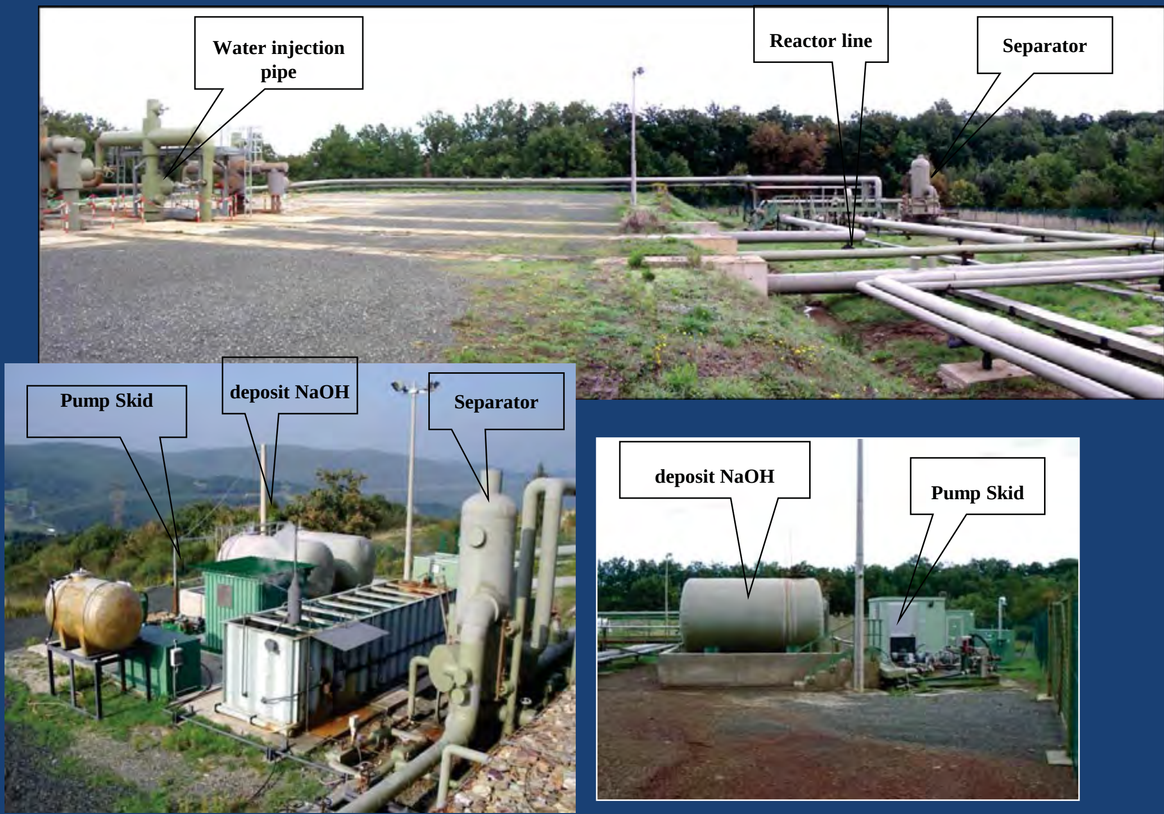
Extra cost of washing equipment ≈1M€

Steam treatment plants inside wells to prevent the corrosion problems

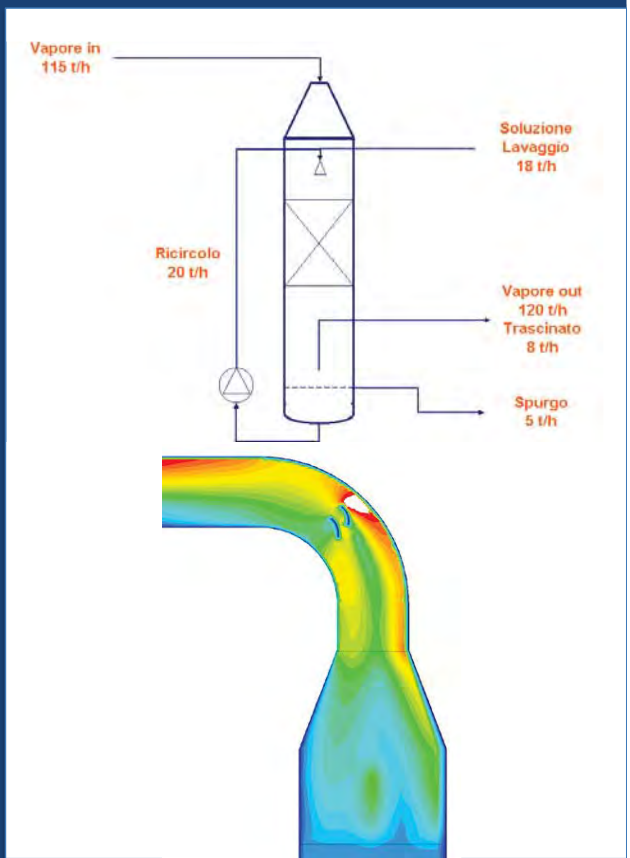




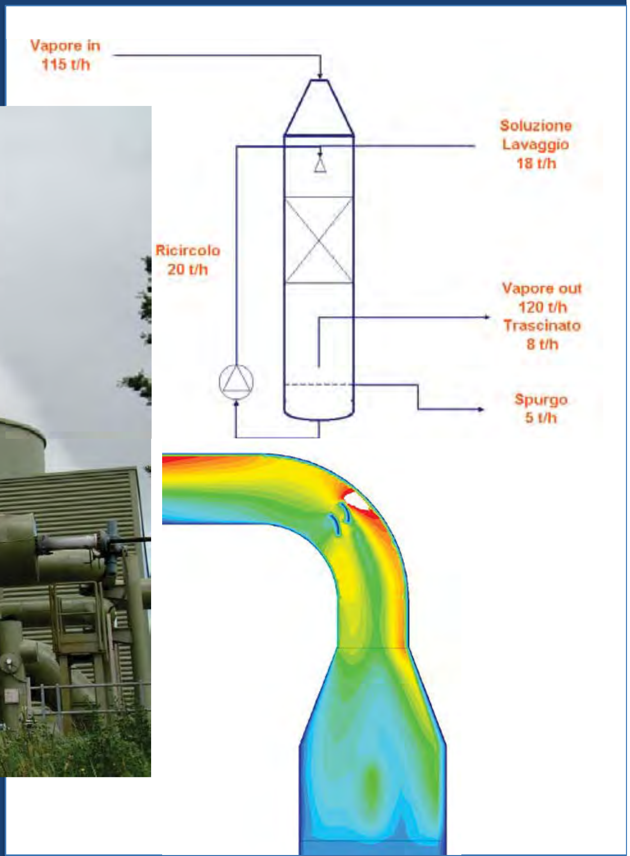
Steam treatment plants at well head



Steam treatment plants at the power plants



Steam treatment plants at the power plants



Overview Operational Issues in *Italy*

Emission and Gas Content

Natural gases and associated minerals are emitted at power plant and, in minimal content, for production test of wells and power plant outage

This problem is relevant only when hydrothermal fluids are particularly rich of natural, incondensable gases and in steam, flash plants. less relevant in binary or DH plants. Most of the problem is under control by monitoring, abatement systems and minimization of outage gas emission, although technology improvement would be beneficial, especially for improving economics.

Monitoring of gas: Hg, As, Sb, Se, NH_3, H_2O, CO_2, H_2S, CH_4, N_2, O_2+Ar

Monitoring of liquid: Hg, As, Sb, Se, Al, Cd, Cr, Fe, Mn, Ni, Pb, Cu, V, Zn, NH_4, S, H_3BO_3

Overview Operational Issues in *Italy*

Emission and Gas Content

Solution 1: abatement systems
AMIS is a system developed by Enel GP to reduce SO_2 and Hg
Abatement efficiency OK (>90%)
Large use of soda

Operational extra cost 0.5k€/year and plant
+ equipment (3-4 M€)

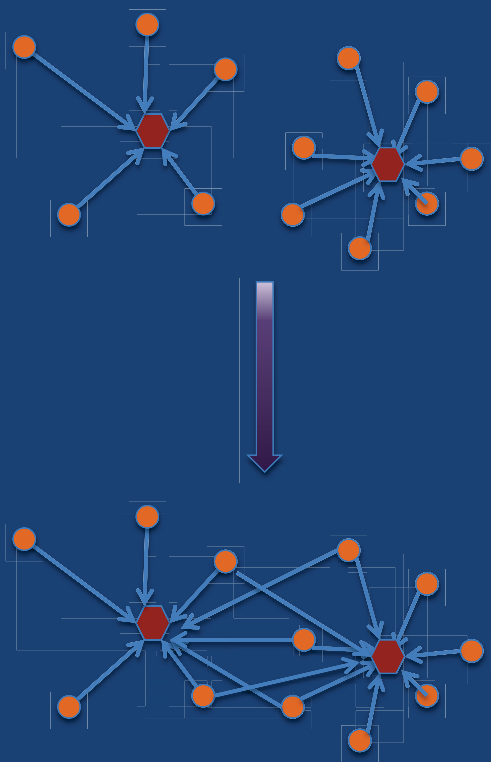
Overview Operational Issues in *Italy*

Emission and Gas Content

Solution 2: minimization of outage gas emission by networking the gathering system of different power plants

This is not always possible

Cost strongly site dependent



Overview Operational Issues in *Italy*

Emission and Gas Content

Large CO_2 content that reduces production (parasitic losses for gas extraction)
solutions: CO_2 capture and storage techniques (CO_2 can be also captured and used for industrial processes)

Other proposed solutions for gas emission:

- total reinjection of fluids (liquid and gas)
  Feasibility to be proved

Overview Operational Issues in *Italy*

Reinjection Issues

Scaling due to cooling of separeted fluid in liquid dominated reservoirs
To avoid scaling, the reinjected fluids have high temperature, with related loss of thermal energy

Example: 20 MW plant, 300t/h hot fluid reinjected at T=180°C

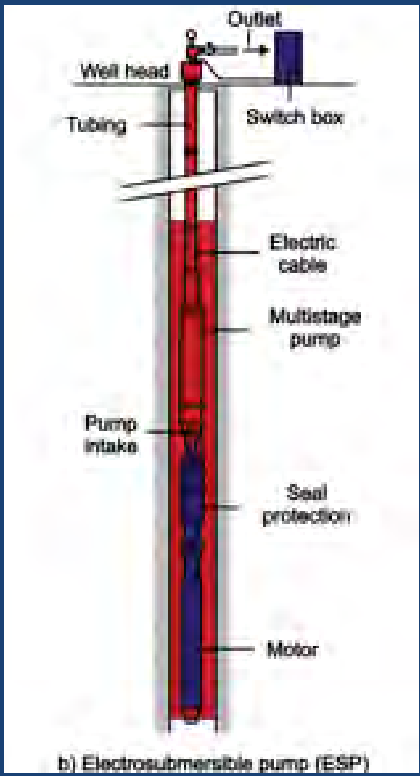
A reinjection at 80°C (T reduction of 100°C) would allow to use the fluids for production, producing 3-5 MW, about 20% of increasing revenues

Overview Operational Issues in *Italy*

Improved plant performance

Solution:
Advanced diagnostic – plant automation, by developing sensors and adapting industrial automation technology

Large **impact** on the performance



Overview Operational Issues in *Italy*

Geothermal system management

Depletion of reservoir

Solution:
data acquisition and monitoring, resource evaluation and management, modelling

This is an **urgent** issue, new make-up wells are required to mantain production at design level

Overview Operational Issues in *Italy*

Auxiliary management

Submersible pump failure
Liquid reservoir, „low“ temperature

Solution:
replacement of pumps every 4 years

Cost: 3-5 k€ / pump

Overview Summary: Operational Issues in *Italy*

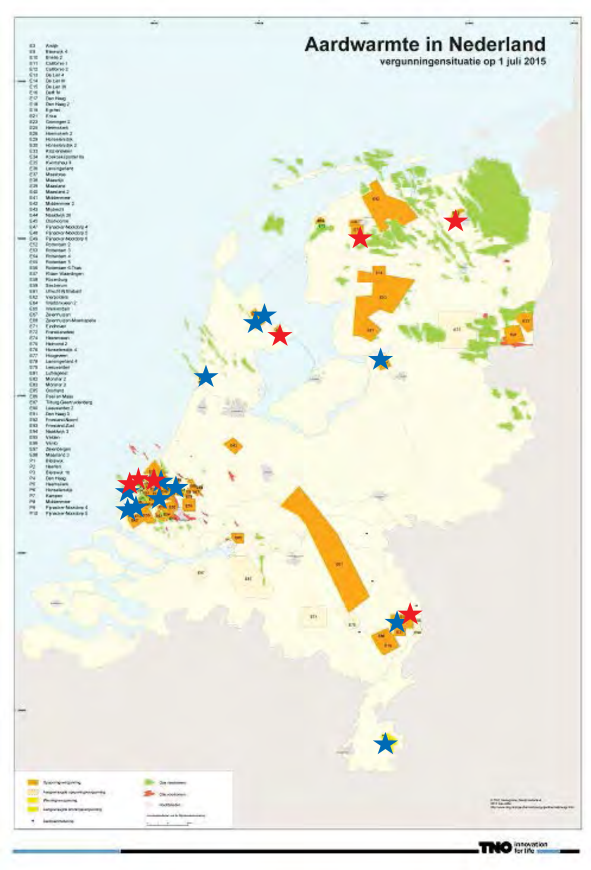
	solved		unsolved
	Issue	*Solution*	
Scaling	*Deposit from single flushing fluids, deposit on reinjection wells, pipelines, separators*	*monitoring systems* *chemical treatment (e.g., fluids washing)* *temperature dejection management (i.e. mantain the temperature above the scaling limit. Linked to reinjection constraints)*	improvement of actual technology for chemical or physical treatment and for monitoring systems (including cost reduction)
Corrosion	*corrosion of casing, pipes and turbine*	*monitoring systems* *steam washing to break down the pH of the fluid* *special coating/material*	improvement of actual technology new materials
		avoid condensation by pressure/temperature management	improvement of actual technology

Overview Summary: Operational Issues in *Italy*

	solved		unsolved
	Issue	*Solution*	
Gas content	*Natural gases and associated minerals.*	*Abatement systems*	better economics of abatement systems
	Large CO2 content Reduce production (parasitic losses for gas extraction)	*CO2 extraction/sequestration (it is economical only when used for chemical industry)*	CO2 sequestration and capture technology at economic price
	power plant outage gas emission	*minimization of outage time, harmonization of gathering system to avoid "island" power plant*	total reinjection technology
Reinjection	*Scaling due to cooling of separeted fluid in liquid dominated reservoirs*	*reinjection at high temperature*	Improved utilization of thermal energy

Overview Summary: Operational Issues in *Italy*

	solved		unsolved
	Issue	*Solution*	
Plant performance	*To increase plant performance and availability*	*Advanced diagnostic – plant automation with sensors, industrial automation technology*	
Geothermal system management	*depletion of reservoir*	*data acquisition and monitoring, resource management*	integrated model of geothermal system (from well to plant)
Auxiliary management	*Submersible pump failure*	*replacement of pumps every 4 years*	long-living pumps



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Netherlands

Martin van der Hout

Dutch Association Geothermal Operators

2015 *=DAGO:
12 operational doublets *
5-7 upcoming projects *
1 under suspension, ready to continue
>40 additional exploration licenses
Total invested: 200 M€ *
Annual turnover energy: 25-30 M€ *

Heat:
2015: capacity ± 125 MWh
2014: 1,5 PJ (10 doublets)
= 46 Mm3 natural gas equivalent

www.dago.nu/en

↗ Knowledge and research:

1. Experience
2. Compliancy
3. Transfer

=> Sustainable horticulture

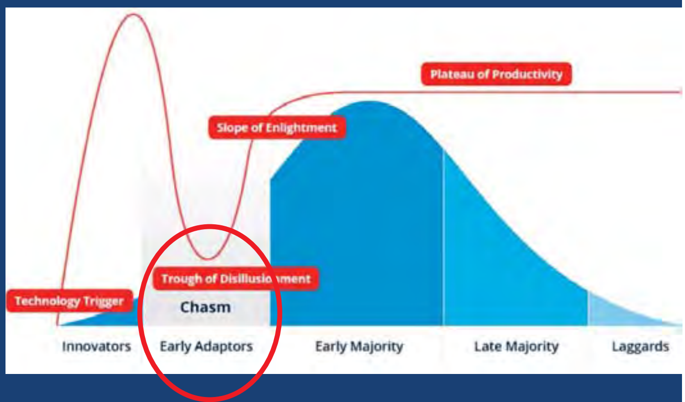
Contribution of Ministry of Economic Affairs, National Greenhouse Organization

General lobby cooperation by
Stichting Platform Geothermie

KennisAgenda = Research Agenda

High potential in NL

+++ All doublets, all well produce (in the end…)
+++ Great fit reservoirs and energy need
++ Transition phase & authorities
++ Business cases
++ Research potential
=> KennisAgenda/TNO
+/? Oil & Gas
+/- Financial challenge



Operational issues - general

- Problems never have one dimensional causes, nor solutions
- Operators need solutions
=> using pragmatic roadmaps, urgently

2010-2015		2020-2025
Reactive	⇔	Prevention
Updates	⇔	Upgrades

Operational issues - Scaling

solved		Unsolved, in progress
Issue	*Solution*	
Pb	*Inhibitor*	Selection, content, monitoring and dosage of **inhibitor,** Costs, sustainability and optimization
	Remove galvanic cells	Optimal material selection in pumps, pipework, screens Focus to one alloy, lowest diversity
	Prevent corrosion, *because of redox reactions* *No ungassing and high pressure* *over surface*	NORM/LSA: contamination Relation pressure / system / temperature / injection
Ca CO3 + some others	*Cleaning of pipes, degasser etc.*	Dosage of CO2 for injector Inhibitor selection Effect injector

NORM: legislation, organization and waste management

Operational issues - Corrosion

Solved		Unsolved, in progress
Issue	*Solution*	
Hypothese decline coupling *Erosion/cavitation*	*Repairments* *No galvanic cells: one alloy* *Set up monitoring programm* *Well integrity management* *1. Selection casing logging tools* *Use inhibitor*	Evolution completion Execution monitoring plan and evolution 2. Detailed selection monitoring tools Determine critical factors & parameters flow velocity Upgrade new projects in alloy casing Install packers safety ESP Composite material GRE use Optimization inhibitor dosage
Surface installation	*No galvanic cells* *Cleaning and testing protocol* *before start* *Proper monitoring* *Inhibitor*	Proper specification description surface installation Leakage seals at pumps

Type of well integrity logging tools ⇔ Alloy, completion, water quality etc.

Operational issues – Gas content

solved		Unsolved = time
Issue	*Solution*	
Surface installation	*Optimization modulair* *Timing, planning, extensive testing programm*	Development criteria can be set up after drilling and testing: time squeeze
Pressure optimization	*Only in respect to realized installation*	Overall concept optimization complex due to multi-phenomena

To degas or not to degas, that's the question

Operational issues - Reinjection

solved		unsolved
Issue	*Solution*	
High pressure 40-60 bar needed *High power costs and low COP*	*Not yet executed* *Thermal fraccing*	Stimulation by: soft acidization, radial drilling, Quantitative Risk Assessments for stimulation Social acceptance

Evaluation stimulation techniques in differente research programms:

- **Over KennisAgenda (Dutch Research Programm)**
- **Cluster initiatives**

Bonus: operational issues in social context

solved		Unsolved
Issue	*Solution*	
Induced seismicity	*Standard methodology, QRA, levelling as oil & gas*	Relevancy
NORM management	*Compliant to 2015 rules*	Comply to EU regulations 2018 Legislation and organisation www.earatom.org
Role out well integrity	*Standard methodology 2016*	Tailor made completion for well integrity management
Social awareness & acceptance	*Reactive*	The `bigger` story to start communicate Induced seismicity, NORM, well integrity

Top 5 of the issues: estimation

Issue	*Urgency*	*Potential impact development QHSE*	*Potential risk or gain Impact issue €*
1. Corrosion completion	Medium / high	Environment, quality	Risk 10 – 50 M€ ?
2. Corrosion surface installation	Medium	Health & Safety	Risk 5 – 10 M€ ?
3. Scaling + NORM	High	Health & Safety	Risk 1 – 5 M€ ?
4. Reinjection => stimulation	Low	Quality	Gain 50 M€ ?
5. Gas optimization	Low	Quality	Gain 1 M€ ?

Operational issues running operations affect severely upcoming projects, image, despite perfect reservoir conditions

Updating running operations: learning by doing, optimizing, curative:
V2010.n

Upgrading new operations; new state of the art:
V2020.0

Running projects still in exploiration phase:
Optimization €/MWh +
Subsidization ruling

2010 updates & 2020 upgrades

Geothermal ERA-NET

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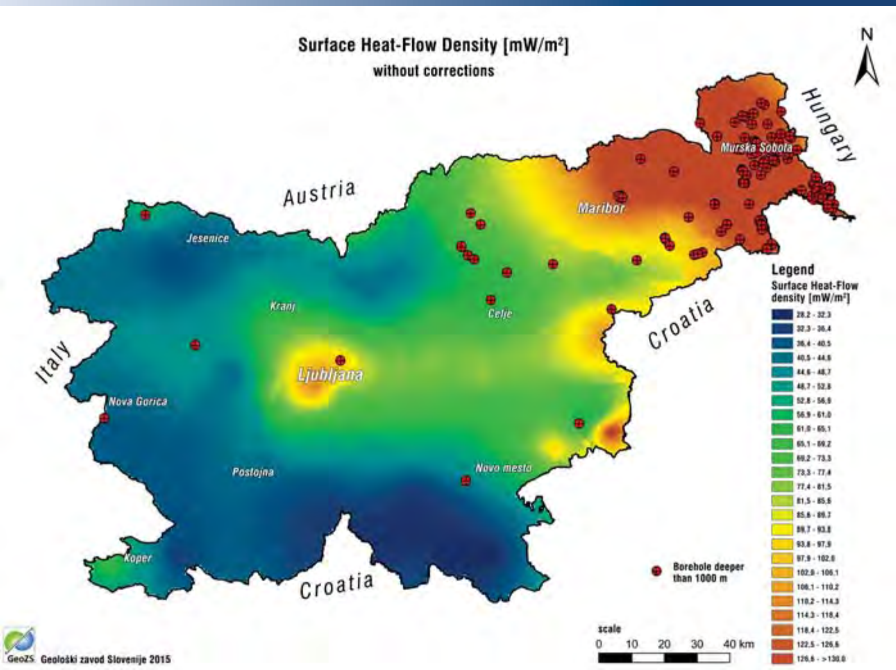
Overview
Slovenia
by Andrej Lapanje

Overview

1. **Geothermal Energy in *Slovenia***
2. **Operational Issues in *Slovenia***
   A. Scaling Issues with Examples
   B. Issues with Gas Content with Examples
   C. Reinjection Issues with Examples

3. **Summary: Solved/unsolved Operational Issues in *Slovenia***

1. Geothermal Energy in *Slovenia* – *potential and exploration*

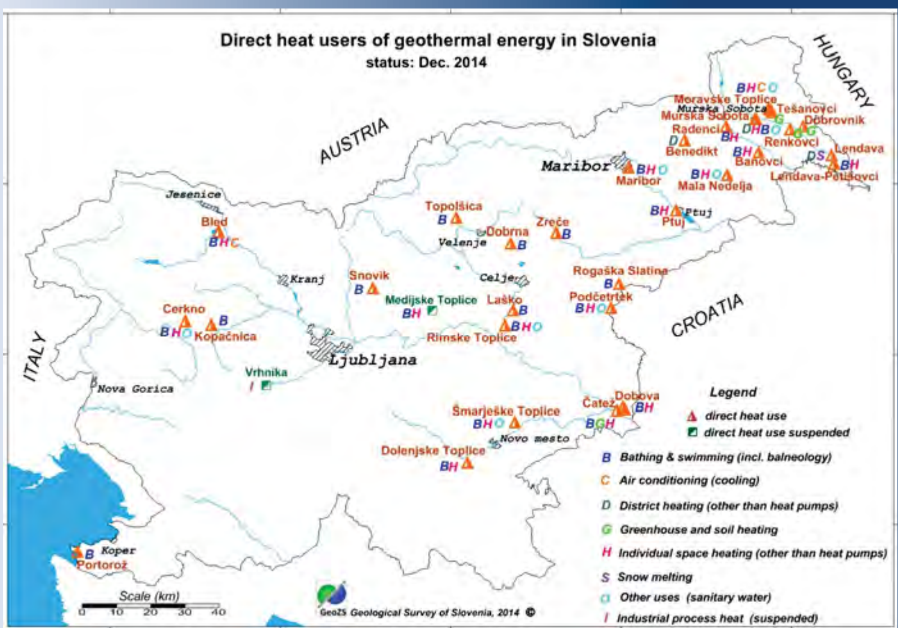


Heat-flow density
30 – 150 mW/m²

Geothermal gradient
10 – 60 mK/m

Temperature at 4 km depth
NE Slovenia ~ 200 °C
Central Slovenia ~ 100 °C
W and SW Slovenia < 80 °C

1. Geothermal Energy in *Slovenia* - *locations*

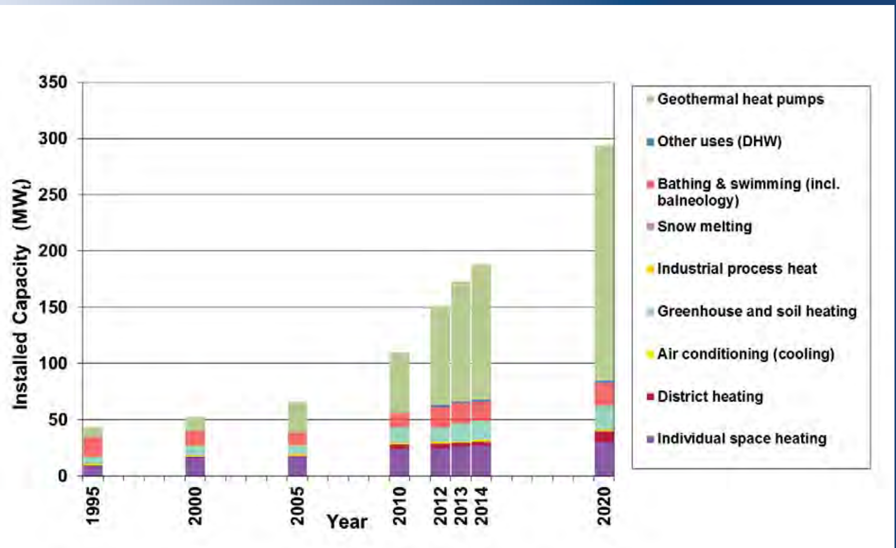


32 direct heat users

- mostly spa and recreation
- individual space heating
- greenhouses

NO geothermal electricity,
There is no geothermal
power station foreseen

1. Geothermal Energy in *Slovenia*



Installed capacity in 2014: 67,26 MW_t

Energy used:
646 TJ equal to 0,2 % gross domestic energy use of primary energy supply

Politics:
ANOVE
NEP

Calls:
For district heating network systems

Scaling Example 1 - Benedikt (NE Slovenia)

- Well Be-2
- Type of water: Na-HCO_3/(CO_2)
- Temperature: 82°C; Yield: 10 l/s
- Mineralisation: 7,3 g/l; Gas: CO_2
- Origin: Raba fault zone, Metamorphic
- basement, dolomitic marble
- Water = same type as in Bad Radkersburg, but not from the same Fm.
- Use: district heating
- Technologically and ecologically not sustainable
- Reinjection is a must
- Inhibitor composition (4,0% as P_2O_5)

Scaling Example 2 - Moravske Toplice (NE Slovenia)

- Wells Mt-1, Mt-4, Mt-5
- Type of water: Na—HCO_3-(Cl)/(CO_2)
- Temperature: 65 - 72°C; Yield: 5 l/s
- Mineralisation >10,0 g/l; Gas: CO_2, CH_4
- Origin: Middle Miocene clastic rocks, sandstones
- Use: heating, balneology
- Problems: possible explosions, lime scaling, FeS precipitation, phenol, benzene
- Addition of inhibitor, degassing in gas separator

Example 2 - Moravske Toplice (NE Slovenia)

Inhibitor:

- AKTIPHOS 640
- neutralised phosporonobutenetricarbon acids in combination of polycarbon acids
- includes 6,7% of PO_4^{3-} in water solution 0,00038 vol.%

Technological solutions – scaling/degassing

- Removing the gas phase:
- Degassing in the air
- Capture and using gases:
-     - for burning (CH_4)
-     - for greenhouses (CO_2)
-     - for beverage companies (CO_2)
- Preventing precipitation:
- Addition of inhibitor

- Planned precipitation of minerals
- Mechanical removal or HCl flushing of scaling from tubing (non-optimal solution)
- Selling tourist attractions made of travertine

Scaling

Well	Common gases	free CH_4 (in %)	free CO_2 (mg/l)	Technological solution
Mt-1	CO_2, CH_4	non-permanent, < 0,25	370-2300	Inhibitor, degassing
Mt-4	CO_2 (CH_4, H_2S)	negligible	470-630	Inhibitor, degassing
Mt-5	CO_2 (CH_4, H_2S)	Negligible	440-690	Inhibitor, degassing
Mt-6	CO_2	Negligible	10-400	degassing
Mt-7	CO_2	Negligible	30-60	degassing
Ve-1	CH_4 (CO_2)	73	0	degassing, burning
Ve-2	CH_4 (CO_2)	59	0	degassing
Ve-3	CH_4 (CO_2)	No data	50-470	degassing
Le-1g	CO_2	Negligible	45	degassing
Pt-20	CO_2 (CH_4)	No data	< 10	degassing
Pt-74	CO_2 (CH_4)	No data	No data	degassing
T-4	CO_2	Negligible	400-1500	Introduction of own CO_2, degassing
T-5	CO_2	Negligible	560	-
Be-2	CO_2	Negligible		Inhibitor, degassing
Ce-2	CO_2	Negligible	8.7	Citron acid preventing iron hydroxide precipitation in pools

Scaling and gas content - conclusions

The prevailing problems are CO_2 degassing and precipitation of calcite/aragonite in the wells and pipelines.

Cost effectiveness of each method depends on local conditions in geothermal aquifers and of utilization system.

Ecological aspects of thermal water utilization (emission to air, surface- and ground waters) are not yet the object of interest.

At the moment, no closed systems of gas rich waters are established in Slovenia. There is no reinjection of ‚black' waters, nor it is foreseen.

Mitigation of degassing should be based upon hydrogeological and geochemical studies of thermal water in the aquifer e.g. *in situ* measurements and sampling.

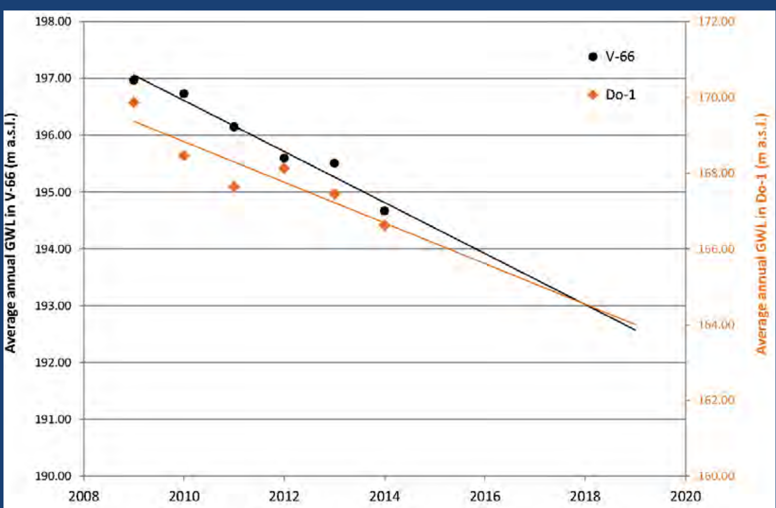
The problems of scaling and high gas content are not solved properly in Slovenia.

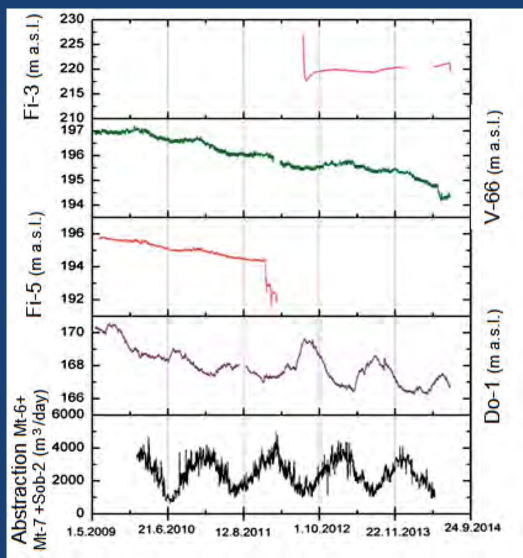
Thermal water user are seeking for new solution but also demand guaranty that solutions will work.

Need for reinjection

- Increasing number of users and abstraction rates deteriorate quantity state
- The abstraction rate is higher than estimated recharge of the aquifer

- Lowering of abstraction or reinjection is a must!





Reinjection

Examples:
- Mt-7 before 2000 (30% of produced amount)
- Le-1g since 2009
- Sob-4g not tested yet

Reinjection

Pipelines,
surface units (filters,
compressors)
~300.000 €

Well
~ 1 million €

Maintenance
~ 40.000 €/year

Conclusions

	solved		unsolved
	Issue	*Solution*	
Scaling	*Carbonate scaling*	*Inhibitors*	Optimization or closed systems
Corrosion	No major issues reported		
Gas content	*CO_2 – safety issues*	Gas separator	More effective separators or closed systems
	CH_4 – safety issues	*EX-Zones,* Gas separator	Gas separator or closed systems
Reinjection	*Low infectivity of sandy aquifers*	*Proper well design, back-washing, microfiber and sand filters*	Further RD&D needed
	Low density of waste water	/	*High temperature of waste water due to lack of end users*

Major obstacles: high investment cost for drilling of reinjection boreholes. Lack of financing for RD&D because of very weak investment sector and absent or just declarative political support.

Schulz et al., 2007

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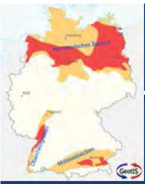
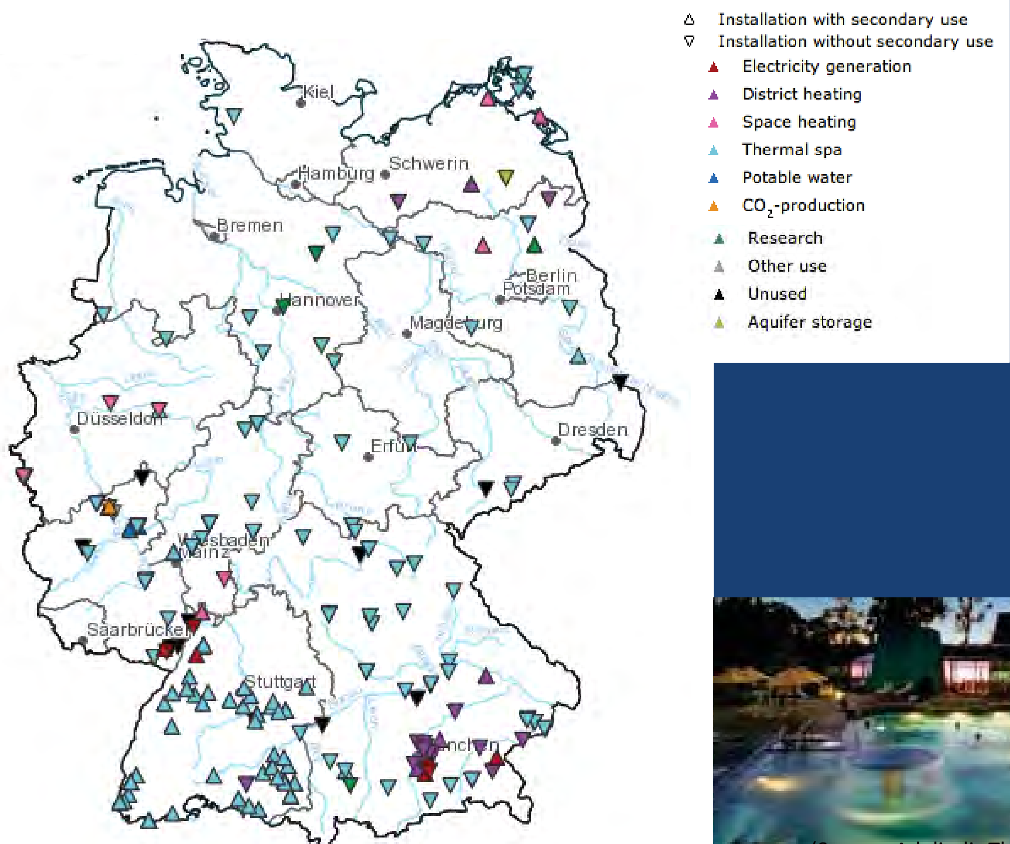
Operational Issues
of Geothermal Energy Installations in Europe

Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

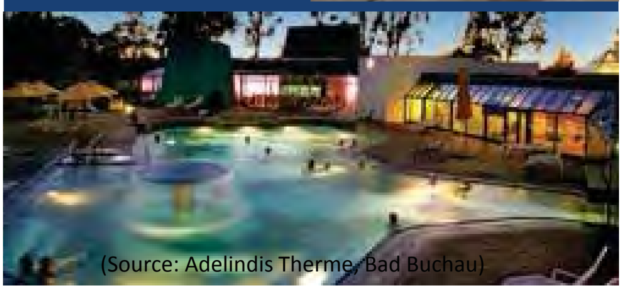
Country Overview
Germany
by Florian Eichinger



Thermal water usage in Germany

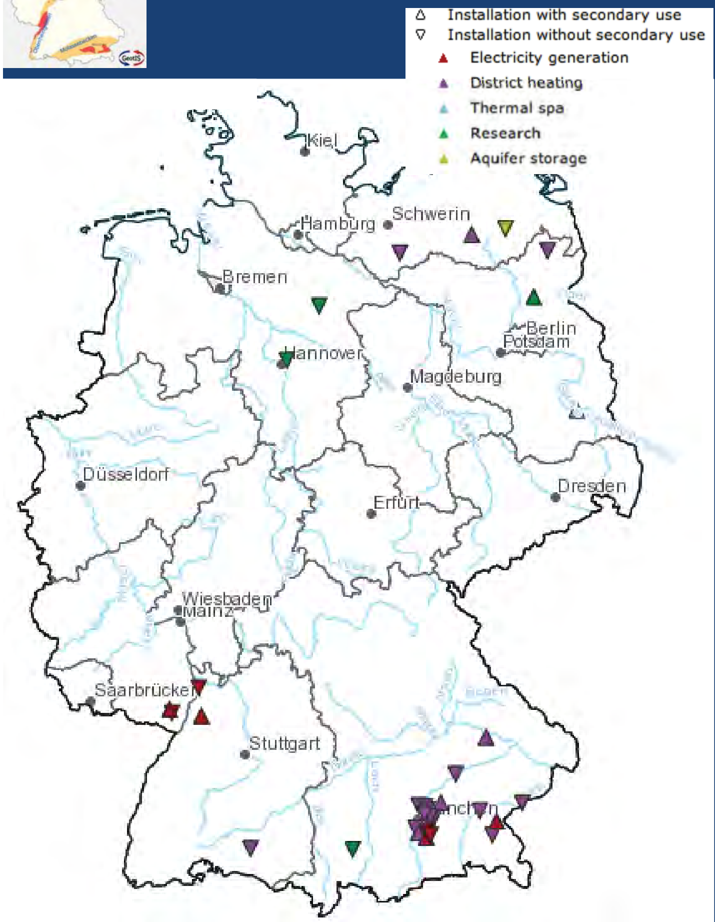


(www.geotis.de)



(Source: Adelindis Therme, Bad Buchau)

Geothermal Energy in Germany



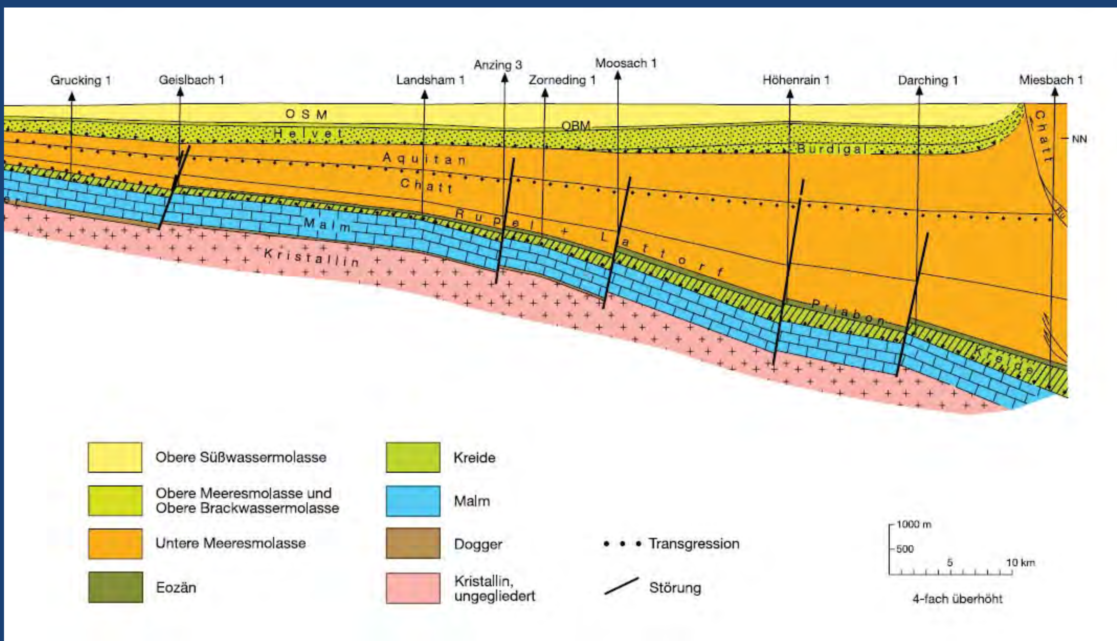
(www.geotis.de)

- 36 plants in operation
  - → Installed power: app. 300 $MW_{thermic}$ (279 MW BMB; 11 MW URV; 9 MW NGB)
  - app. 41 $MW_{electric}$ (35 MW BMB; 6 MW URV)
  - → max. depth: 5600 m b.s.
  - → max. Temperatures up to 165°C
  - → max. pumping rates up to 130 l/s
- 6 plants under construction
- over 35 projects in planning stage (among 5 EGS projects)

Source: Erdwärme Grünwald

Thermal Water Characteristics

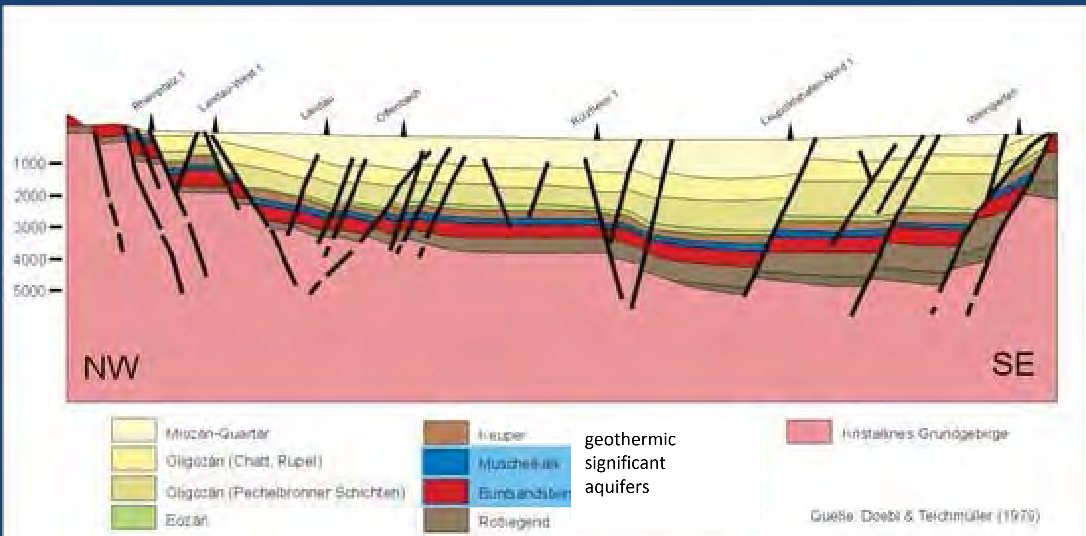
Thermal water of the malm aquifer from the Bavarian Molasse Basin (BMB)



- TDS = 600 – 800 mg/L
- Water type: Na-Ca-HCO_3-Cl
- H_2S and hydrocarbon bearing
- Gas content = 80 – 120 Nml/kg (70 % CO_2, 20 % CH_4, 10 % N_2)
- Radioactivity < 1Bq/kg H_2O

Thermal Water Characteristics

Thermal water of the Muschelkalk and Buntsandstein aquifers in the Upper Rhine Valley (URV)

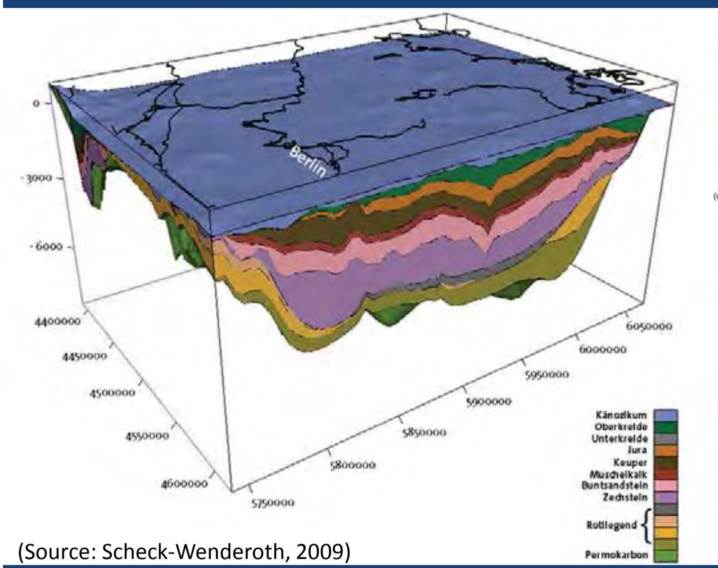


(Source: Zukunft Tiefe Geothermie Freiburg, modified after Doebl & Teichmüller, 1979)

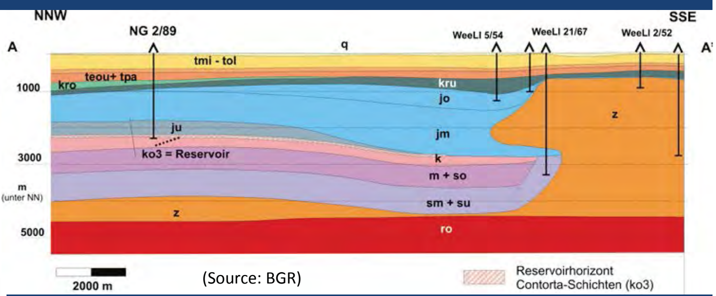
- TDS = 85 – 130 g/L
- Water type: Na-Ca-Cl
- H_2S and hydrocarbon bearing
- Gas content = 700 - 1500 Nml/kg (> 95 % CO_2)
- Radioactivity 50 – 200 Bq/kg H_2O

Thermal Water Characteristics

Thermal water of the Keuper, Buntsandstein and Permian aquifers in the Northern German Basin (NGB)



(Source: Scheck-Wenderoth, 2009)



(Source: BGR)

- TDS = > 250 g/L
- Water type: Na-Ca-Cl
- H_2S and hydrocarbon bearing
- Gas content = 100 - 1000 Nml/kg (strongly variing)
- Radioactivity 20 – 100 Bq/kg H_2O

Operational Issues in Germany: Scaling

Bavarian Molasse Basin

- Occurrence of scalings in four geothermal plants

- Mineralogical composition: Calcite, Pyrite

- Occurrence in and on the ESP, rising pipes, filters, surface pipes and heat exchanger

→ Cleaning (acidification) intervals of filters between 24 and 72 h

→ Lifetime of ESP between 6 weeks and 6 months

→ Cleaning of heat exchanger every 4 – 6 months

⇒ Substantial financial damage due to downtime of the plants

⇒ Difficulties in finding new investors and bank loans for power producing projects

Solution: Application of inhibitors ⇒ in the moment not allowed due to federal regularies

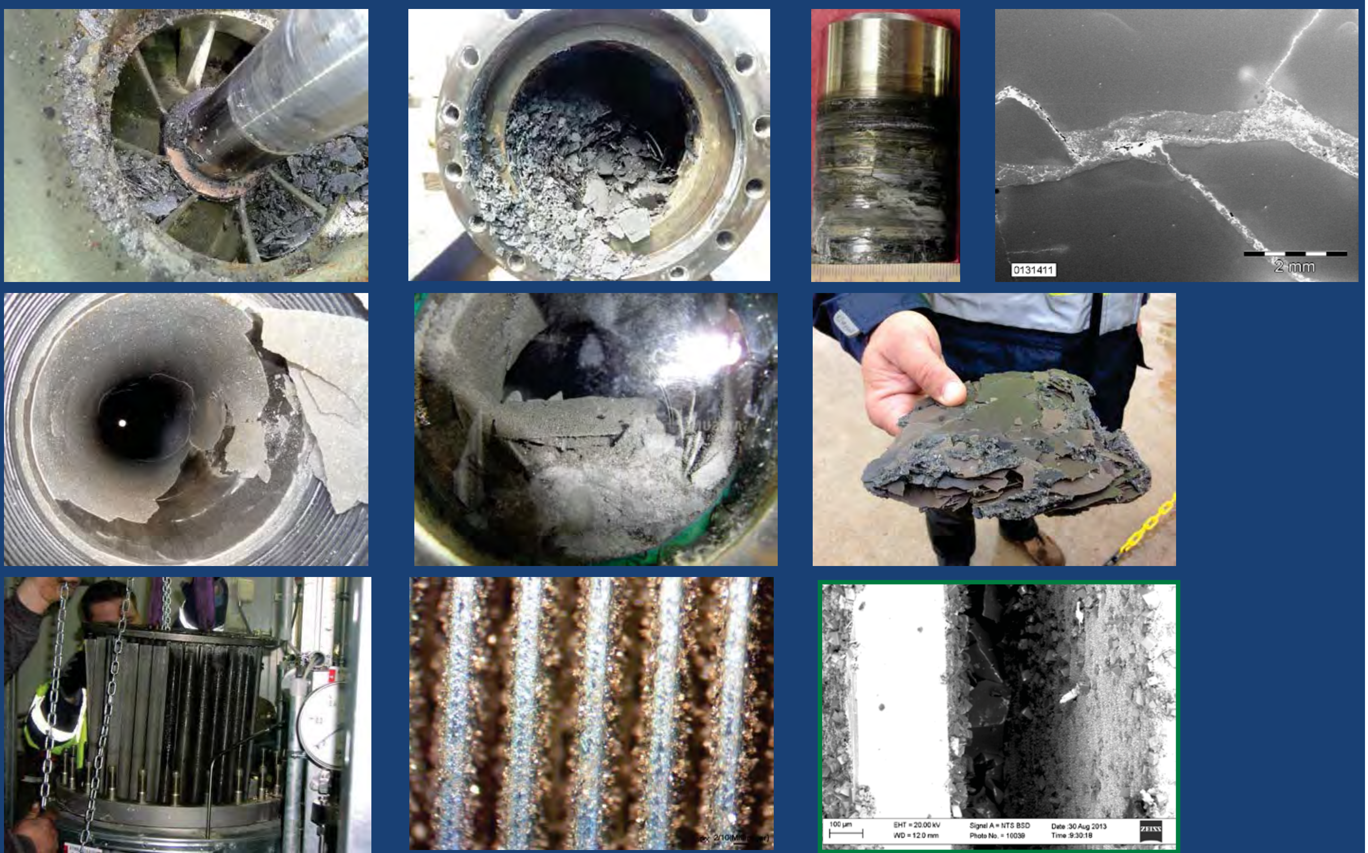
Operational Issues in Germany: Scaling

Bavarian Molasse Basin

ESP

Rising pipe

Filter



Operational Issues in Germany: Scaling

Bavarian Molasse Basin

Heat Exchanger

Operational Issues in Germany: Scaling

Upper Rhine Valley

- Occurrence of Ba- and Sr-Sulphate scalings in rising, injection and surface pipes and heat exchanger

⇒ blocking of devices and substantial maintenance requirements

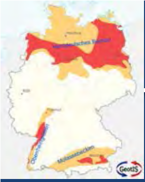
⇒ Nuclear radiation on the surface devices and difficult disposal of solids

Solution: Application of inhibitors

Barite scales on injection pipe (80 m b.s.)
(Scheiber et al., 2014)

Barite scales from heat exchanger
(Scheiber et al., 2014)

SEM picture of Barite and Celestite scales from surface pipe (Rauppach & Wolfgramm, 2012)



Operational Issues in Germany: Scaling

Northern German Basin

- Occurrence of Ba- and Sr-Sulphate and Pb-sulphide scalings in rising, injection and surface pipes and heat exchanger in plants producing from aquifers in triassic sedimentary layers (Rhät Sandstone)

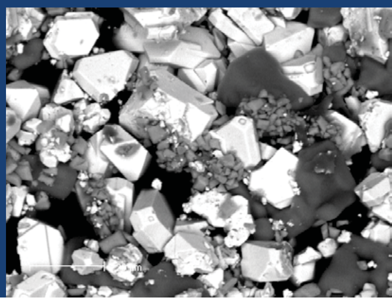
→ blocking of devices and substantial maintenance requirements

Solution: Application of inhibitors

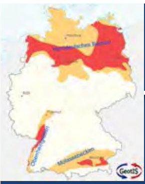
- Occurrence of Barite ($BaSO_4$), Laurionite (PbOHCl), Magnetite (Fe_3O_4) and Copper (Cu) in production well and aquifer areas behind filter in plants producing from aquifers in permian layers

→ blocking of production well and aquifer close to filter are

Barite and Celestite scaling in heat exchanger (Degering et al., 2008)



Barite and Galena scalings from surface pipes (Wolfgramm et al., 2009)



Operational Issues in Germany: Scaling

Northern German Basin

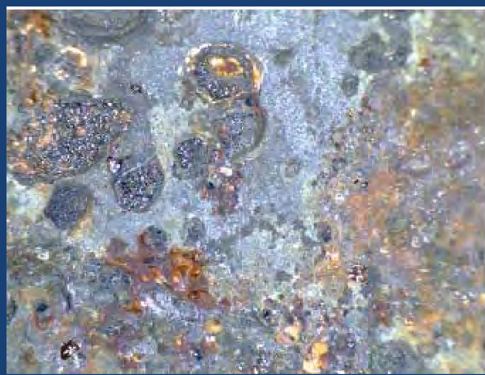
Scalings from a prouction well in the filter area (Regenspurg, 2013)

SEM image of scaling (Barite, Laurionite, Magnetite) (Regenspurg, 2013)

SEM image of scaling (Barite, Laurionite) (Wolfgramm, 2014)

Operational Issues in Germany: Corrosion

Geothermal Region	Corrosion inducing parameter	Corrosion in geothermal installations
Bavarian Molasse Basin	H_2S, CH_4	no significant corrosion
Upper Rhine Valley	Cl^-, H_2S, CH_4	no significant corrosion
Northern German Basin	Cl^-, M^+, H_2S, CH_4, O_2	- corrosion induced by O_2 entrance in surface devices - corrosion of metall casing induced by dissolved metals → Metal precipitation



Operational Issues in Germany: Gas Content

Geothermal Region	Gas concentrations	Gas composition
Bavarian Molasse Basin (BMB)	80 – 120 Nml/kg	app. 70 % CO_2, 20 % CH_4, 10 % N_2, traces of HHC, He, Ar
Upper Rhine Valley (URV)	700 - 1500 Nml/kg	> 95 % CO_2, traces of N_2, CH_4, HHC He, Ar, H_2
Northern German Basin (NGB)	100 - 1000 Nml/kg	Triassic aquifers: app. 80 % CO_2, 11 % N_2, 9 % CH_4, traces of HHC, He, Ar Permian aquifers: app. 85 % N_2, 14 % CH_4, traces of CO_2, H_2, He, Ar

Prevention of degassing

BMB: Pressure maintenance, but micro degassing on bend tubes, valves and rough areas

URV: Pressure maintenance, controlled degassing in combination with inhibitors

NGB: Pressure maintenance, but formation of gas bubbles which reduce productivity

Operational Issues in Germany: Reinjection

BMB: „Carbonate dominated“ systems

- Prevention of scalings in the injection well by adequate pressure keeping

URV, NGB: „Sulphate dominated“ systems

- Formation of sulphate scalings in the injection wells → blocking of the injection well and reservoir fractures

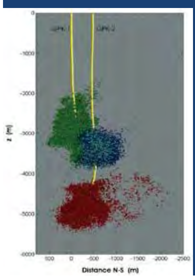
⇨ Application of inhibitors and pressure maintenance

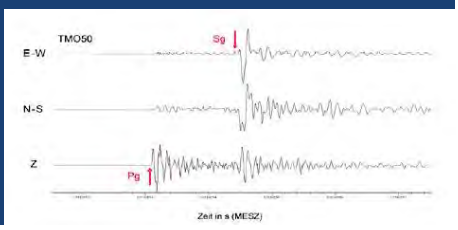
Operational Issues in Germany:

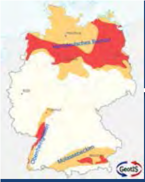
Induced Seismicity in the seismic active Upper Rhine Valley

- Induced seismicity due to fluid injection during operation
  - → Seismic monitoring
  - → Graduated scheme, developed with mining authorities, to follow when microseismicity accumulates.
  - → Adjustment of reinjection volumes and pressures
  - → but: still large debate about the main driving parameter (flow rate, injected volume, injection pressure?) of induced seismicity

- Triggered and induced seismicity due to drilling and stimulation
  - → detailed characterisation of the tension regimes in the planning and exploration phase
  - → Seismicity monitoring before and during drilling, stimulation and borhehole development phase
  - → Rapid adjustment of the parameters during these phases







Operational Issues in Germany:

Other issues:

- Public acceptance and dialogue with citizens movements
- Increasing investment costs
- ESP technology
- Success Insurances
- Improvement of the effectiveness in the generation of electricity of geothermal power plants

Geothermal Energy in Germany – A short summary

→ Geothermal energy is an absolut success story, although the boom of the early 2000 is over

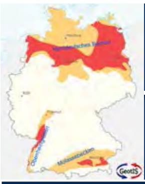
→ Still several open questions and unsolved problems

→ Future of power producing projects depends on govermental subsidies and solution of open questions

→ Development and construction of heat projects continues





Operational Issues in Germany: Summary and Open Questions

	solved		unsolved
	Issue	*Solution*	
Scaling (1a)	*URV, NGB: Ba- and Sr-Sulphate scalings in rising pipes and surface pipes and devices*	*Application of inhibitors*	
	URV, NGB: Enhanced radioactivity in sulphate scalings	*Application of inhibitors*	No inhibitors for radioactive Pb210
	NGB: NaCl scalings in production well	*Pressure- and temperature keeping during drilling and borehole development*	
	NGB: Formation of Pb- and Cu bearing scalings in the rising pipe and borehole close area of the production well	*Prevention of electrochemical corrosion by application of adequate materials (higher alloyed steels)*	Removal of Cu above ground
			NGB, URV: Metalsulphide scalings
			BMB: Carbonate- and sulphide scalings - in and on the pumps - in the rising pipe - in filter systems - in entrance heat exchanger Possible solutions: - Application of inhibitors Problem: federal regulations - Development of new filter systems - Usage of coated rising pipes → Ongoing research projects and active discussions between the individual operating companies

Operational Issues in Germany: Summary and Open Questions

	solved		unsolved
	Issue	*Solution*	
Induced seismicity (1b)	*URV: Induced seismicity due to fluid injection during operation*	*- Seismic monitoring - Graduated scheme, developed with mining authorities, to follow when microseismicity accumulates. - adjustment of reinjection volumes and pressures: run power plant as stable and smooth as possible*	*- still large debate about the main driving parameter (flow rate, injected volume, injection pressure?) of induced seismicity*
	URV Triggered and induced seismicity due to drilling and stimulation	*- detailed characterisation of the tension regimes in the planning and exploration phase [but hard to derive, in-situ only possible in and in the very vicinity of the borehole (HTPF, borehole break-outs, ...), Fault Plane Solution from microseismicity is unreliable] - Seismicity monitoring before and during drilling, stimulation and borhehole development phase) - Rapid adjustment of the parameters during these phases (Reaction is necessary, but careful! Example Soultz: experience from stimulation is that largest events occured during shut-in, therefore practise of ‚step wise shut-in')*	

Operational Issues in Germany: Summary and Open Questions

	solved		unsolved
	Issue	*Solution*	
Corrosion (2)	Corrosion induced by oxygen	- Pressure keeping - Application of inert gas - Adjusted design of surface devices	
			Corrosion induced by H_2S → ongoing and planned research projects
Gas content (3)	*Formation of free gas phases during production (and injection)*	*- Adequate pressure maintenance in the production well, surface devices and injection well - URV: Controlled degassing and application of inhibitors*	*NGB: potentially high amounts of free gas (N_2 and CH_4) and formation of gas bubbles reduce productivity*
Reinjection (4)	Formation of scalings due to pressure release in the upper meters of the injection well	- Adequate pressure maintenance	
			Potential decrease of injectivity due to a decrease of the permeability of water-conducting fractures by the formation of scalings → ongoing and planned research projects

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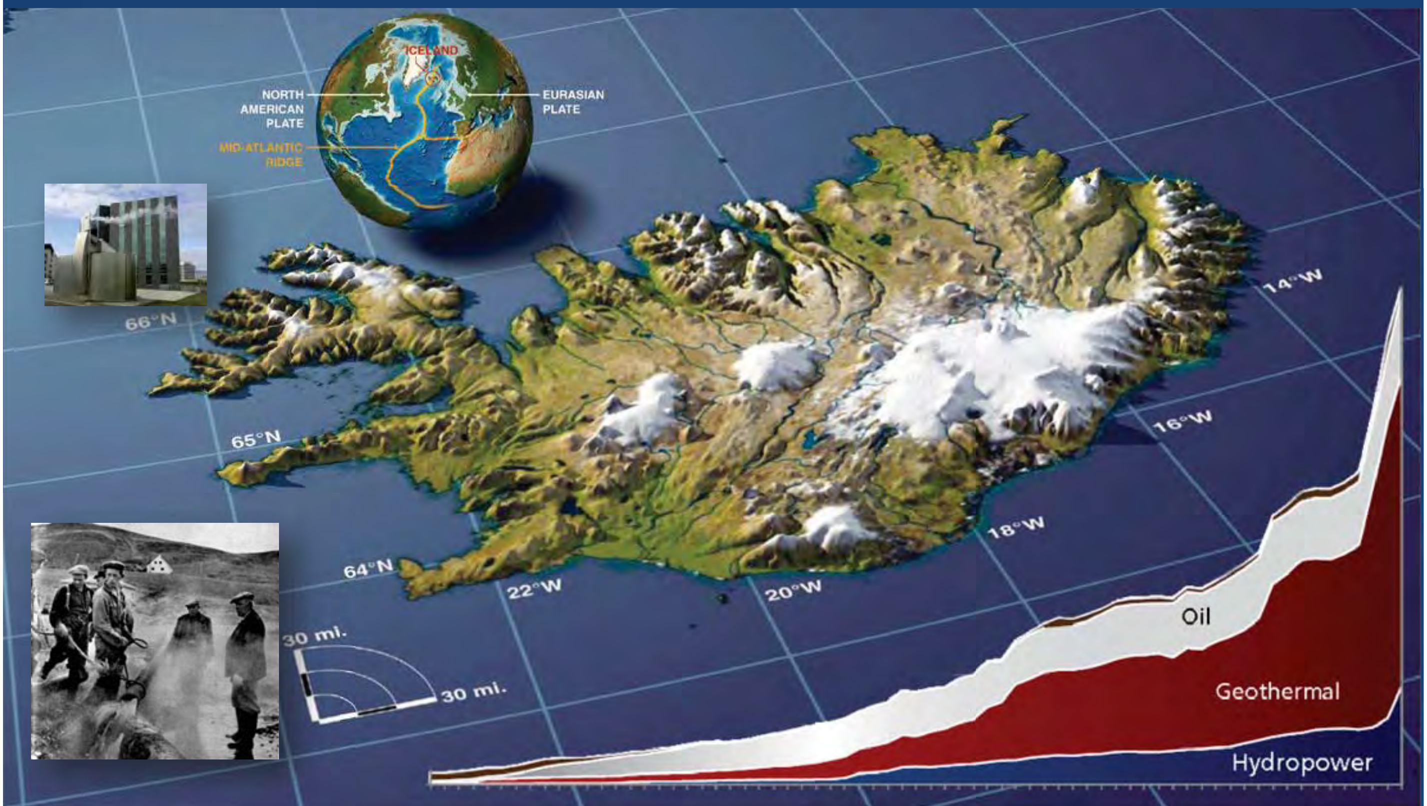
Operational Issues
of Geothermal Energy Installations in Europe

Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

Country Overview *Iceland*

By Hjalti Páll Ingólfsson
Operational Manager of GEORG

GEOTHERMAL ENERGY IS VERY IMPORTANT TO ICELAND

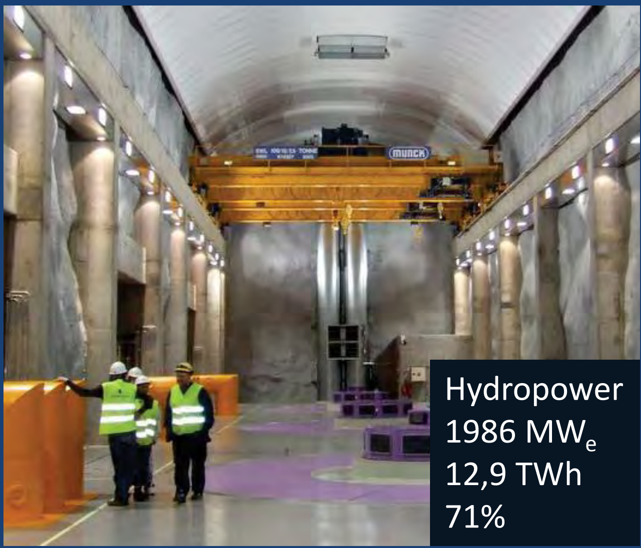


Electricity Generation and Use 2014

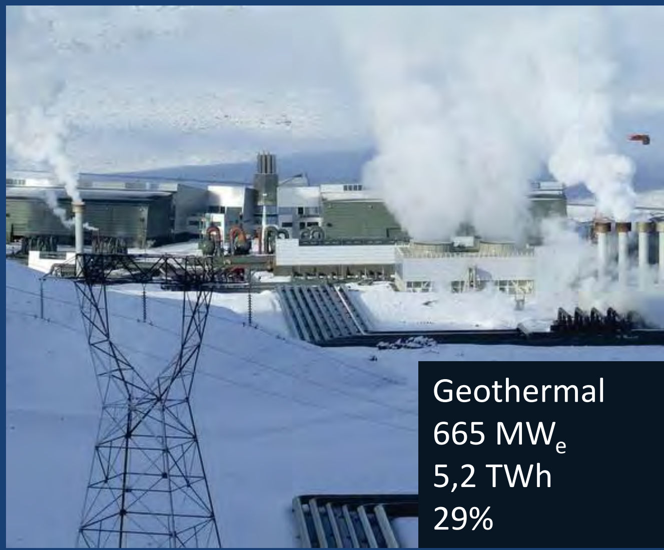
General use	3 TWh	17%
Large industries	14 TWh	77%
Losses & plant use	1 TWh	5%

Wind
3 MWe
8 GWh

Fossil fuels
106 MWe
2 GWh

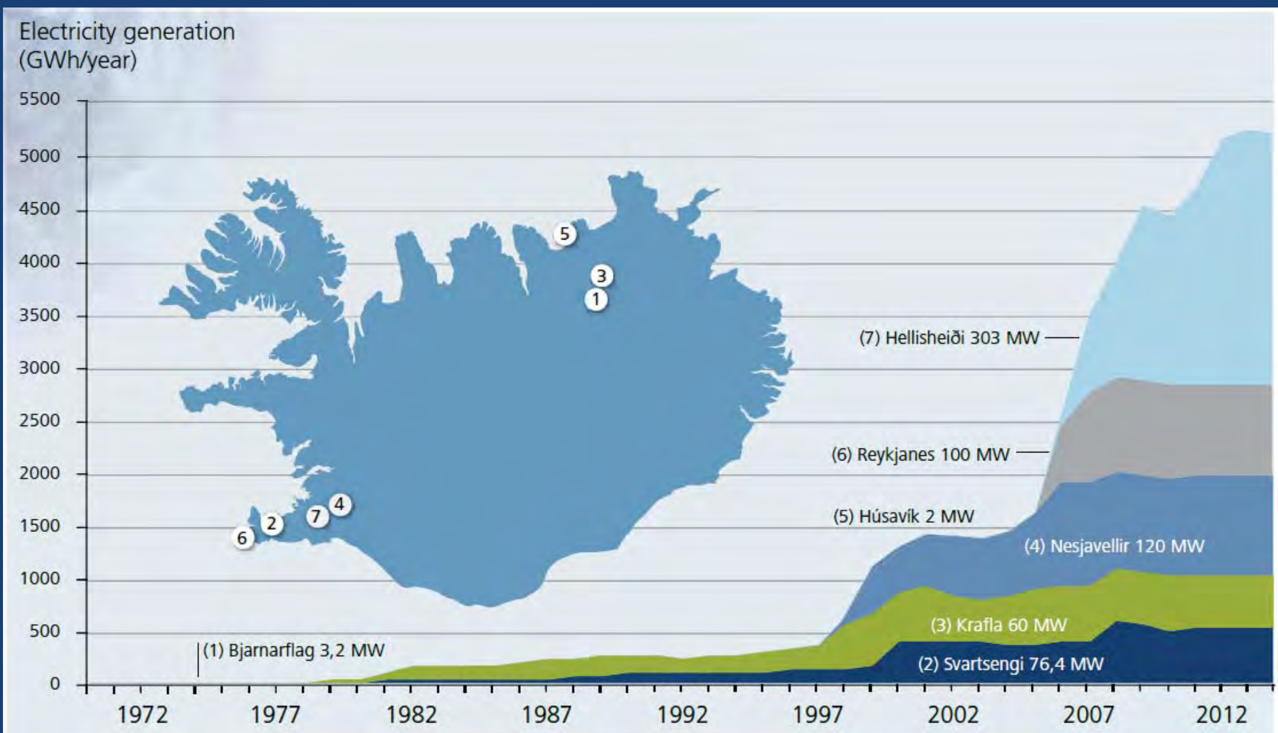


Hydropower
1986 MW_e
12,9 TWh
71%

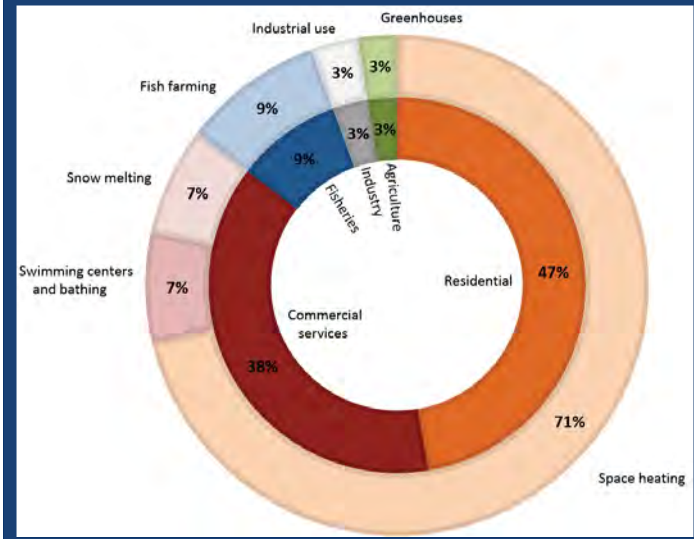


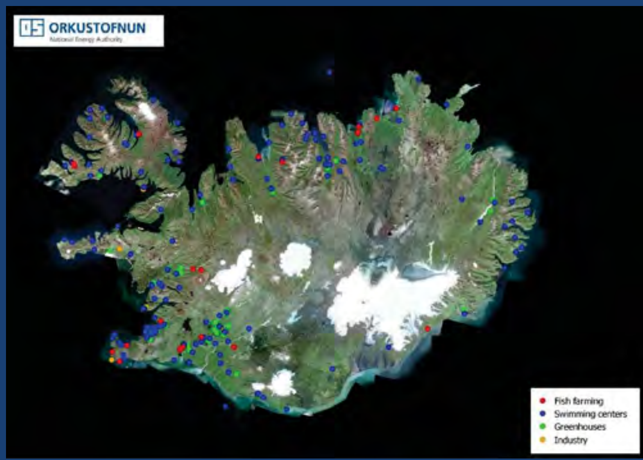
Geothermal
665 MW_e
5,2 TWh
29%

Electricity Generation with Geothermal



Geothermal Heat 2014





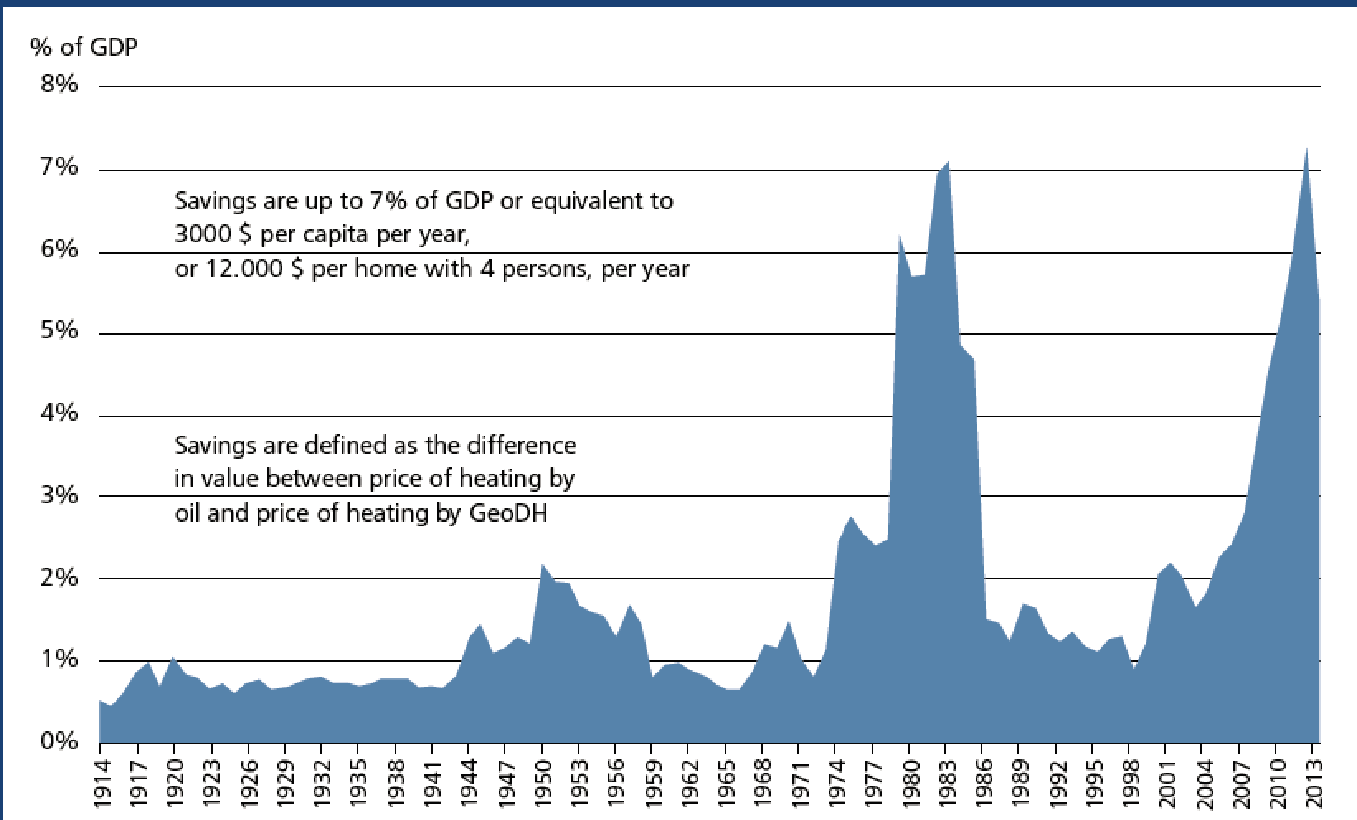
28.1 PJ in total
Inner ring: IEA/Eurostat categorization
Outer ring: IGA categorization





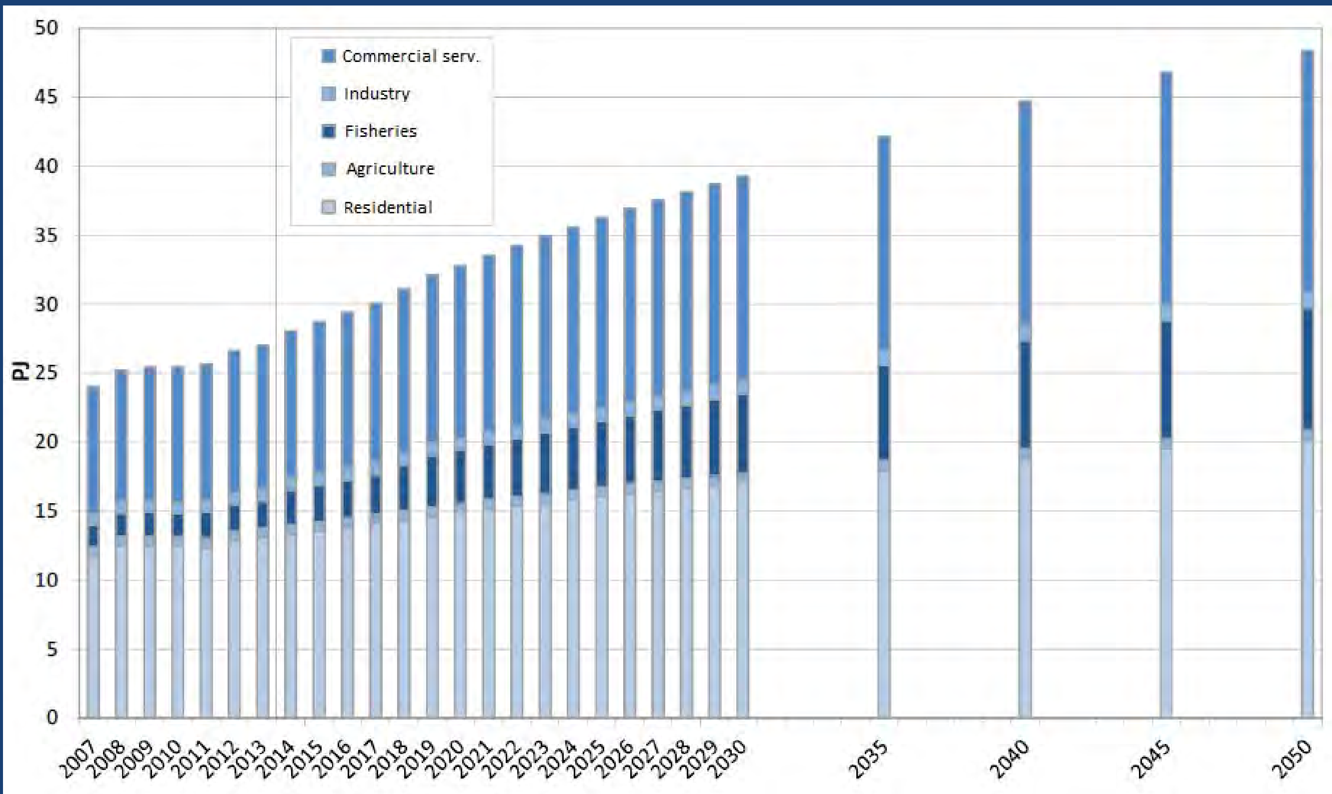
Economic Benefits of Geothermal District Heating

as a % of GDP 1914-2013

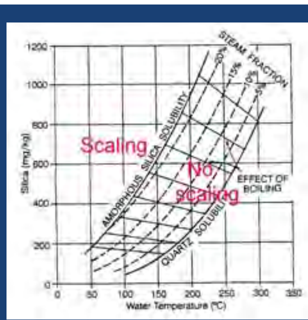


Geothermal Heat Forecast 2014–2050

Preliminary data in review



Statistics Iceland predict a 36% increase in population until 2050. This is estimated among other factors to increase geothermal heat use by 70% until 2050.



Types of scaling occurring in geothermal waters

- Silica scales
  - Found to some extent in all high temp installations but by maintaining the temperature above the solubility level for amorphous silica the scaling should not occur
  - In geothermal CHP plants silica scaling can occour in heat exchangers and pipes
  - In the dilute high temperature fields where the chloride concentration is low the precipitation of amorphous silica can be postpone by slow flow rate through heat exchangers allowing the aqueous silica to form polymers in the solution
  - A problem in flash turbines and when reinjecting low pressure geothermal fluids
- Iron silicate scales
  - Occur in saline geothermal fluids or in fluids disturbed by the effects of volcanic gas
  - Normally do not form at higher pressures than 16-18 bar
- Sulphide scales
  - In saline geothermal fluids or in fluids disturbed by the effects of volcanic gas sulphide deposits are prone to form by reaction of metal(s) with H2S.
- Calcium carbonate scales
  - Common in wells with reservoir temperatures of 140-240°C, and are primarily found at the depth where the water starts to boil in the well
  - Inhibitors have been used to prevent calcite deposition in geothermal wells.
- Magnesium silicate scaling
  - Magnesium silicates are formed upon heating of silica containing ground water or mixing of cold ground water and geothermal water.

The main species causing corrosion in geothermal waters:

- Hydrogen Ion
  - The corrosions rates of most materials increases as the pH of the fluid decrease
- Chloride
  - The chloride ion accelerates corrosion of metallic surfaces.
  - “pitting” as well as uniform corrosion.
  - Stress corrosion cracking in some types of stainless steel
- Hydrogen Sulphide
  - Copper and its alloys are attacked by hydrogen sulphide.
  - Sulphide stress cracking in high strength steels
  - Mild steel more suitable
- Carbon Dioxide
  - Mild oxidizing agent that causes increased corrosion of plain carbon steels
- Ammonia
  - Ammonia causes increased corrosion of copper-based alloys, and is especially important in
- Sulphate
  - Sulphate is the primary aggressive ion in some geothermal fluids.
- Oxygen
  - Usually not present in geothermal fluids except in fluids at low temperature and in heated ground waters for residential use
  - Hydrogen sulphide reacts with the oxygen and prevents corrosion

Scaling and Corrosion

Lessons learned in Icelandic district heating systems

LAGNAVEFURINN lagnaval.is

- Compacted knowledge on district heating systems in Iceland
  - Consults in selecting material for pipelines, heat exchangers and radiators
  - Based on data on chemical composition of the geothermal waters all-around Iceland

lagnaval.is

KRANAVATN | HITAKERFI | UPPLÝSINGAR

Hitakerfi - Gegnumstreymi

OR-HAB Akranesveita

Orkuveita Reykjavíkur gerir þá kröfu á veitusvæði sínu að í nýbyggingum sé varmaskiptir á heitu neysluvatni og það sé ekki heitara en 65°C. Farið í takkann "upphitað vatn" til að fá ráð um lagnaefni þar sem það á við.

Lagnaefni sem mælt er með án skilyrða.	
Efni	Athugasemdir
Stálofnar	Hentar.
Pottofnar	Hentar.

Lagnaefni sem hægt er að nota ef vissum skilyrðum er fullnægt.	
Efni	Athugasemdir
Svart stál	Getur hentað, þar sem engin hætta er á utanaðkomandi raka. Hætta er á tæringu utan frá, ef raki kemst að rörunum. Notið ekki í dreifbýli eða smærri bæjum þar sem langar lagnaleiðir eru úr plasti.
Galvaniserað stál.	Getur hentað, þar sem engin hætta er á utanaðkomandi raka. Hætta er á tæringu utan frá, ef raki kemst að rörunum. Notkun galvanhúðaðra röra getur valdið útfellingu sinksambanda í ofnlokum o.þ.h.
Ryðfrítt AISI 316 stál.	Getur hentað, ef tekið er tillit til hættu á tæringu utan frá. Tæring myndast ef raki kemst utan á rörin og vatnshitastig er yfir um 65°C. Við þau skilyrði þurfa ryðfríar lagnir að vera aðgengilegar og helst sýnilegar, þannig að hægt sé að sjá hvort hrúður er að myndast utan á rörunum t.d. við samskeyti. Þéttihringir í þrýstitengjum og/eða lóðmálmar þurfa að þola áætlað vatnshitastig.
Álofnar	Ekki ráðlagt nema tryggt sé að góð reynsla sé af álofnum á staðnum. Leitið frekari upplýsinga.

Lagnaefni sem ekki er mælt með notkun á.	
Efni	Athugasemdir
Ryðfrítt AISI 304 stál.	Ekki mælt með vegna hættu á tæringu utan frá.

Efnagreiningar veitu

Efnagreiningar veitunnar sem ráðgjöf grundvallast á hafa verið settar hér inn. Unnt er að velja úr efnagreiningu og fá ráðgjöf miðað við þá efnagreiningu. Í framhaldi af því er síðan unnt að breyta efnagreiningunni og finna hentug lagnaefni fyrir tiltekna efnasamsetningu.

Mælistaður	Dags	°C	pH	CO_2	O_2	Cl	H_2S	Ca	Mg	SiO_2	F
Safngreining f. ráðgjöf		80,0	9,20	16,00	0,00	35,00	1,20	3,10	0,00	127,00	2,40

High enthalpy
Scaling and Corrosion

- **Silica scaling occurring inside geothermal pipes after 14 days of use. Samples for corrosion testing can be seen totally sealed by the scale.**

High enthalpy
Scaling and Corrosion

- **Sulphides scales precipitated in one year. To the left the scales (mainly ZnS covered by Cu-sulphide) coats the fluid-flow control valve (14 cm long). To the right the scales (mainly ZnS) coats the inner surface of the pipe (7 cm thick).**

IDDP-1

IDDP-1

Landsvirkjun

The steam is superheated. When it condenses it forms water with pH 2,5-3

- Highly corrosive. Not suitable for carbon- or stainless steel

Solid particles

- Iron dust (Fe_3O_4, $FeCl_2$)
- Silica dust

4

IDDP-1 fluid

Gas content of Icelandic Geothermal waters

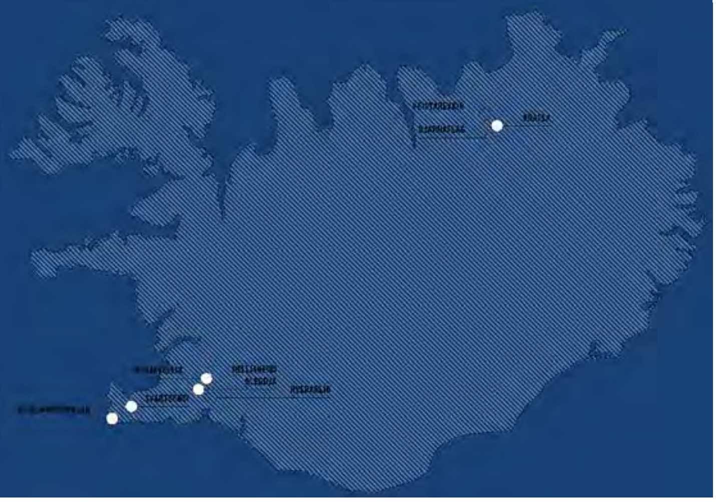
- Mainly carbon dioxide (CO_2) and hydrogen sulphide (H_2S)
- Other gases in much smaller amounts are hydrogen (H_2), nitrogen (N_2), methane (CH_4) and argon (Ar)

- New regulation 514/2010 on atmosperic H_2S concentration
  - Health references
    - 24 hour running average 50 µg/m^3
    - Yearly average 5 µg/m^3

Exhaust and references 2012

Location	MW	CO_2 (t/year)	CO_2/ MW	H_2S (t/year)	H_2S/ MW
Hellisheiði	303	43.158	142	12.370	56
Nesjavellir	90	18.612	207	8.700	126
Krafla*	60	44.300	667	6.810	83
Reykjanes	100	25.090	251	860	9
Svartsengi**	55	53.840	979	1020	19

* 2011
**Installed capacity 75 MW

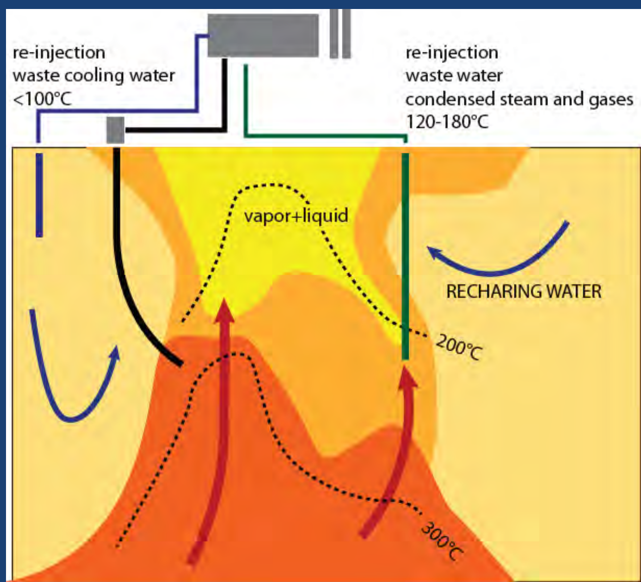


Hæðarendi, SW-Iceland

- Since 1986, a plant produces CO_2 from geothermal waters
  - 160°C, 1.4% wt. gas content
  - 6 l/s produces 2000 tCO_2/y,
    - sufficient for the Icelandic market (food, greenhouses)

Sulfix and Carbfix projects

- **One possible options of reducing H_2S and CO_2 is re-injection and mineralization into the geothermal systems**



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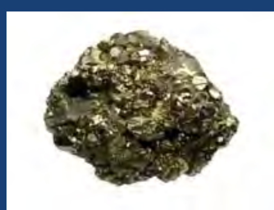
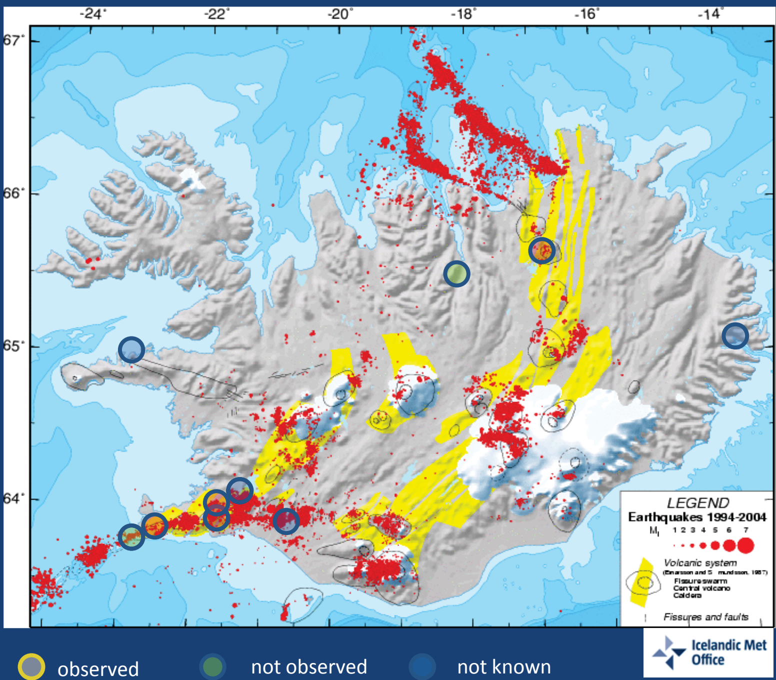


basalt

H_2S or CO_2 in water

Sulfide (H_2S) or
stable carbonate minerals (CO_2)

Reinjection - seismicity



observed · not observed · not known

Induced seismic event
Seismic event, e.g., an earthquake that is induced by manmade activities such as fluid injection, reservoir impoundment, mining, and other activities. The term "induced" has been used to include "triggered seismic events" and so sometimes the terms are used interchangeably. See "triggered seismic events" below and in this report.

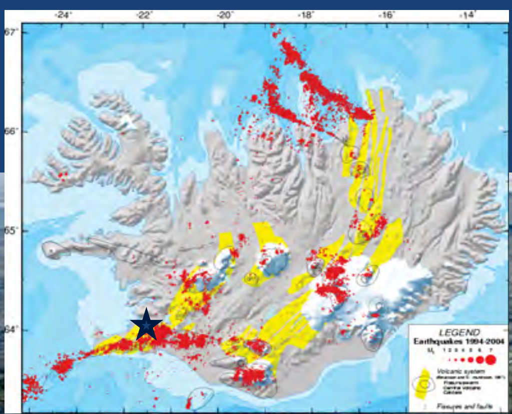
DOE protocol

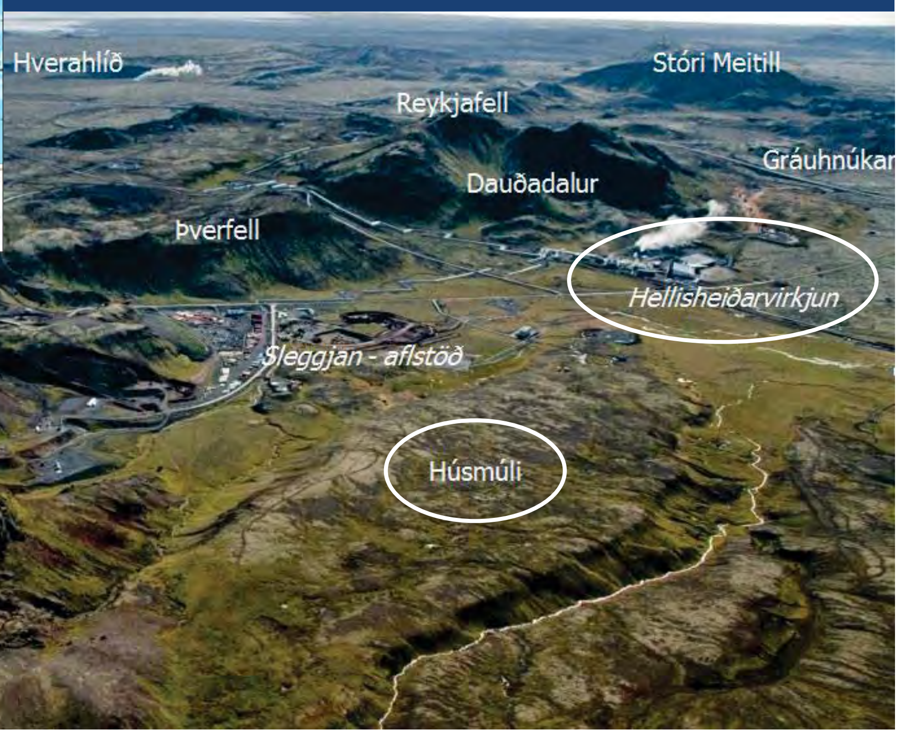
Triggered seismic event
Seismic event that is the result of failure along a pre-existing zone of weakness, e.g., a fault that is already critically stressed and is pushed to failure by a stress perturbation from natural or manmade activities.

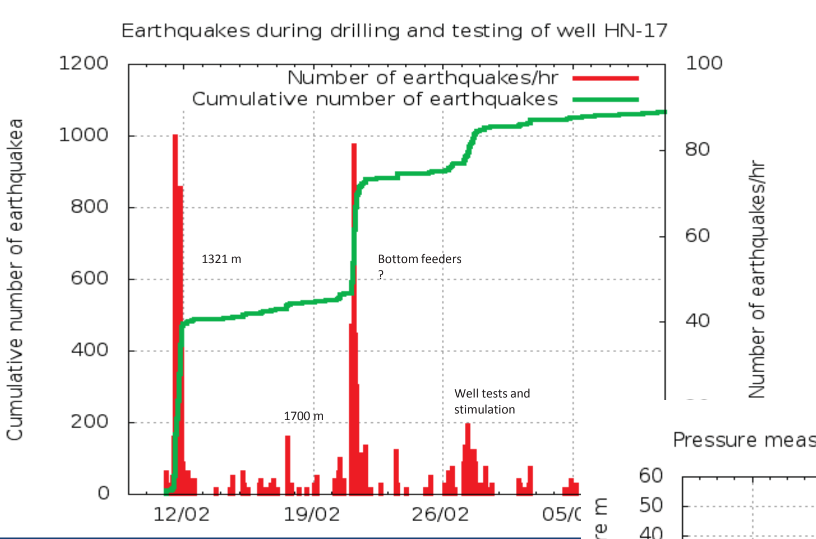
DOE protocol

Reinjection - seismicity

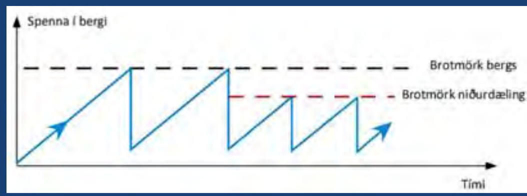
Húsmúli

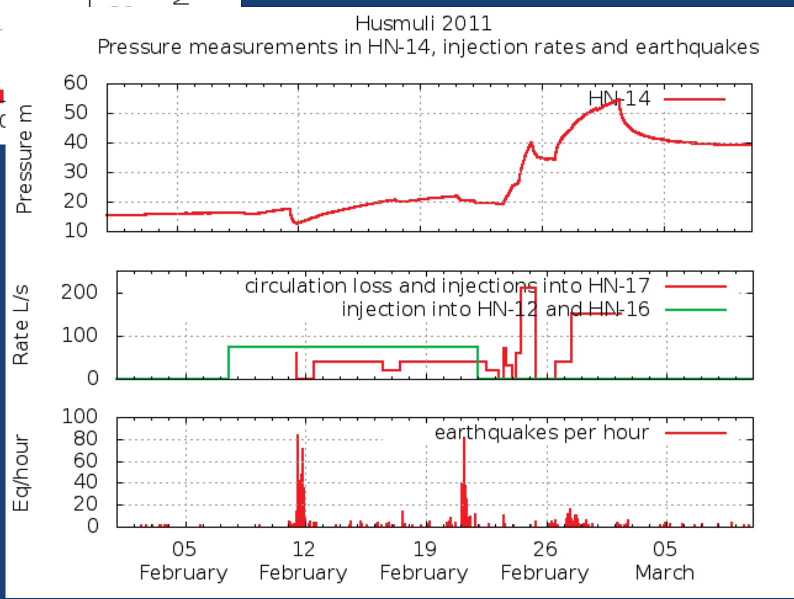






Clear example of triggered seismic event





Matrix

	solved		unsolved
	Issue	*Solution*	
Scaling	*Scaling in Low temp fields*	*Various ways, depending on the site and situation http://www.lagnaval.is*	Silica precipitation in ultra high temp fields - IDDP wells
Corrosion	*Corrosion in low temp fields*	*Various ways, depending on the site and situation http://www.lagnaval.is*	Develop materials that can withstand superheated and supercritical conditions
	Acid scrubbing	*Wet Scrubbing Low cost and robust, but reduces energy output of plant*	Find more energy efficient ways to remove acid components from the geothermal steam
Gas content	*Gas emissions from geothermal plans*	*Carbfix and Sulfix*	Cost reduction on gas separation and reinjection
	CO2 content in low temp field	*Harness it and sell it (Hæðarendi)*	Value creation from the separated gases (an alternative to reinjection)
Reinjection	*Triggered seismic events*	*Start injection slowly Keep flow steady Inform and educate the public*	Clogging of injection wells due to scaling

Other issues: High emphasis on developing material to withstand the conditions of a supercritical steam and power output of up to 10 time normal output.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Geothermal ERA-NET

OpERA

Operational Issues
of Geothermal Energy Installations in Europe

Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

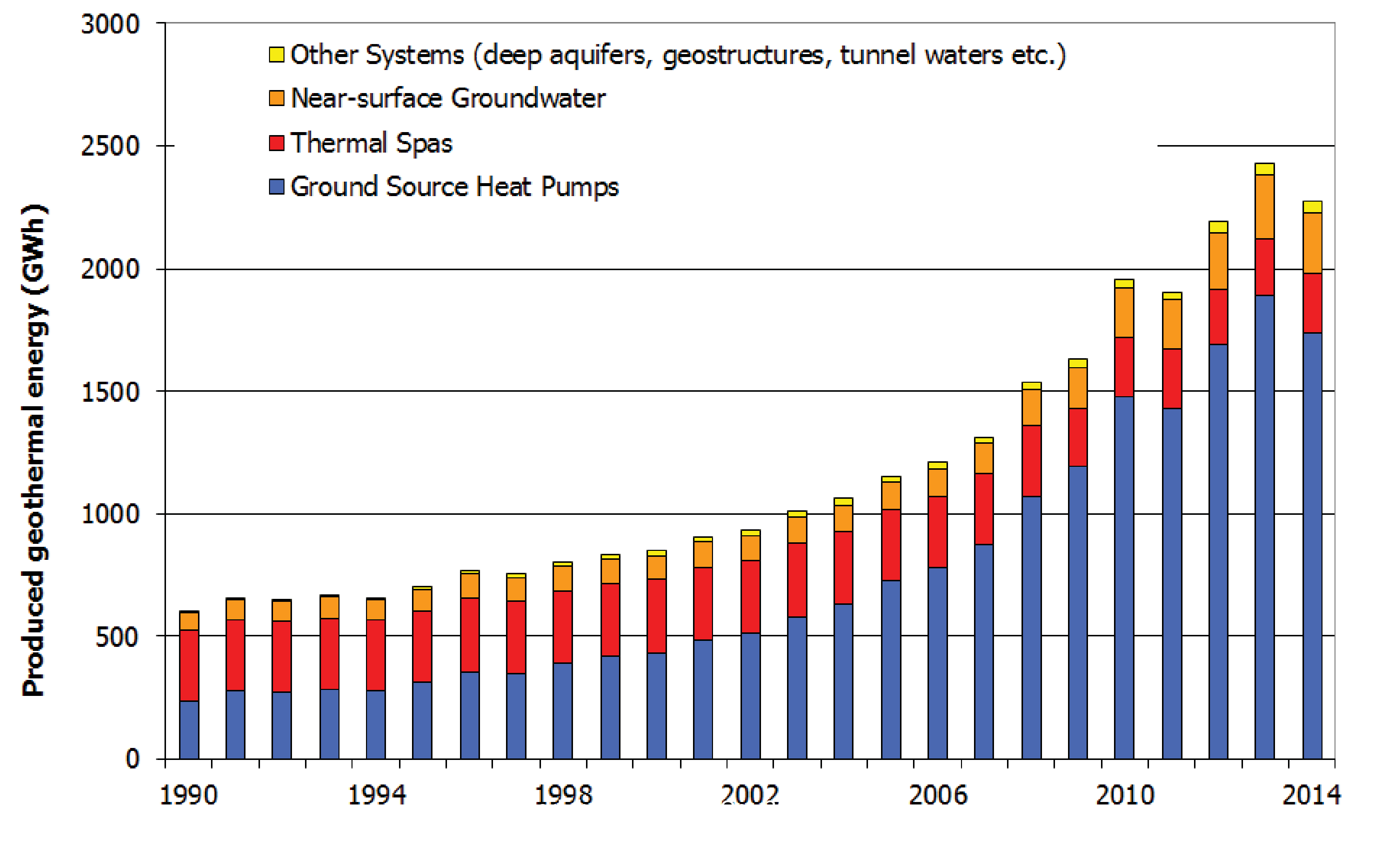
Country Overview
Switzerland

by Bernd Frieg

Overview

1. **Geothermal Energy in *Switzerland***
2. **Operational Issues in Switzerland**
   A. Corrosion Issues with Examples
3. **Summary: Solved/unsolved Operational Issues in Switzerland**

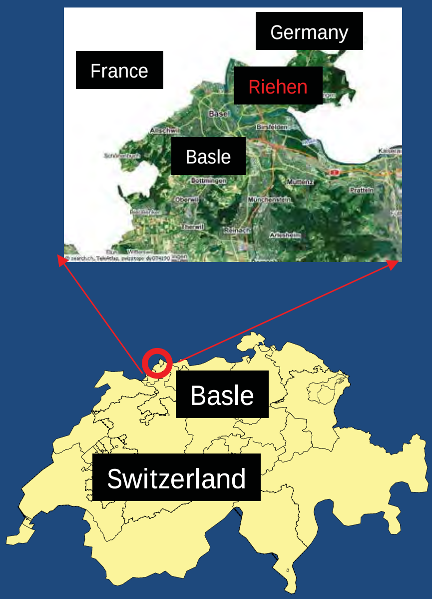
Near-surface geothermal energy in Switzerland – unseasonably (?) warm 2013/2014 winter



Geothermal energy in Switzerland – direct use and combined heat and power

- Combined heat and power exploration project in St Gallen encountered natural gas and limited hotwater
- Direct use geothermal energy project in Riehen (Ct. BS) continues to produce heat
- Direct use project in Schlattingen (Ct. TG) undergoes production optimization (corrosion inhibition & acid treatments in horizontal wellbore section)
- Project maturation continues in Switzerland (CHP hydrothermal project in Lavey-les-Bains (Ct. VD) and CHP EGS project in Haute-Sorne (Ct. JU) are close to FID
- Exploration activities in Cts. GE, AG, FR, VS, VD

District Heating Riehen (CH)



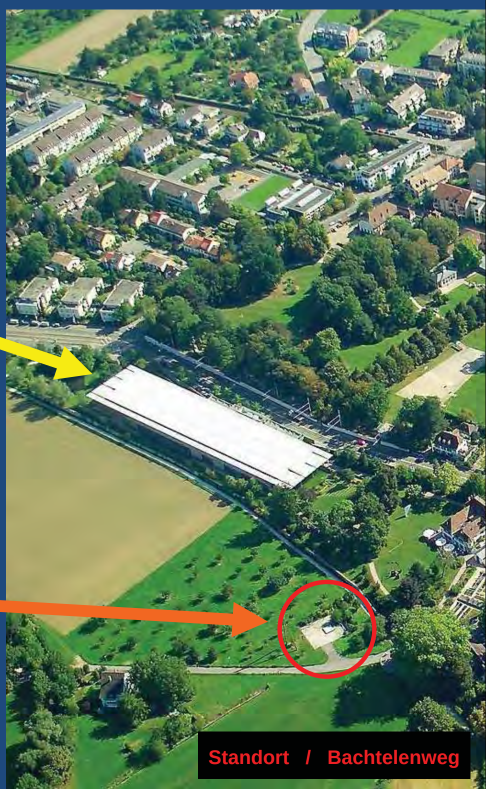
1980 – 1987 Conceptual Studies, Planning and Design of Wells
1988 Drilling operations RB1 (producer) and RB2 (injector)
1989 - 1993 Phased construction of district heating network, initially exclusively fossil fuelled
1989 Long term well production test to test sustainability
1990 Decision to use geothermal energy
1992 Construction of a base load facility for geothermal energy
1994 Operation of geothermal base load facility (April 1994)
1997 First cross-border heat supply to neighbouring community in Germany
2004 Peak shaving gas fired facility installed
2006 Riehen-Plus : Conceptual studies to combine scheme with those of 2 neighboring Swiss communities

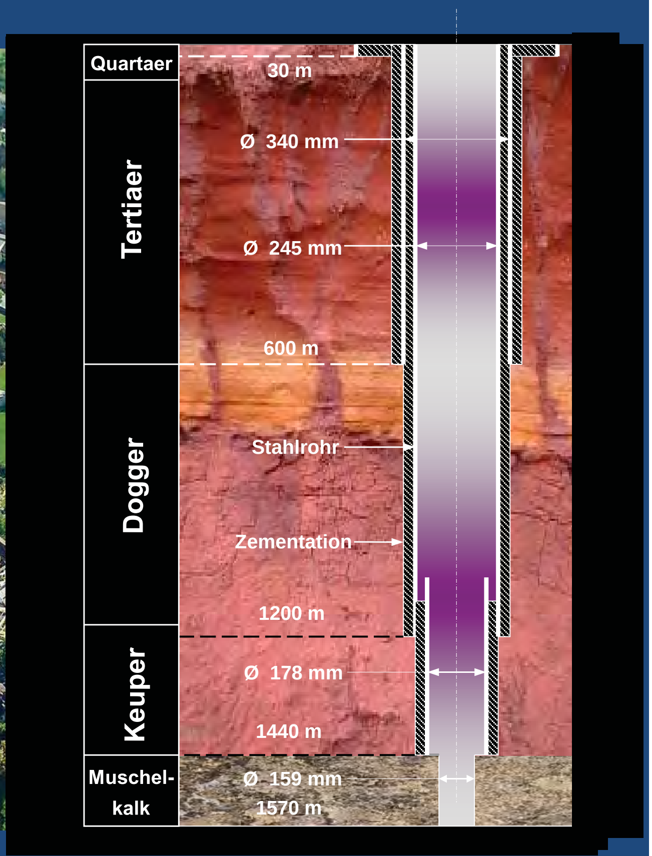
Richard Grass, Community of Riehen
Karl-Heinz Schädle, Gruneko AG
Gunter Siddiqi, Swiss Federal Office of Energy
IEA Sustainability Workshop, Taupo (New Zealand) 10 Nov 2008

Operating in a highly sensitive area

Major Swiss tourist attraction: Fondation Beyeler Art Museum

Production well with artificial lift installations (underground cellar structure)





Technical Data – Riehen Scheme

Depth Production Well:	1547 m
Depth Injection Well:	1247 m
Temperature at Aquifer:	66°C
Wellhead temperature: (constant since 1994)	62-68°C
Production rate:	~ 18 l/s
Injection pressure: (constant since 1994)	~ 7 bar
Production pump landed at a depth of 390 m:	168 kW (228 h.p.)

Operations Data:
1994/6-2004: paper copies of weekly traces
2004 to today: electronic format

Salinity: 1989 – 17 g/l; 2007 – 16 g/l

Bubble point: 10.5 bar

Gas-Liquid Ratio: 0.6 %

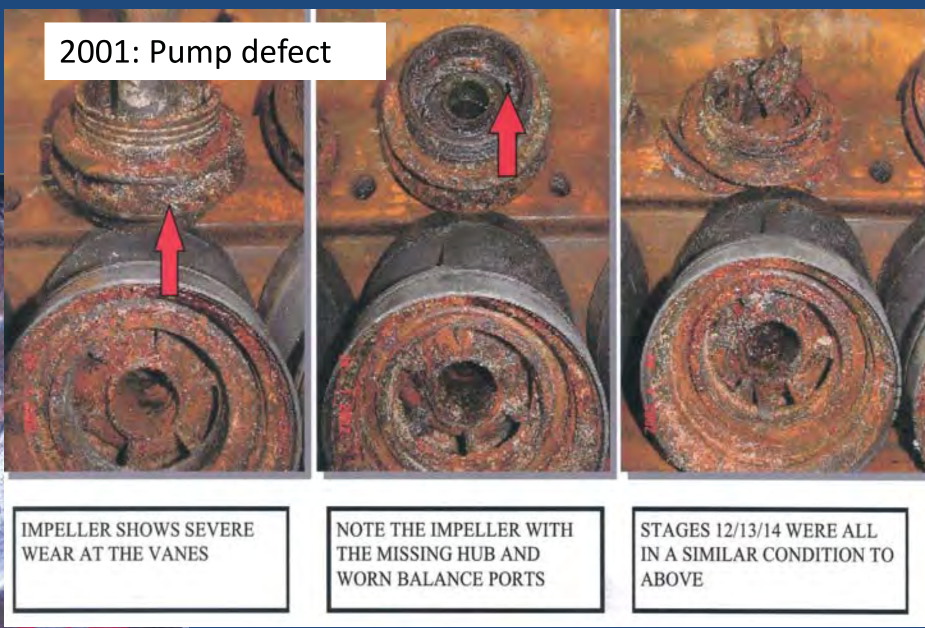
H_2S: < 0.1 mg/l

Traces of CO_2, Ar, He, N_2, H_2, H_2S, C_1-$C_{6?}$

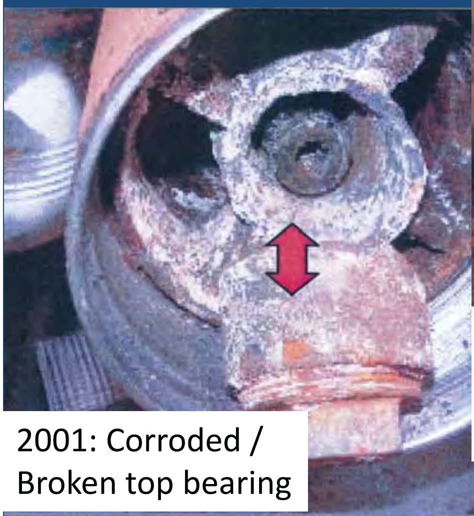
Inhibitor: Corridos 45 dosage: 5 mg/l

Corrosion rate (from coupons): 0.06 mm/yr
but in previous years: 0.8 mm/yr

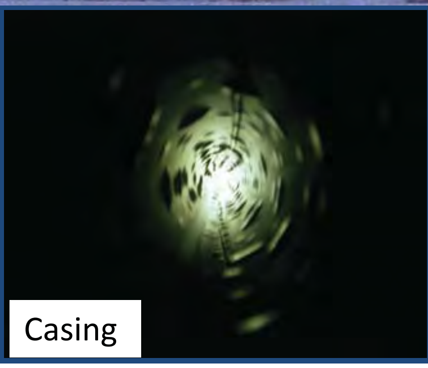
Corrosion at Riehen



2001: Pump defect



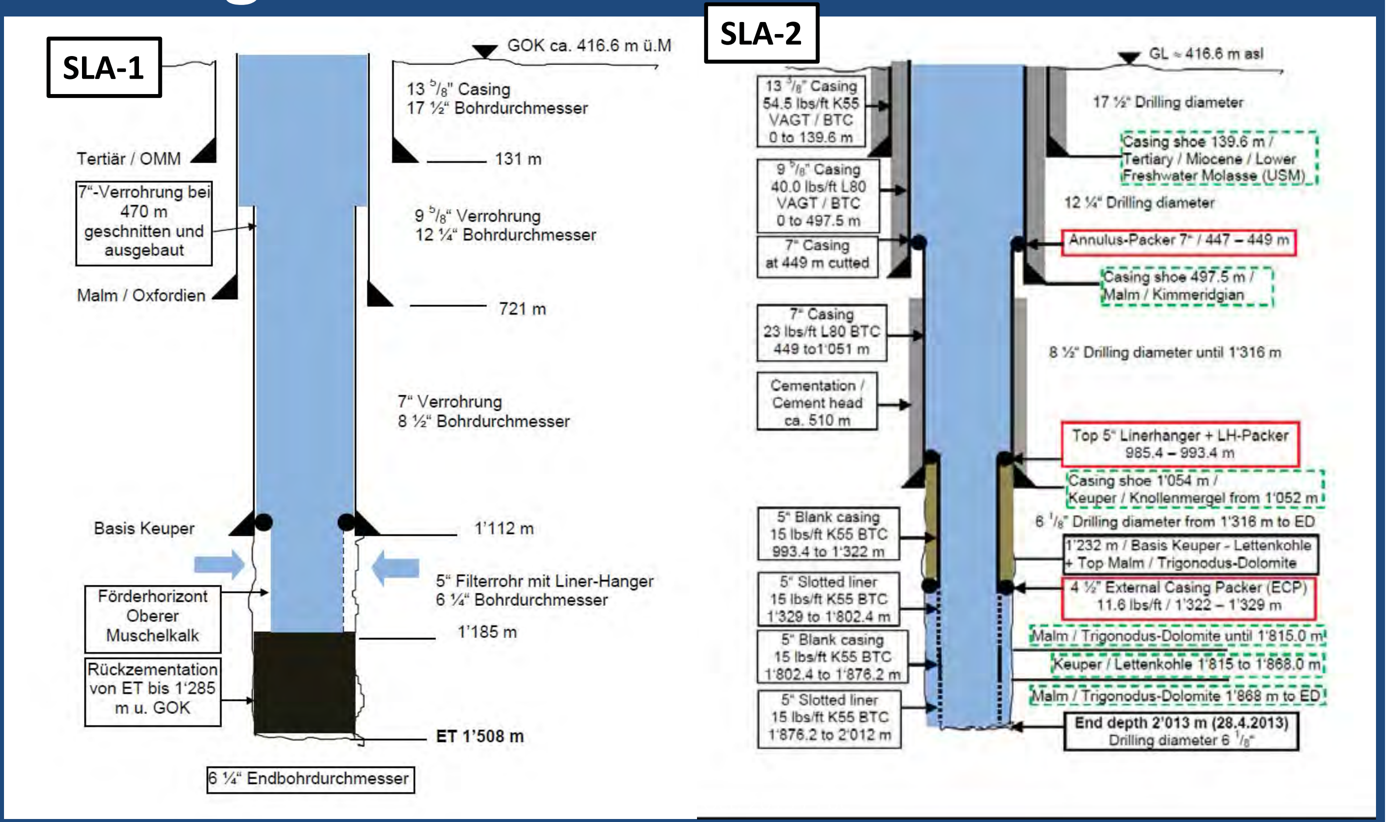
2001: Corroded / Broken top bearing



Casing

2008: Production tubing

Schlattingen (Ct. Thurgau) Casing schemes



H_2S smell – A problem to be solved

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Tagblatt Online, 5. August 2013, 01:36 Uhr

Schlattingen: Es stinkt zum Himmel

Artikel weiterempfehlen
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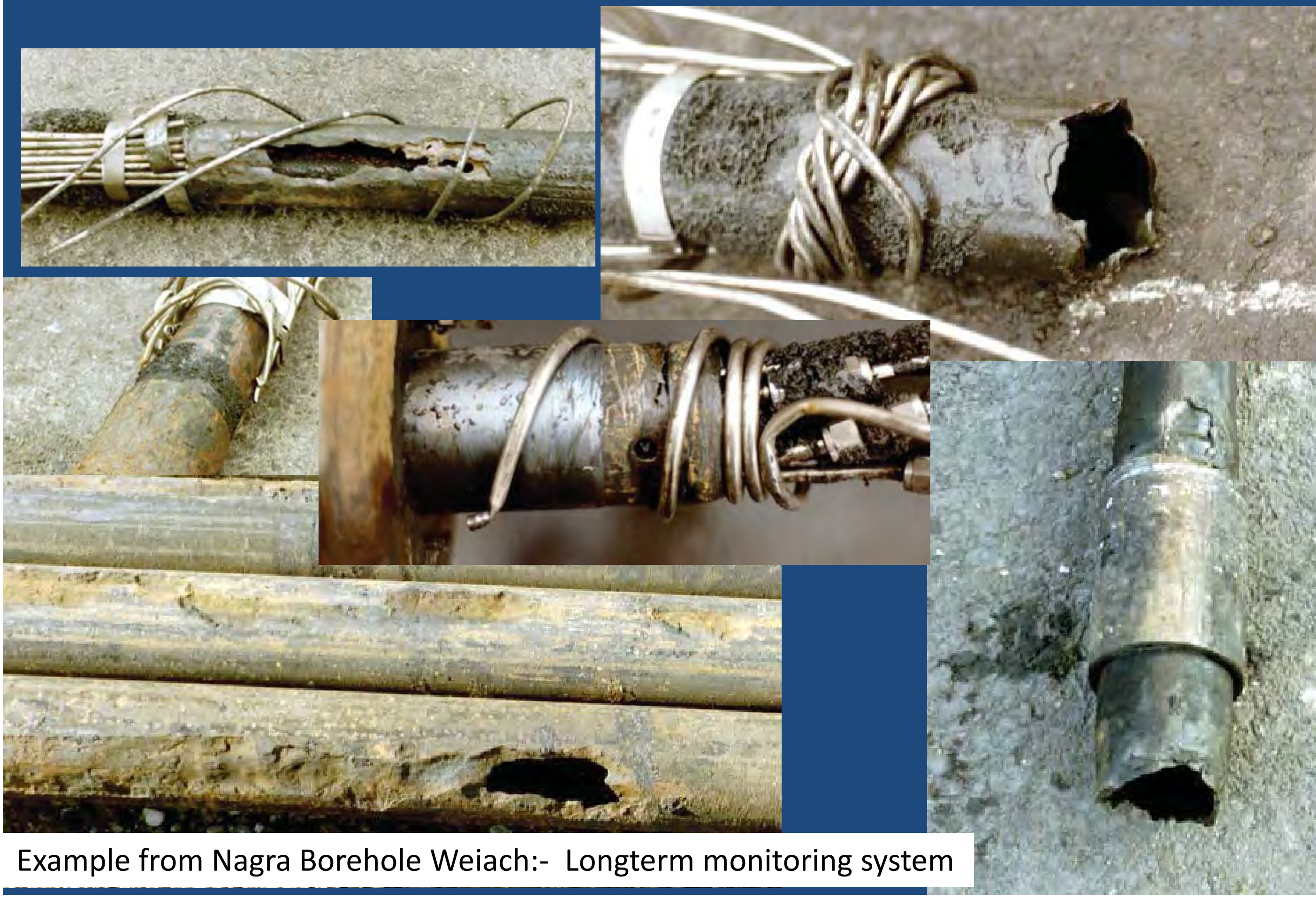
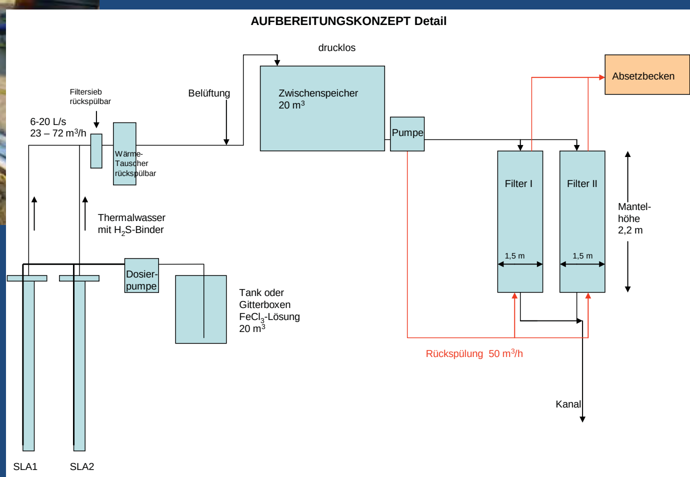
SCHLATTINGEN. Im Gebiet um die Geothermiebohrung in Schlattingen stinkt es zum Himmel, wie Anwohner berichten. Das kantonale Amt für Umwelt bestätigte entsprechende Recherchen von Tele Top. Laut Amtsleiter Marco Baumann sei bei Probebohrungen schwefelhaltiges Wasser an die Oberfläche befördert worden. Zuletzt trat der Gestank Anfang Woche auf. Das Amt für Umwelt hat auf Reklamationen reagiert und mit dem Betreiber nach Lösungen gesucht. In der ersten Phase der Probebohrungen sei der Schwefelgehalt im Wasser über dem zulässigen Grenzwert gelegen, sagte Baumann. (red.)

H_2S corrosion – A problem to be solved

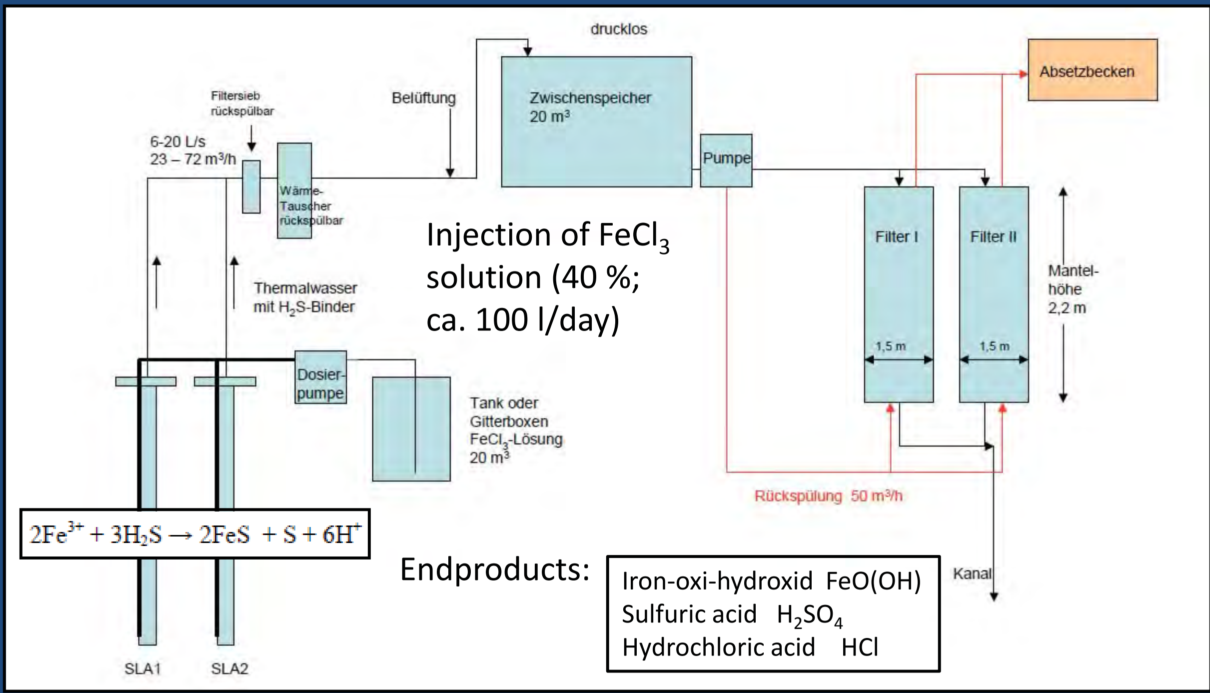


Example from Nagra Borehole Weiach:- Longterm monitoring system

H_2S – Neutralisation test



Conditioning concept
(H_2S concentration 10 -20 mg/l)



Injection of $FeCl_3$ solution (40 %; ca. 100 l/day)

$$2Fe^{3+} + 3H_2S \rightarrow 2FeS + S + 6H^+$$

Endproducts:

Iron-oxi-hydroxid $FeO(OH)$
Sulfuric acid H_2SO_4
Hydrochloric acid HCl

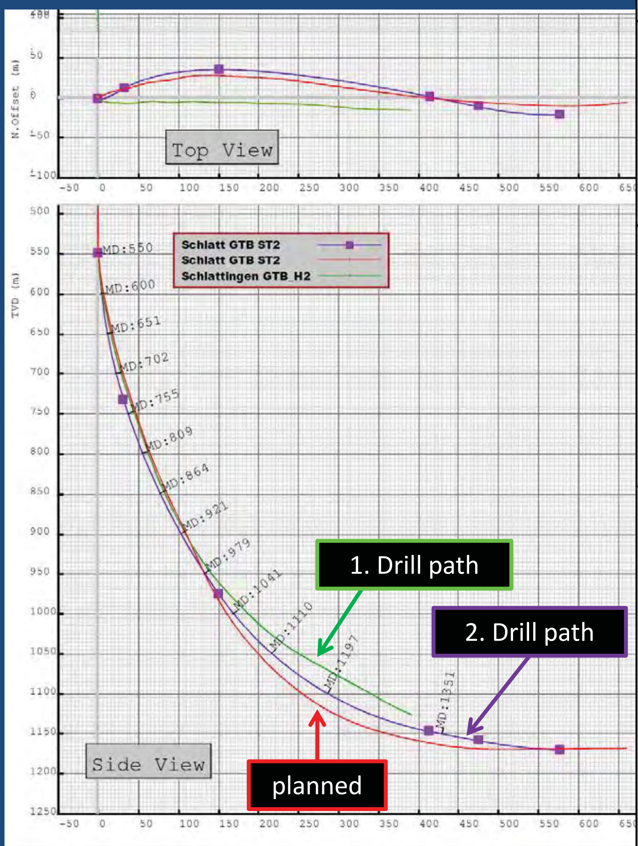
Chemical reactions with iron chlorid solution:

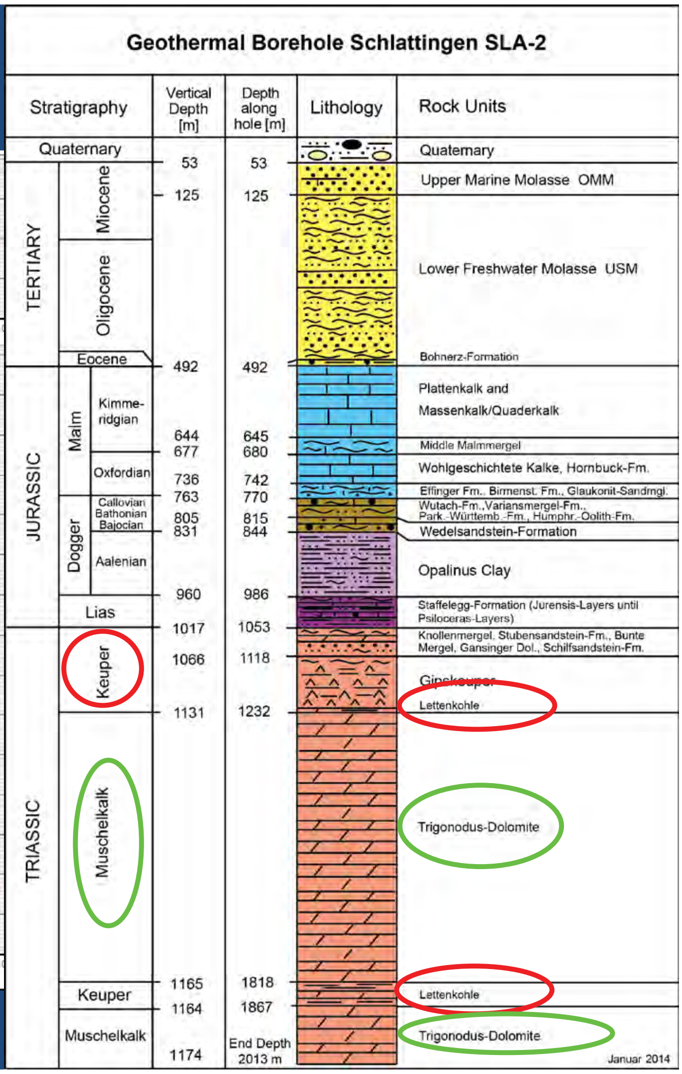
$$2FeCl_3 + H_2S \rightarrow 2FeCl_2 + S + 2HCl$$
$$2\,FeCl_2 + 2H_2S \rightarrow 2FeS + 4HCl$$
$$2FeCl_3 + 3H_2S \rightarrow 2FeS + S + 6HCl$$

De-ironed filter with O_2:

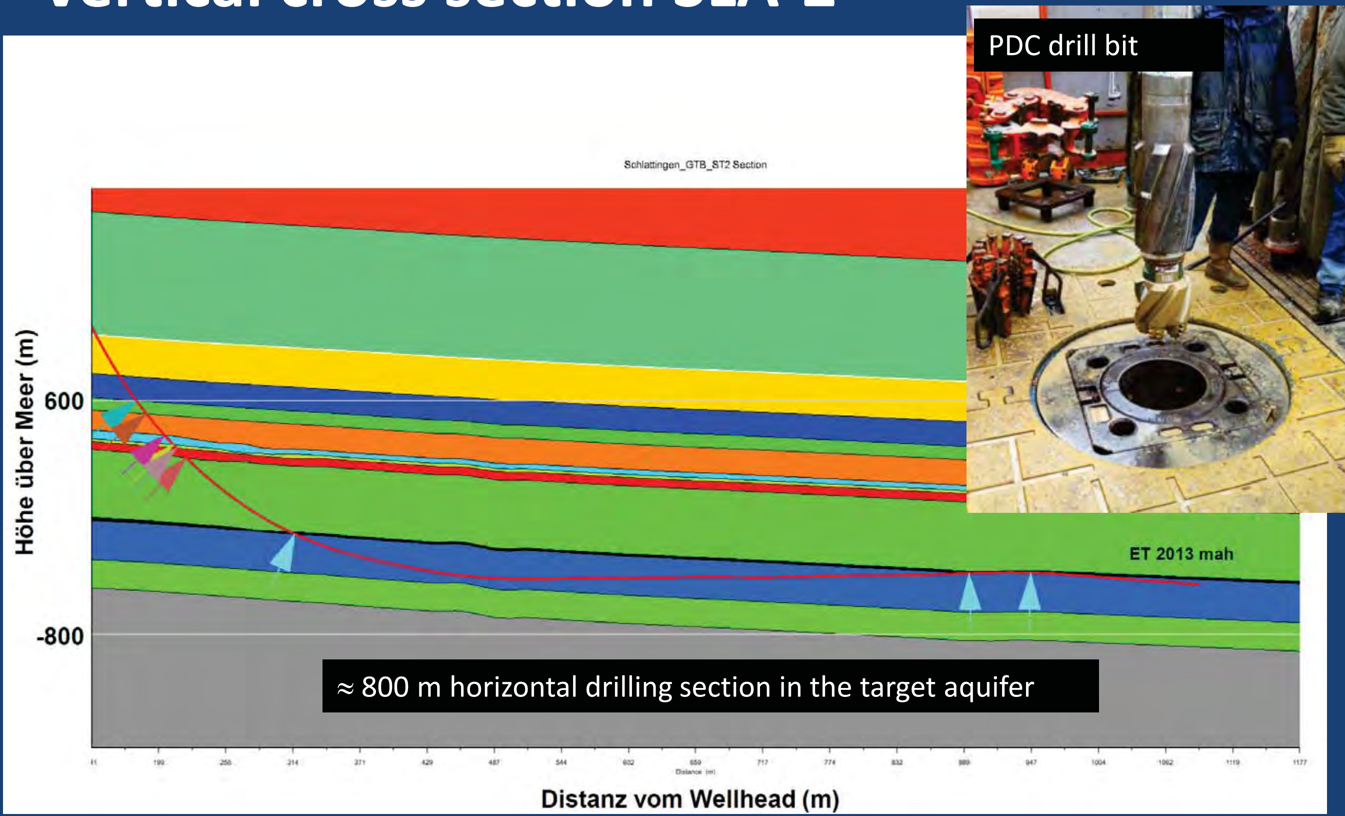
$$2FeS + 2O_2 + 2\,H_2O \rightarrow 2FeO(OH) + 2H_2SO_4$$
$$S + 1{,}5O_2 + H_2O \rightarrow 2H_2SO_4$$
$$2FeCl3 + 3H_2S + 3{,}5O_2 + 3H_2O \rightarrow 2FeO(OH) + 3H_2SO_4 + 6HCl$$

Drilling of SLA-2





Vertical cross section SLA-2



Summary matrix Switzerland

	solved		unsolved
	Issue	*Solution*	
Scaling	*N/A* … … … …	*N/A* … … … …	N/A … … … …
Corrosion	*Salinity / (H2S)* *H2S* … … …	*Inhibitor (Riehen)* *Neutralisation (Schlattingen)* … … …	Riehen … … … …
Gas content	*N/A* … … … …	*N/A* … … … …	N/A … … … …
Reinjection	*N/A* … … … …	*N/A* … … … …	*N/A* … … … …

Geothermal ERA-NET

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Operational Issues
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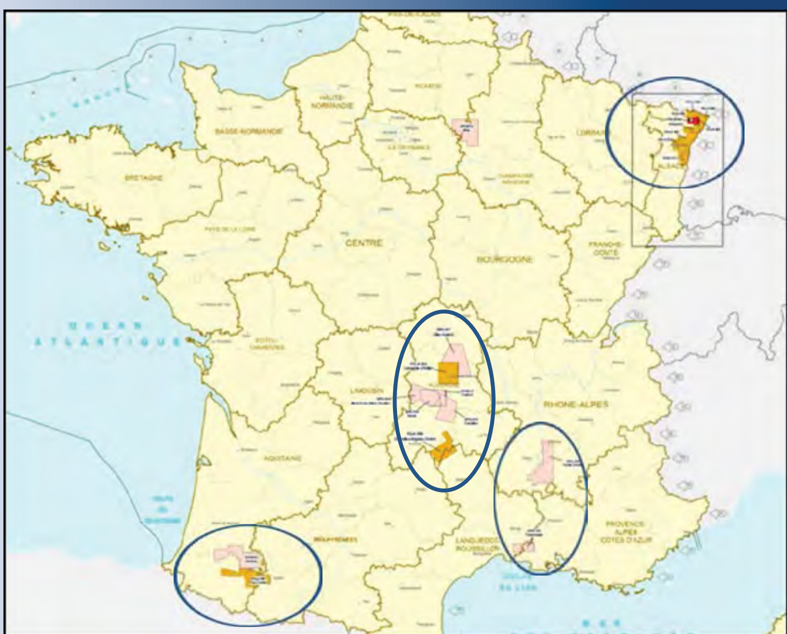
Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

France

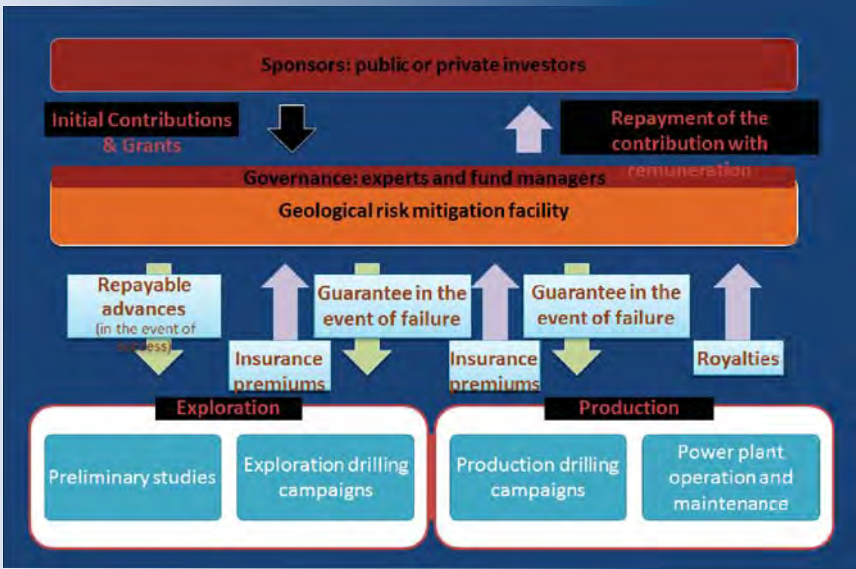
by Christian BOISSAVY
President ot the French Geothermal
Association for Professional

Geothermal Energy in France:
Electricity generation



- **Two operating plants in Soultz-sous-Forets and Guadeloupe island for 17 Mwe installed.**
- **More than 20 permits for high temperature production (up to 150°C). Four in the Caribbean islands and the rest in France onshore.**
- **Four main developers (Electricité de Strasbourg Géothermie, Fonroche, Electerre de France and Teranov).**
- **Expected installed power in 2030 is planned at 80 MW.**

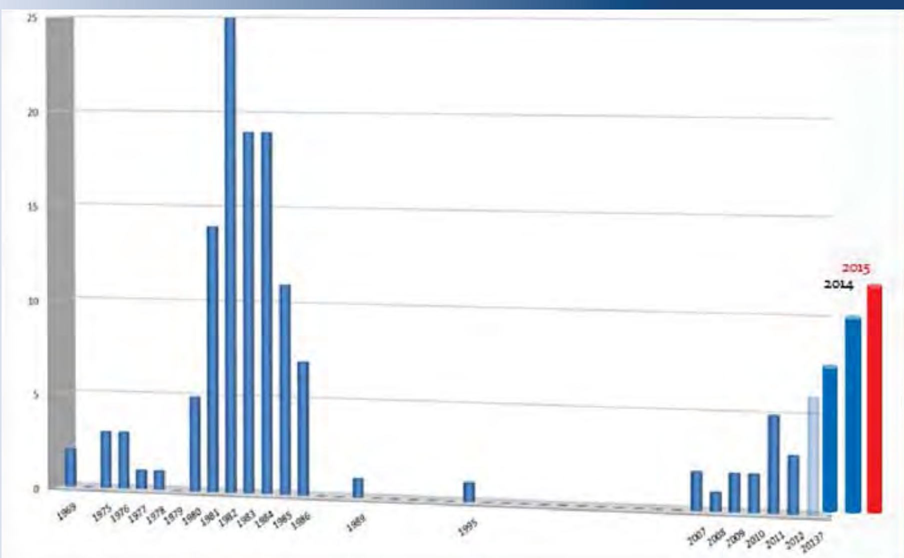
Geothermal Energy in France: Electricity generation



- A fund to cover geological risks at the initial phase or the projects. GEODEEP with 15 companies involved including: EDF, Clemessy, Engie, Cryostar, COFOR, CFG Services, Fonrocche, Electerre…
- 100 M€ with a private-Public participation 50/50 for both EGS plants in France and volcanic operations in french overseas and abroad.

GEODEEP
FRENCH GEOTHERMAL CLUSTER FOR HEAT AND POWER

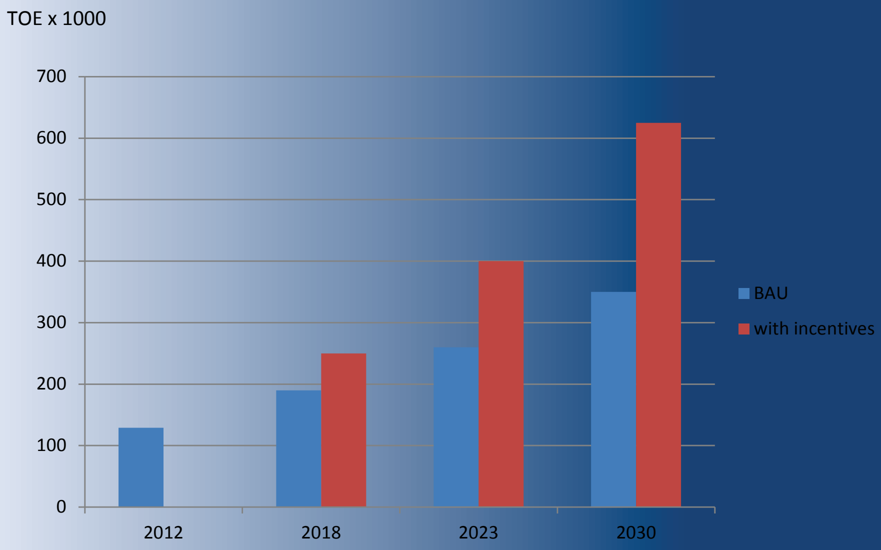
Geothermal Energy in France District heating networks



For the period 2007-2015

20 new geothermal doublet and 16 revamping of old wells drilled in the 80's

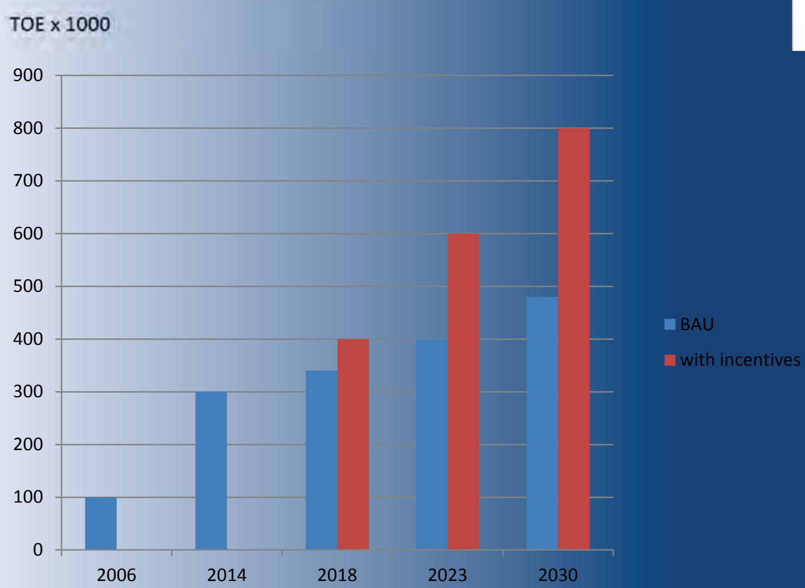
Geothermal Energy in France
District heating networks



Incentives are the continuation of the Heat fund managed by ADEME which provide a subsidy of 20 to 30% of the investment for doublet drilling and additional support to district heating network, especially for the adaptation of the DH to low temperature.

Geothermal Energy in France
Geothermal heat pumps

Sales evolution of heat pumps (2 to 50 kW)



Main incentives should be: take into account geothermal heat pumps in the RT 2012 (energy building regulation for new constructions). Consider cold production and geothermal free cooling.

Stop the tax credit of 30% applied for biomass, solar thermal and geothermal but also for gas boiler

Geothermal Energy in France
Milestones of Dogger exploitation

- **1960's-Pre-oil shock:** First attempt (abandoned and second attempt was successful
- **1973-1978-Post first oil shock:** Four completed doublets and enforcement of the legal framework
- **1979-1986-Post second oil shock:** 51 completed doublets with over 90% of success ratio, first well damage symptoms
- **Late 1980's-Early exploitation stages:** Corrosion/scaling damages and equipment failure (submersible pumps and others)
- **1990's-Technological and managerial maturation:** technical improvements, with R&D stimuli, debt renegotiation, abandonment of 20 non economic and severely damaged doublets
- **2007-2015- Restart of the geothermal business:** ADEME geothermal fund support, private investment, new doublets with upgraded production

Geothermal Energy in France
Scaling and corrosion

> Dogger "water" with a high concentration of salt (10 to 25 g/L) and sulphide

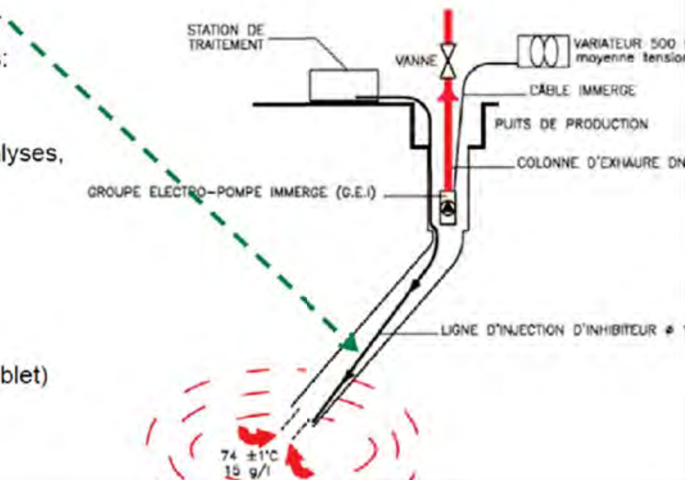
- Corrosion: risk of casing perforation
- Deposit: impact on flow rates and under deposit corrosion

> Preventive solutions

- **Deposit/corrosion inhibitor**
- Suitable operating conditions: maintain fluid pressure to avoid degassing
- Monitoring (geochemical analyses, logging...)

> Curative solutions

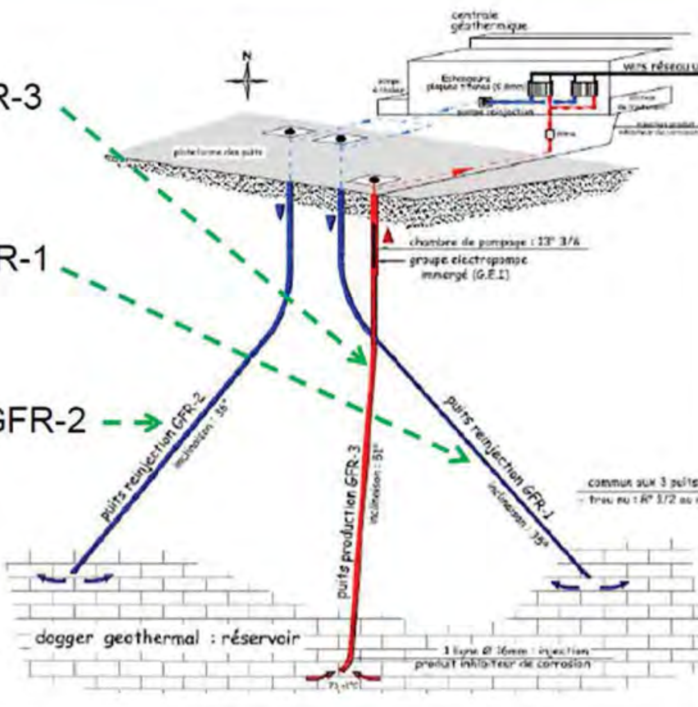
- Cleaning
- Casing relining
- New wells (triplet or new doublet)



Geothermal Energy in France
Scaling and corrosion

Fresnes triplet

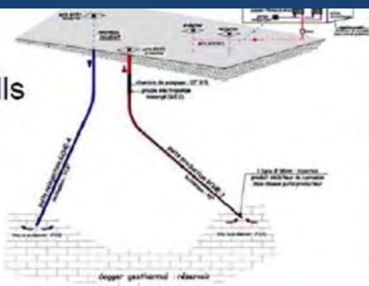
- New production well: GFR-3
  - Highly deviated (51°)
  - Flow rate: 300 m3/h
- Existing injection well GFR-1
  - New 7'' liner
  - Flow rate: 155m3/h
- Existing production well GFR-2
  - Converted in an injection well
  - New 7'' liner
  - Flow rate: 145m3/h
- 30 years without "thermal breaktrough"

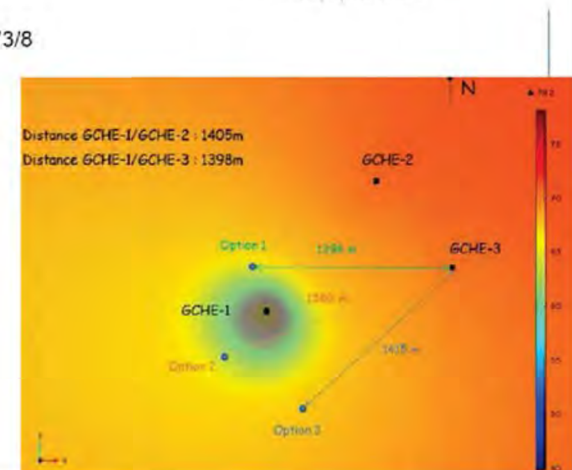


Geothermal Energy in France
Scaling and corrosion (large diameter wells)

Chelles new doublet

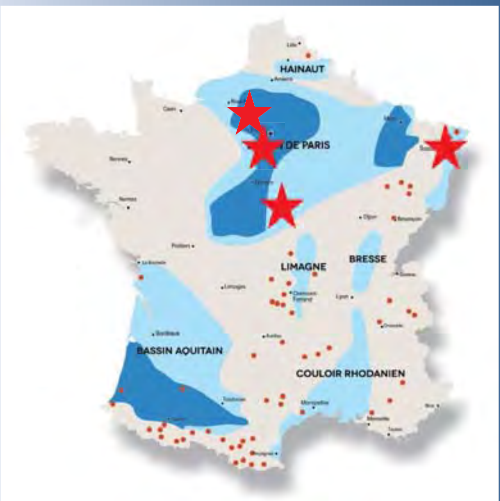
- Closure of existing GCHE-1 and GCHE-2 wells
  - "Cold bubble" underneath the existing platform: use of the existing well platform, with two deviated wells
- New generation design
  - Open hole: 8''1/2,
  - Tubing: 9''5/8,
  - Pumping chamber: depth of 250m, 13''3/8
  - Flow rate: 300 m3/h
- New production well GCHE-3
  - located at the East of the platform to optimize temperature
  - Highly deviated (42°)
- New injection well GCHE-4
  - Deviated (14°)
- 30 years without "thermal breaktrough"





Geothermal Energy in France

Reinjection in sandstone reservoirs

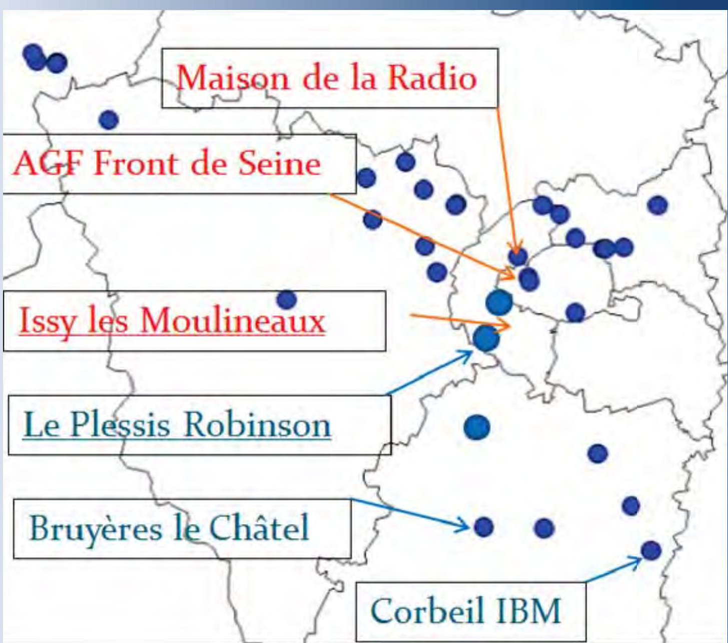


Various experiments carried out in the 80's: Melleray, Achères, Cergy Pontoise with Triassic sandstones as reservoir target. Production is fine but injection appears very difficult using normal pressures. No clear solutions at the moment except triplet array with one production well and one injection well or production well producing from Triassic formation and injection well in Dogger. Geothermal waters compatibility is the possible obstacle and depletion of Triassic a question mark.

In Ritershoffen drilled in 2014 no injection problems in the reservoir made of Bundsandstein sandstones and granite.

Operational issues in France

Reinjection in sandy reservoirs

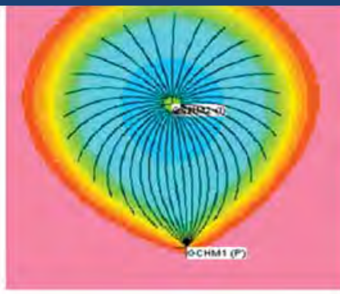


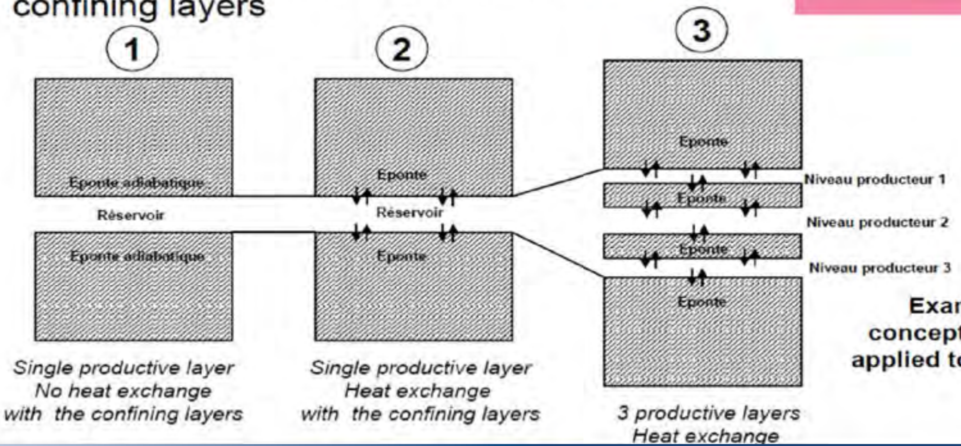
33 wells are present in the zone of which 22 are exploited for water production and 3 are geothermal. For Neocomian sands 3 wells are producing one for industrial water and the second for geothermal (single production well).

The reinjection problem has been solved using large diameter drilling in the reservoir, adapted pre-gravel packed stainless steel screens and over pumping compared to the expected exploitation flowrate.

Operational issues in France
Thermal breakthrough

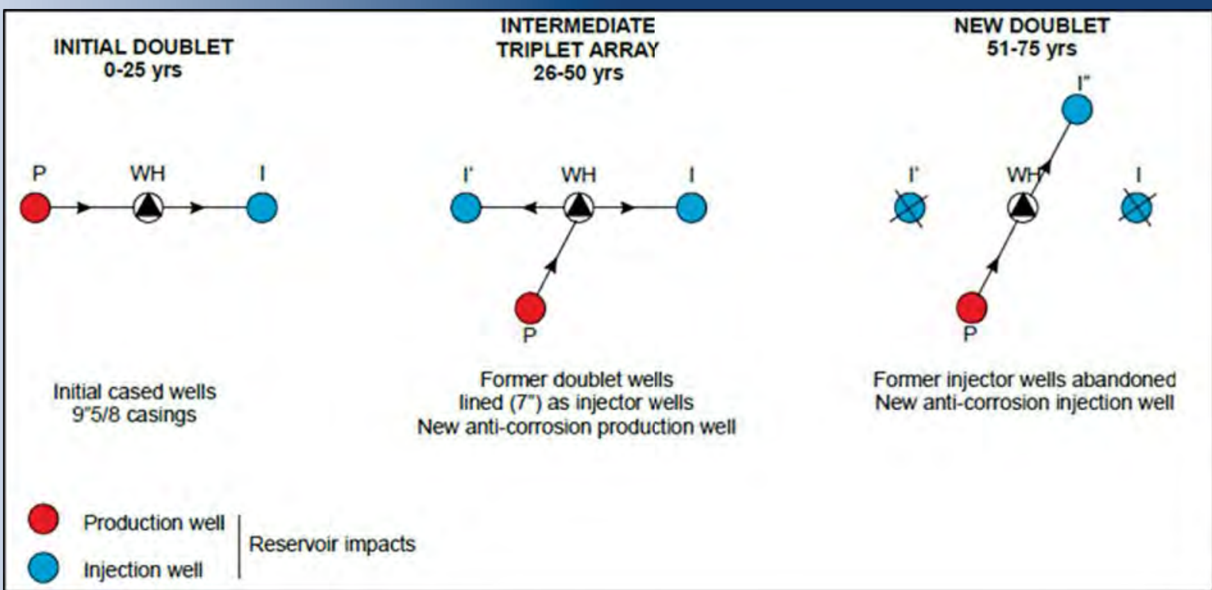
- Cold injected water, even if it is heated by the surrounding rock, will at the end cause a drop of temperature in the production well: but when?
- Modeling was initially pessimistic, because it was underestimating the thermal role of the confining layers



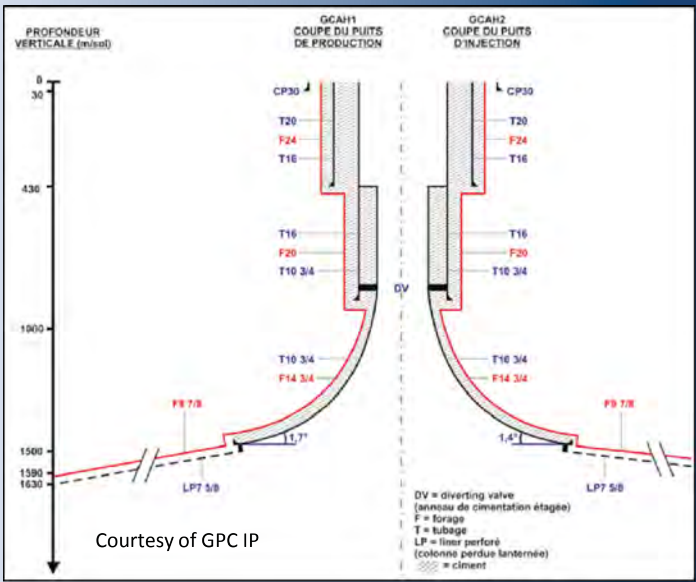


Examples of conceptual models applied to the doublet

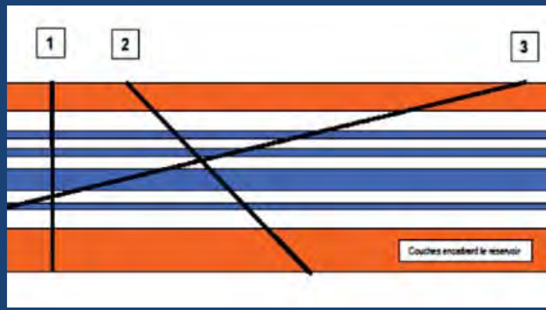
Operational issues in France
Well design for revamping



Operational issues in France
Well design for the future



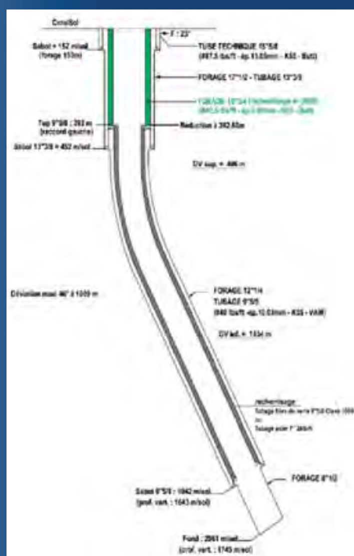
Courtesy of GPC IP

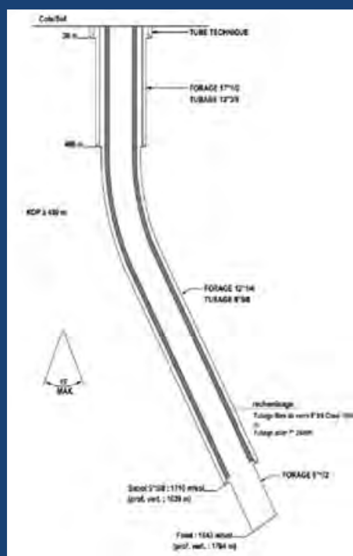


A new doublet will be drilled sub-horizontally in the reservoir allowing a significant increase in the production flow-rate or giving the possibility to exploit the reservoir even if the permeability is low. (expected flowrate at 450-500 m3/h)

Operational issues in France
Composite casing

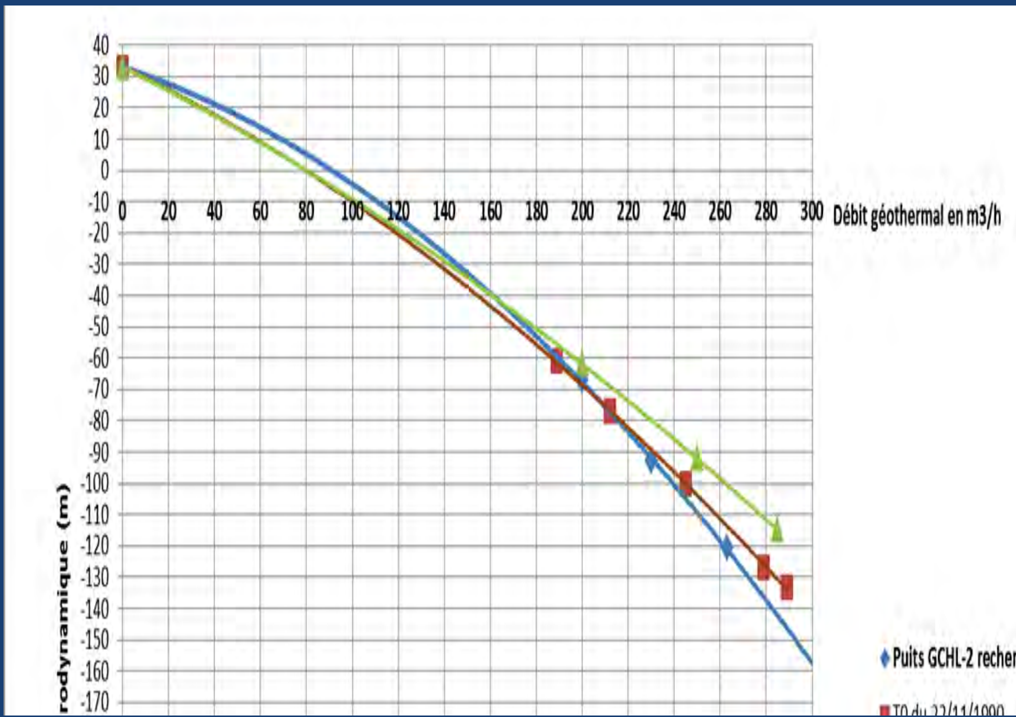
Courtesy of CFG Services



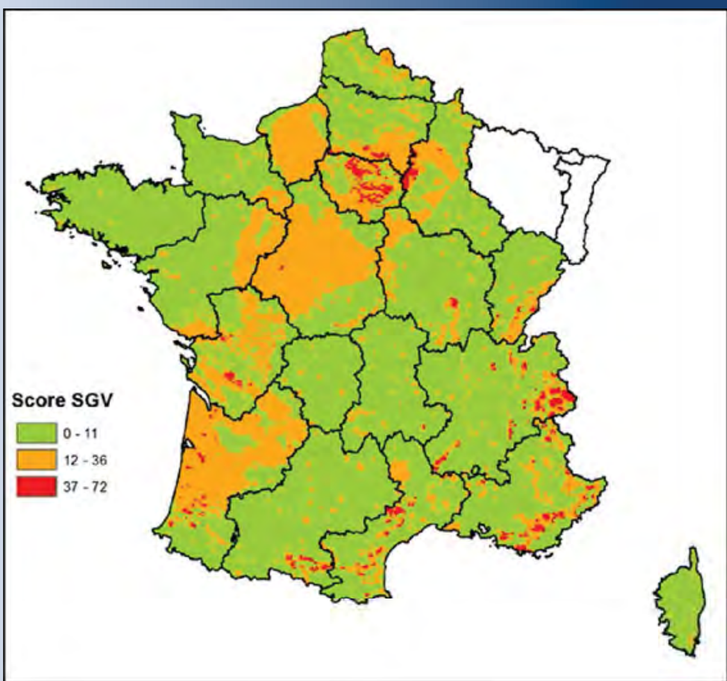


Last innovation (August 2015): casing in an old doublet (9’’5/8) using composite casing 6’’5/8 Class 1000

Operational issues in France
Composite casing in Chevilly (Final results)



Operational issues in France
Shallow geothermal law (july 2015)



Some problems arising like in Bad Wurttemberg (gypsum, salt formations, karst…) obliged the French authorities to adopt a new geothermal law for shallow resources. This text will allow to develop small plants with drilling down to 200 m depth (before 100 m) and power produced from the underground resource at m maximum of 500 kWth (before 230 kW). As counter part the drillers has to get a certificate (Qualiforage)

Green zones: simple declaration
Orange zone: need of an expert to approve the realization
Red zone: administrative authorization is needed

Conclusions

	solved		unsolved
	Issue	*Solution*	
Scaling and corrosion	***Internal corrosion and scaling***	*-Remediation by jetting during workover* *-Installation of downhole chemical treatment* *-Continuous control of the geothermal loop with corrosion coupons* *-Re-lining old wells with composite casing*	
	External corrosion	*-Casing in composite for new wells* *-New acquisition logging tool to follow the phenomena*	A new promising tool already tested to be fully validated

Conclusions

	solved		unsolved
	Issue	*Solution*	
Reinjection	*Reinjection in sandstones*	*1 production well and 2 injection wells*	Reinjection at the same flowrate in sanstones formations
	Reinjection in poorly cemented sands	*Adapted diameter, pre-gravel packed screens and over pumping*	

Other issues:

- **Spacing in between production and injection wells to be secured in order to avoid cold bubble problems**
- **Drilling in large diameter to allow re-lining with a reasinable diameter after 30 years of exploitation**
- **For shallow geothermal using heat pump, preliminary detailed hydrogeological approach and professional expertise**

OpERA

Operational Issues
of Geothermal Energy Installations in Europe

Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

Country Overview
Denmark

by
Søren Berg Lorenzen

Danish Geothermal
DISTRICT HEATING

Overview

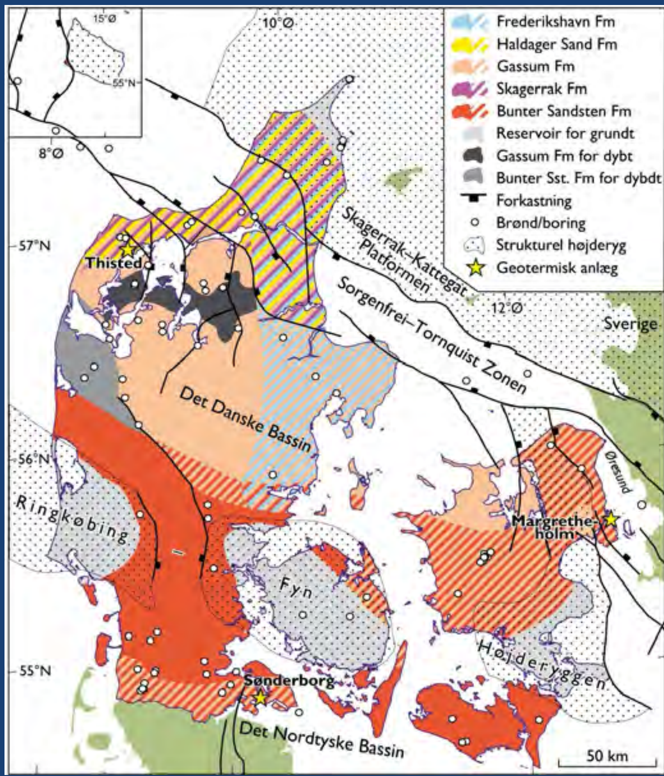
1. **Geothermal Energy in Denmark**

2. **Operational Issues in Denmark**
   A. Scaling Issues with Examples
   B. Corrosion Issues with Examples
   C. Issues with Gas Content with Examples
   D. Reinjection Issues with Examples
   E. (Other issues with Examples)

3. **Summary: Solved/unsolved Operational Issues in Denmark**

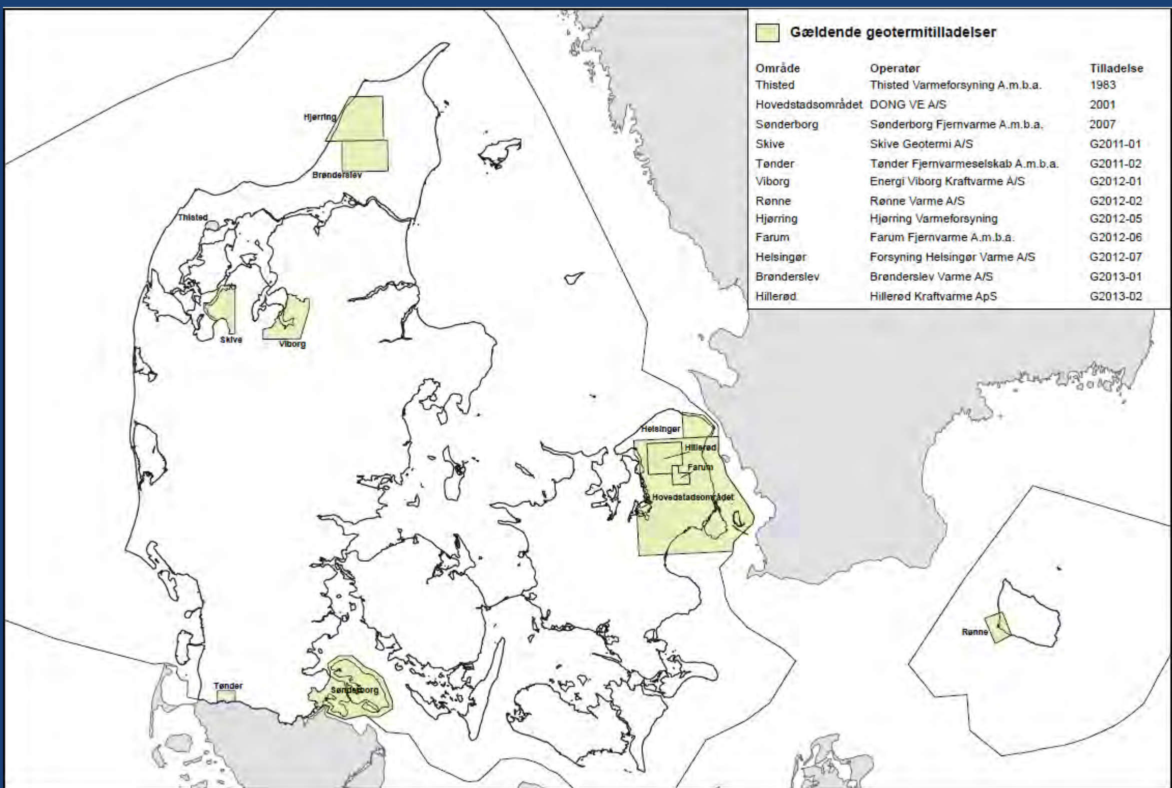
Danish Geothermal
DISTRICT HEATING

Geothermal Energy in Denmark



Danish Geothermal
DISTRICT HEATING

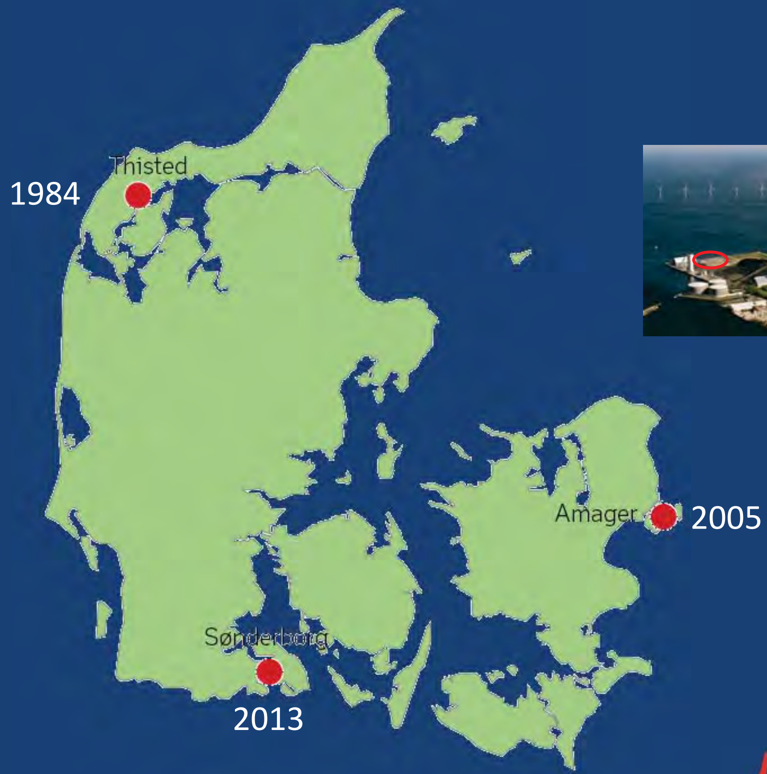
Geothermal Energy in Denmark



Område	Operatør	Tilladelse
Thisted	Thisted Varmeforsyning A.m.b.a.	1983
Hovedstadsområdet	DONG VE A/S	2001
Sønderborg	Sønderborg Fjernvarme A.m.b.a.	2007
Skive	Skive Geotermi A/S	G2011-01
Tønder	Tønder Fjernvarmeselskab A.m.b.a.	G2011-02
Viborg	Energi Viborg Kraftvarme A/S	G2012-01
Rønne	Rønne Varme A/S	G2012-02
Hjørring	Hjørring Varmeforsyning	G2012-05
Farum	Farum Fjernvarme A.m.b.a.	G2012-06
Helsingør	Forsyning Helsingør Varme A/S	G2012-07
Brønderslev	Brønderslev Varme A/S	G2013-01
Hillerød	Hillerød Kraftvarme ApS	G2013-02

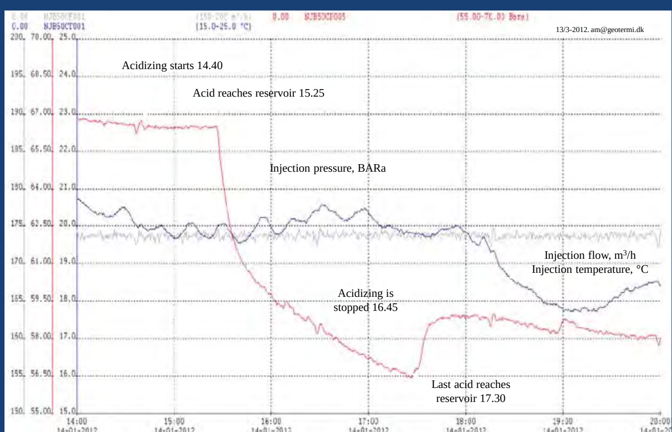
Danish Geothermal
DISTRICT HEATING

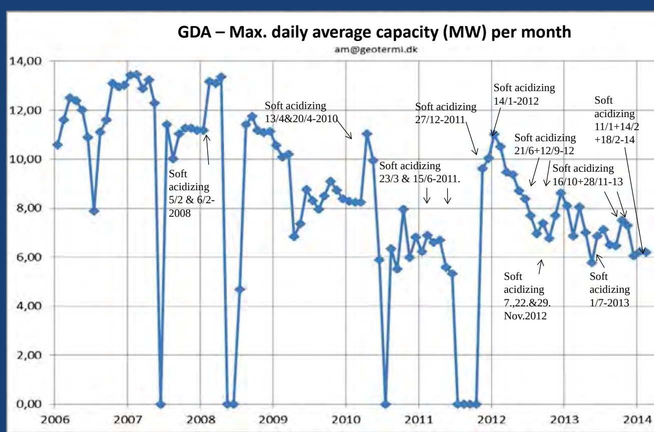
Geothermal Energy in Denmark



Scaling

Calcite (CaCO3) precipitation is believed to be an issue in Copenhagen





The calcite particles can be dissolved by cooling the water (to below 20 °C) – or, if need be, through soft acidizing (which also seems to be able to remove corrosion products, at least to some extent)

Corrosion

Corrosion rates for iron casing and piping of 0.05-0.2 mm per year have been measured.

With a high salinity (15-20 weight-%), keeping air out is very important.

This is done by detecting and fixing leaks – and by protecting the surface installations and wells with nitrogen (N_2) gas.

Danish Geothermal
DISTRICT HEATING

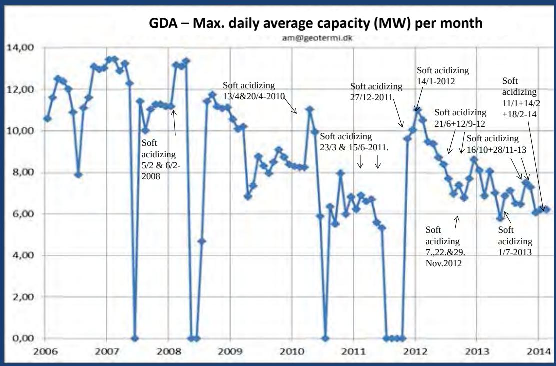
Gas content

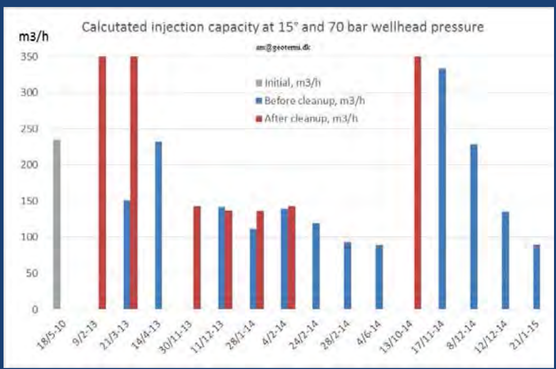
Degassing of methane (CH_4) is a known problem in Thisted, where two vertical wells are connected by a 1 km pipeline with relatively low pressure – has been solved through an increased surface pressure and extra safety precautions when servicing the surface pipeline.

Degassing of CO_2 is a known problem in Copenhagen, leading to a change in water chemistry and a possible precipitation of calcite ($CaCO_3$). Initially, the calculated/estimated bubble point was too low – has therefore been increased.

Danish Geothermal
DISTRICT HEATING

Reinjection problems





Danish Geothermal
DISTRICT HEATING

Matrix

	solved		unsolved
	Issue	*Solution*	
Scaling	*Calcite*	*Soft acidizing*	Lead precipitation Unidentified precipitations?
Corrosion	*Base corrosion*	*Keep air out*	
Gas content	*Methane* CO_2	*Keep pressure above bubble point*	
Reinjection	*Calcite and corrosion products*	*Soft acidizing*	Particles clog up screens with base pipe

Other issues: Integration with heat pumps gives a more efficient but also more complex system

Danish Geothermal
DISTRICT HEATING

Geothermal ERA-NET

OpERA

Operational Issues
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Expert Workshop
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Country Overview
Austria
by G. Goetzl

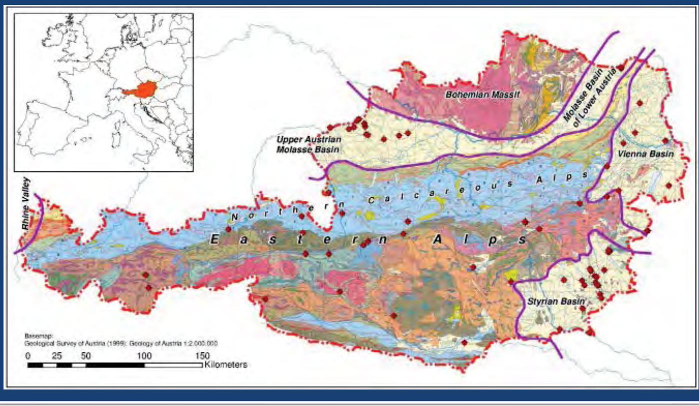
Overview

1. **Geothermal Energy Austria**

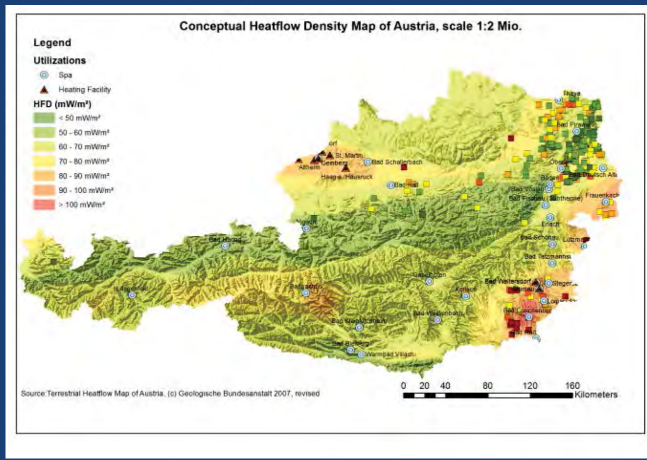
2. **Operational Issues in *Austria***
   - A. Scaling Issues with Examples
   - B. Corrosion Issues with Examples
   - C. Issues with Gas Content with Examples
   - D. Reinjection Issues with Examples
   - E. Radioactive emission

3. **Summary: Solved/unsolved Operational Issues Austria**

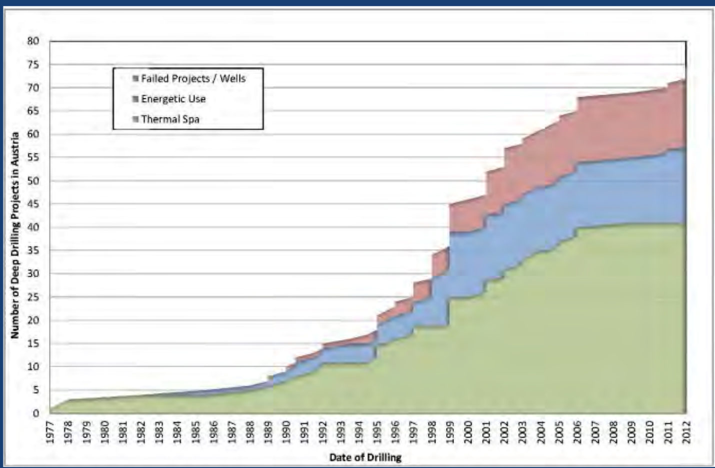
Geothermal use in Austria



Geothermal provinces in Austria (taken from Goldbrunner & Goetzl, 2013)



Heat Flow in Austria (Goetzl, 2007)



Develpment of geothermal use in Austria (taken from Goldbrunner & Goetzl, 2013)

Geothermal use in Austria

Table D: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis s.	Is the heat from geo-thermal CHP?	Is cooling provided from geo-thermal?	Installed geotherm. capacity (MW_{th})	Total installed capacity (MW_{th})	2012 geo-thermal heat prod. (GWh_{th}/y)	Geother. share in total prod. (%)
Altheim	Doublet Altheim	2000	yes	No	12	18	28.6	100
Geinberg	Doublet Geinberg	2000	No	No	5.1	7.1	24	100
Simbach a. Inn / Braunau a. Inn	Doublet Simbach-Braunau	2003	No	No	9.3	40.7	46.1	77
Obernberg	Doublet Obernberg	2000	No	No	5.3	5.3	11.8	100
St. Martin im Innkreis	Doublet St. Martin	2002	No	No	5	29	18.9	60
Haag am Hausruck	Doublet Haag	1996	No	No	5	5	6	100
Bad Blumau	Bad Blumau	2001	Yes	No	7.5	7.5	18	100
Bad Waltersdorf	Bad Walters-dorf	1979	No	No	2.3	5	5.5	70
Total					**51,5**	**117.6**	**158.9**	

Direkt use for district heating (taken from Goldbrunner & Goetzl, 2013)

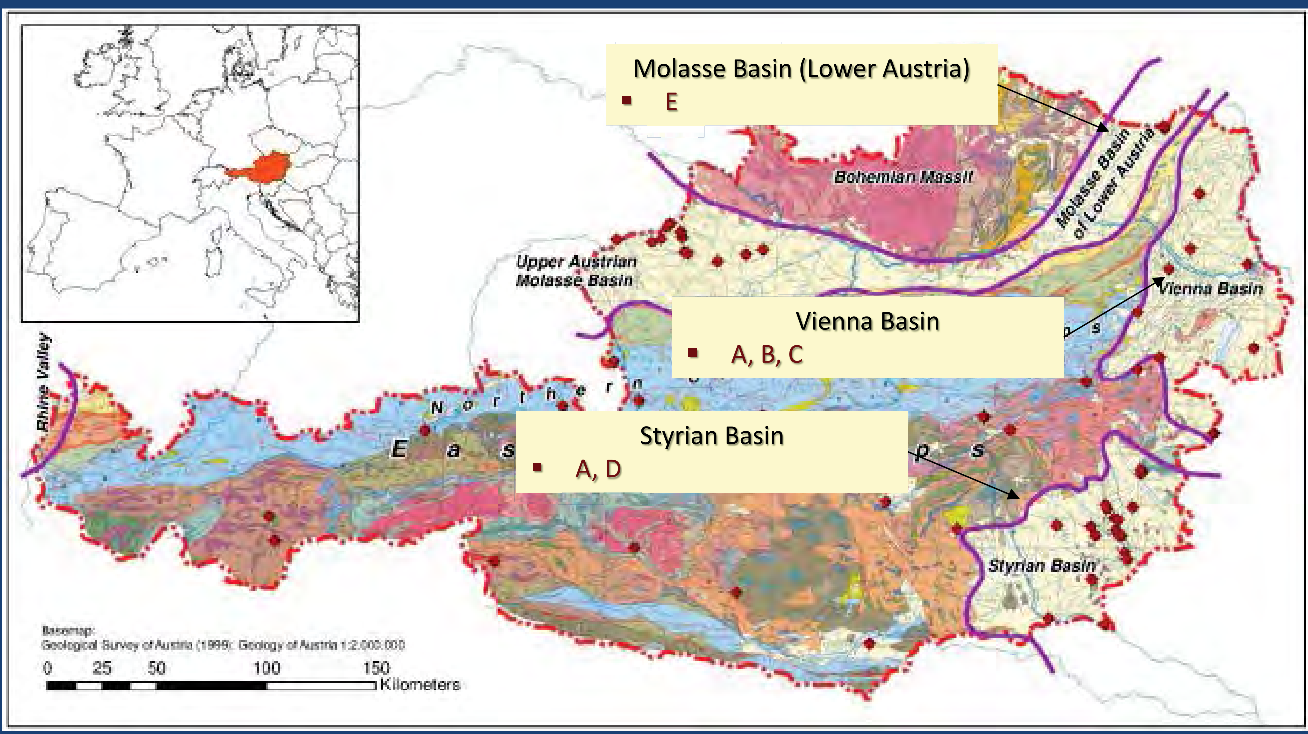
Geothermal use in Austria

Summary

- ➢ Currently there are 2 provinces with geothermal use for heat and power production: Molasse Basin Upper Austria & Stryria Basin
- ➢ Only 1 / 8 hydrogeothermal use for DH faces hydrochemical challenges (Bad Blumau, Styrian Basin)
- ➢ Predominately used aquifer in Austria (Malm Kalk, Molasse Basin) shows low content of mineralization and absence of problematic gases

Operational Issues in Austria

Introduction



Operational Issues in Austria

Case studies

Issue	Problem	Styrian Basin	Vienna Basin	Molase Basin (Lower Austria)
A- Scalling	Co2 + carbonates Fe^{++} + oxygene	Bad Blumau	Vienna Aspern* Vienna Aspern*	--
B- Corrosion	NaCl	--	Vienna Aspern*	--
C- Gas content	H2S	--	Aderklaa** Baden	--
D- Reinjection	Miocene reservoirs	Fuerstenfeld	--	--
E- Other issues	Radioactive emissons	--	--	Laa a.d. Thaya

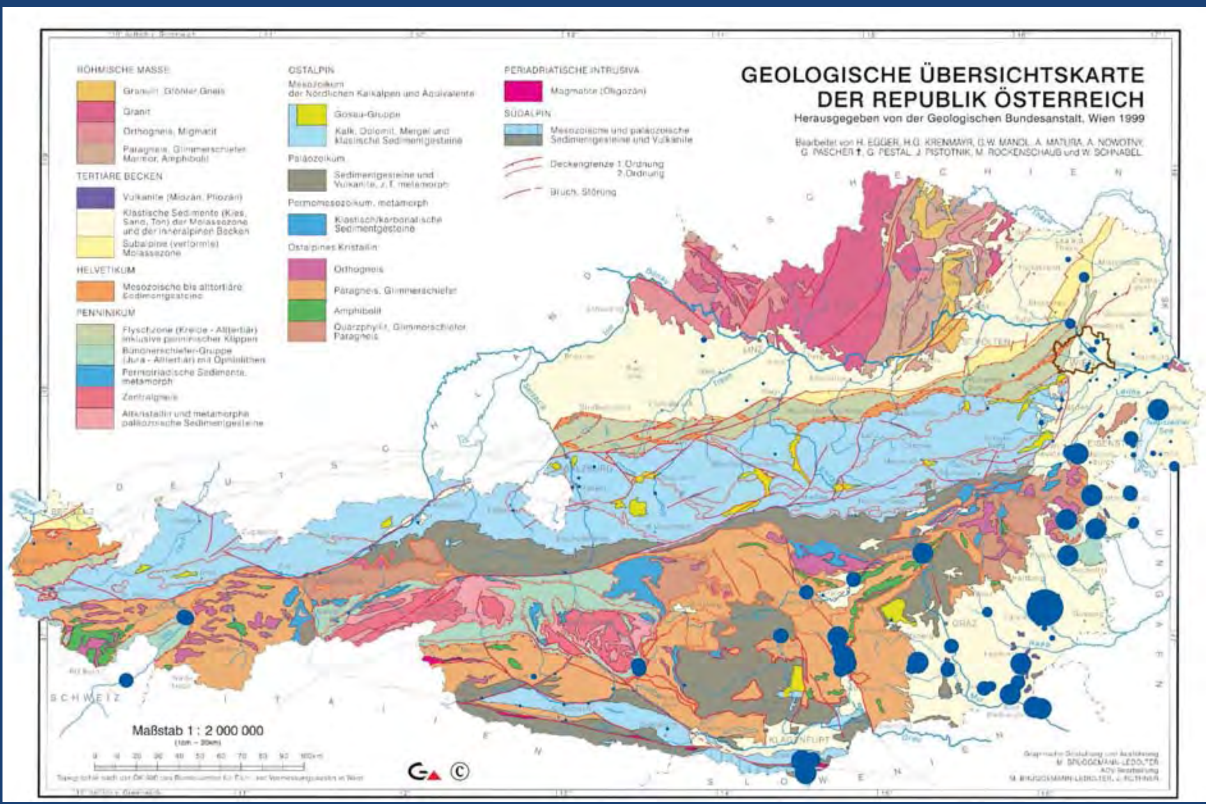
* Not realized, only desktop feasibility study (Straka, 2006)
** Hydocarbon exploitation

Current activities

NoScale (Project manager Edith Haslinger Edith.Haslinger@ait.ac.at)

Operational Issues in Austria

Co2 hot-spots in Austria

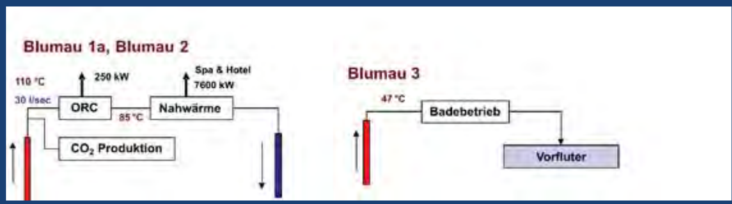


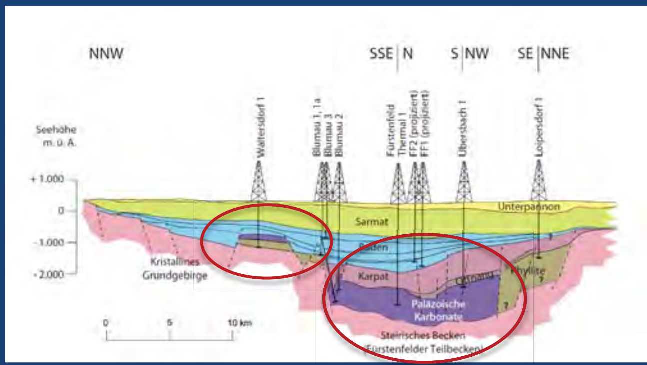
Operational Issues in Austria

Case Study Blumau

The spring „Vulkania“

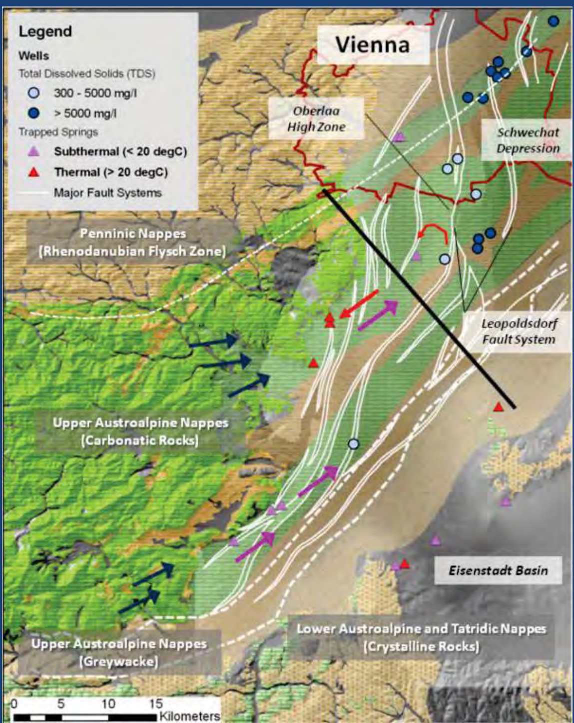
- Formation T > 120°C
- Outflow T ~ 110°C
- Reservoir Depth ~ 2800m
- Free yield 80l/s (gaslift)
- Production yield 30l/s
- TDS: 17,6 g/l
- Gas : water 9:1(97%CO_2)
- Dissolved CO_2 ~ 5mg/kg
- ➔ **CO2 liquified 1.5 t/h**!!
- Closed to semi-open aquifer

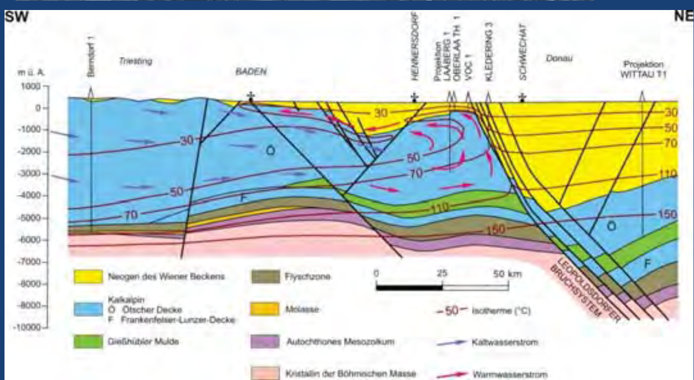




Operational Issues in Austria

Case Study Vienna „Aspern“ (2006)





Operational Issues in Austria

Case Study Vienna „Aspern“ (2006)

Main ions (mg/l)	
Cl^-	92.970
Na^+	51.300
HCO_3^-	153
Ca^{2+}	6.135
Mg^{2+}	875
SO_4^{2+}	522
FE^{2+}	16

Gas	
Total gas content	35 mol/m³ 0.781Nm³/m³
CH4	88%
CO2	6.2%

Problems

- Scaling of carbonates
- Scaling of iron oxides
- Corrosion

Operational Issues in Austria

Case Study Vienna „Aspern“ (2006)

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Gas	
Total gas content	35 mol/m³ 0.781Nm³/m³
CH4	88%
CO2	6.2%

Problems

- Scaling of carbonates
- Scaling of iron oxides
- Corrosion

Solution

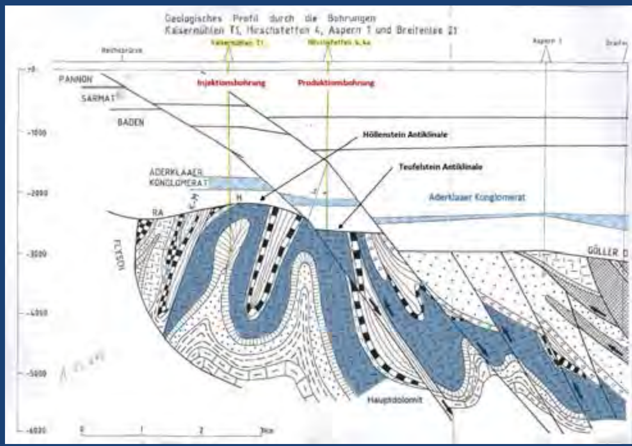
- ✓ Provide mimum pressure (40 bar)
- ✓ Prevent contact to oxygene (nitrogene sealing)
- ✓ Coated tubing
- ✓ Titan HX
- ✓ Gas separator

Caloric value: 36MJ/m³!

Operational Issues in Austria

H_2S

- Aderklaa gas reservoir near Vienna
  - Mimum distance of wells to settlement: 500m
  - Warning system and special training for relief forces

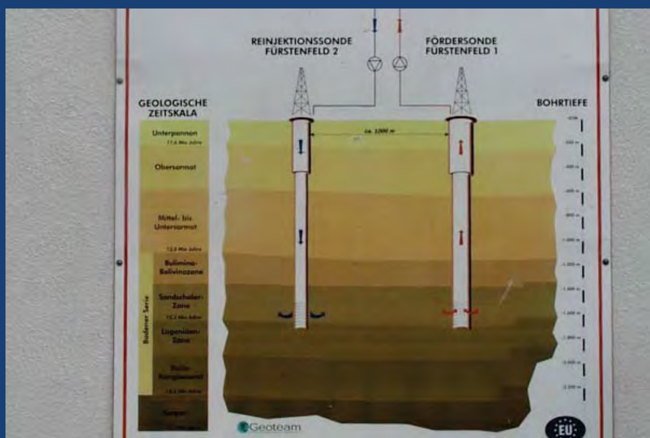


- Spas Oberlaa (Therme Wien) & Baden (near Vienna)
  - No traetment, low content

Operational Issues in Austria

Injectivity

- Fuerstenfeld (Styrian Basin)
  - Reservoir: Miocene sandstones
  - Good productivity
  - Poor reinjectivity: increase of hydraulic resistance after period of few weeks of injection!
  - Problem could not be solved, project abandoned!



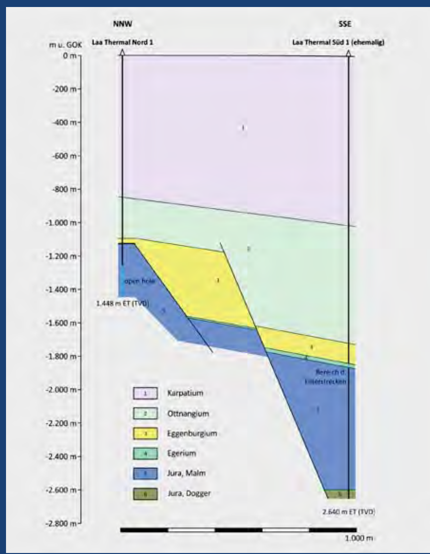
- Vienna Basin (hydrocarbons)
  - Miocene Sandstones and sands show good productivity (K≤ 2.000 mD available)
  - Injection into sandston reservoirs avoided!
  - Injection in Miocene conglomerates and Mesozoic carbonates

Operational Issues in Austria

Other issues - radioactvity

- Spa Laa a.d. Thaya

- Yield 05 l/s
- Reservoir: Marl limestone
- TDS: ~ 45.000 mg/l
- Radium: 3.33 bq/l



Taken from Elster (2014)

Matrix[4]

	solved		unsolved
	Issue	*Solution*	
Scaling	*Bad Blumau: high CO2 content*	*Separation of CO2 and selling to the nutrition industry*	High content of carbonates and dissolved iron at thermal water in the Vienna Basin (not used yet)
	Bad Radkersburg: high CO2 content	*Acidification of tubing and alternating use of wells*	
	High CO2 content at Various spas in Austria	*Use CO2 for therapy*	
Corrosion	*Issue 1*	*Solution 1*	High salinity of thermal water in the Vienna Basin (not used yet)
Gas content	*Baden: Vienna Oberlaa: low content of H2S in thermal water*		*Water used for balenology only, no protective measures necessary*
Reinjection	*Schoenkirchen, Matzen: Waste waters from hydrocarbon industry*	*Injection into Mesozoic carbonates and Tertiary conglomerates (> 20 ys.)*	Fuerstenfeld: Reinjection of thermal water into Tertiary sandy aquifers

Other issues: High content of H2S in potential thermal reservoirs near and inside Vienna ➔ future challenge

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OpERA

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Austria
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› OpERA „Operational Issues across Europe“

Summary and Follow-up

WP4: Development of Joint activities

Dr. Stephan Schreiber

Project Management Jülich

Geothermal Energy and Cross-cutting Programs

Overview

- The Concept
  - Step 1a: The MAGNA CARTA
  - Step 1b: Expert Publication (Follow-up)
  - Step 2: Future Joint Activities & possible level (JA2?/JA3?)
- Summary and Results of Day 1

The Concept of OpEra

› Summary of operational issues in the participating countries

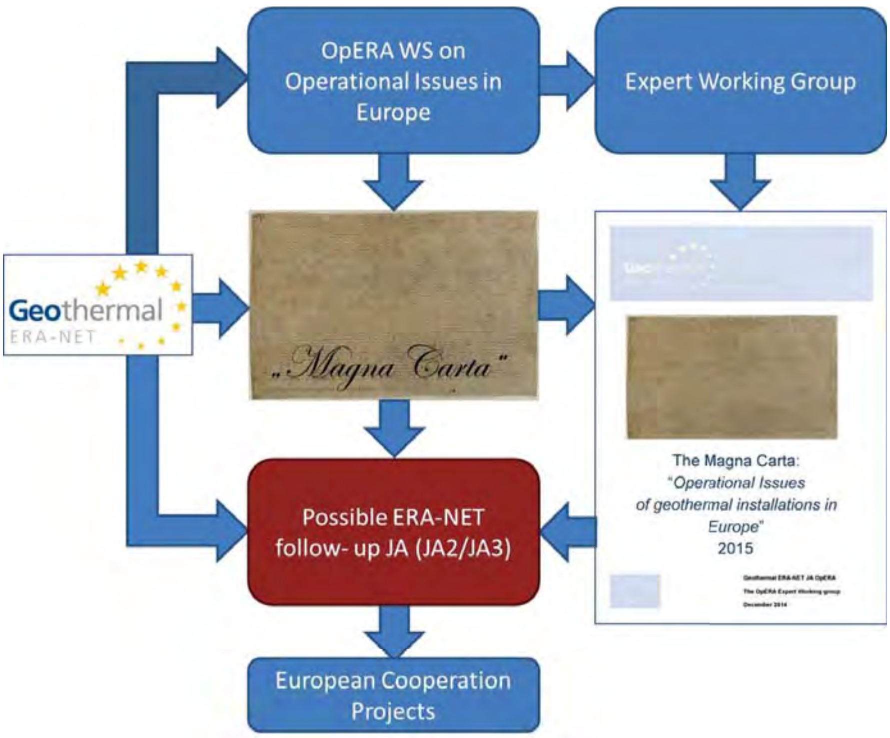
› Trans-national knowledge and information Exchange

› First approach for trans-national cooperation on specific topic

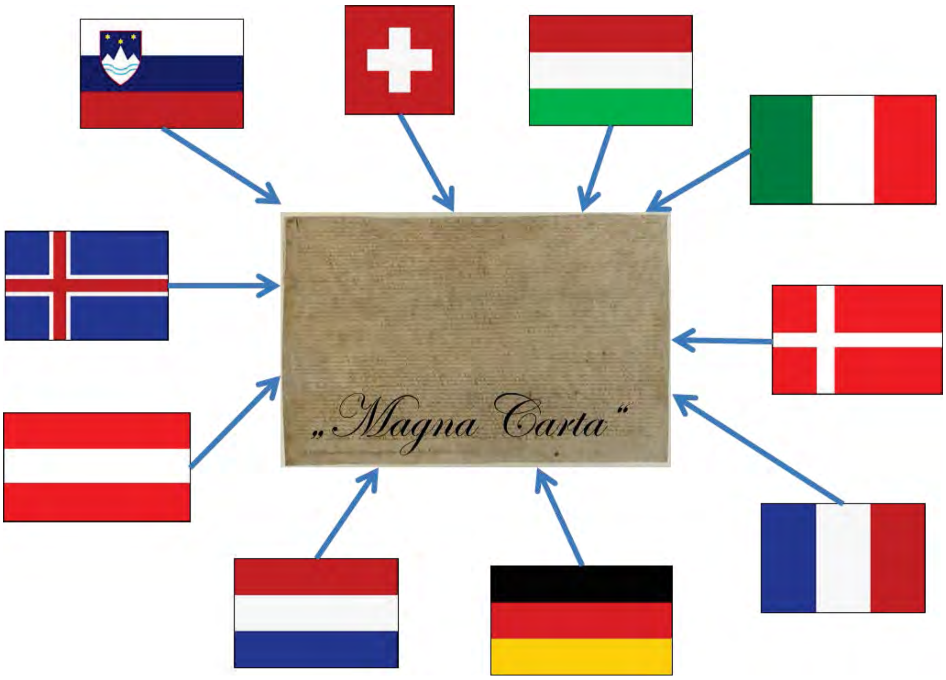
› Building the base for further cooperation, if the benefit of this approach is proven

Projektträger Jülich Forschungszentrum Jülich
Geothermal ERA-NET
Federal Ministry for Economic Affairs and Energy

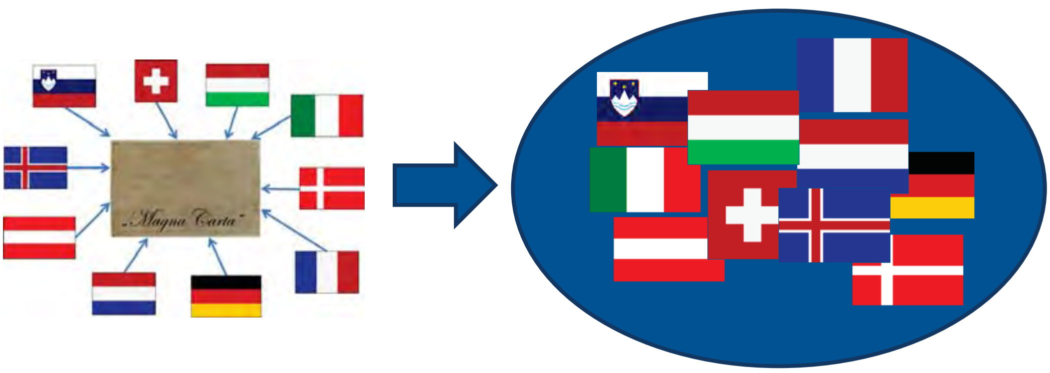
The Concept of OpERA



The „MAGNA CARTA“



The „MAGNA CARTA“ – The next logical step



› Deepen the cooperation by forming an expert group

Follow up: The Expert Group

- Task:
  - Summarize the Magna Carta and the Results of the WS in a publication
- Who?
  - You + the OpERA steering committee
- Timeframe?
  - End of 2015 – early 2016
- Workload?
  - Managable (~1DINA4 page per expert, layout by us)

Projektträger Jülich
Forschungszentrum Jülich
Geothermal ERA-NET
Federal Ministry for Economic Affairs and Energy

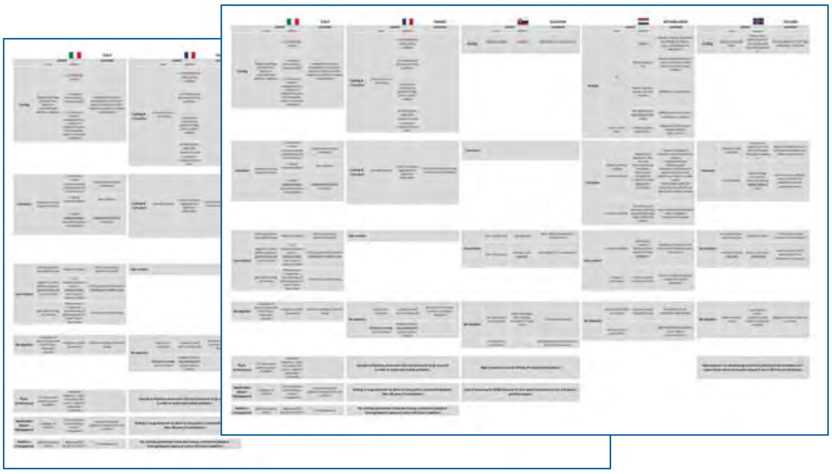
Follow-up: Future JA (JA2/JA3?)

- Based on the results of the workshop, the urgency of RD&D and the need for cooperation in Europe can be quantified
- The Geothermal ERA-NET Committee will discuss the results and findings next week in Brussels
- A decision on possible follow-up JA
- At least further cooperation schemes for the field of operational issues will be proposed.
- <u>All activities related to a further JA will be in parallel to the work of the expert group</u>

Summary and results

With this concept in mind…

…Let´s have a look at the Magna Carta



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Geothermal project Koekoekspolder

GREENHOUSE GEO POWER Koekoekspolder

lead scaling issues

Geothermal ERA-NET

Expert Workshop
1 & 2 October 2015

Radboud Vorage
Greenhouse GeoPower

Short introduction

GREENHOUSE GEO POWER Koekoekspolder

Radboud Vorage

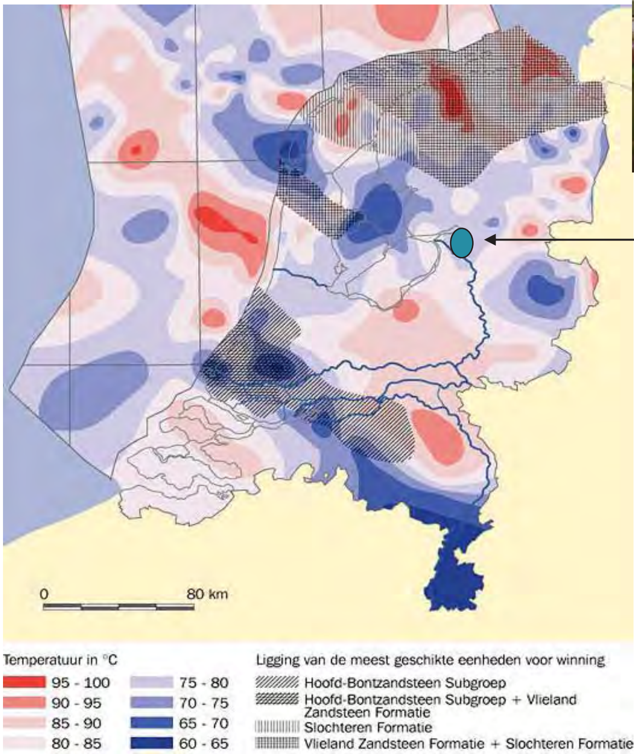
Engineer, MSc (WUR)

- Project manager
- Involved in Koekoekpolder and Venlo CLG
- First cluster project in horticulture
- GreenhouseGeoPower
- Member of DAGO

DAGO Dutch Association Geothermal Operators

Koekoekspolder

IJsselmuiden



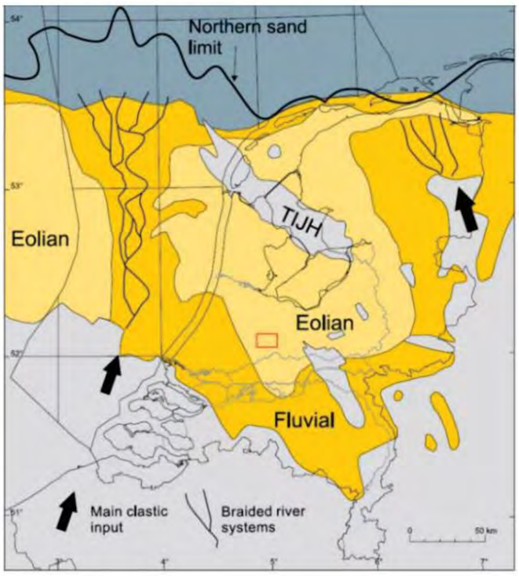
Koekoekspolder

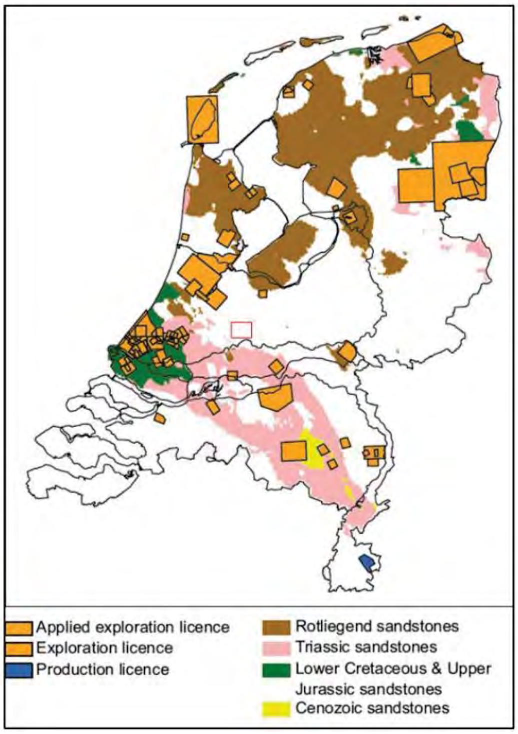
Sandstone layer

1.850-1.950 meters of depth

About 74 degrees

Geothermal projects in the Rotliegendes sandstone

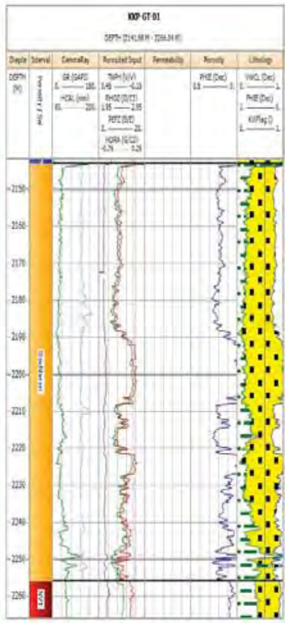




- Koekoekspolder (1)
- ECW Wieringermeer (2)
- Floricultura (1)

Geology in Koekoekspolder

- Sandstone formations, 70 -100 meter thick
- Carboon-**Perm**-Trias (270-300 mlj. years)
- Slochteren- Rotliegendes

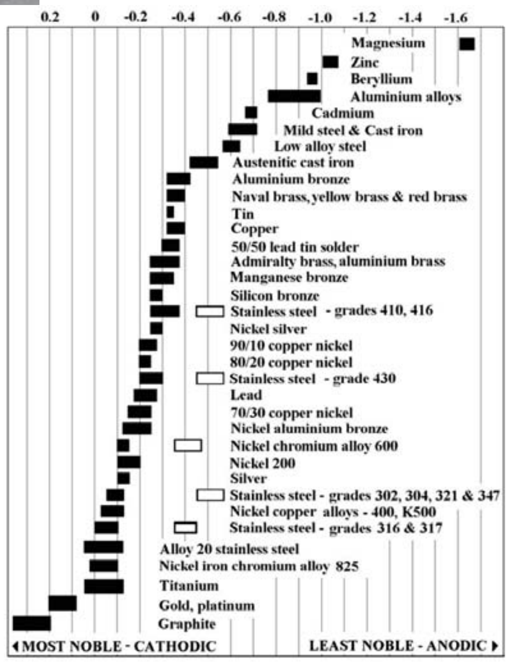


FIRST SIGNS OF SCALING

Pump

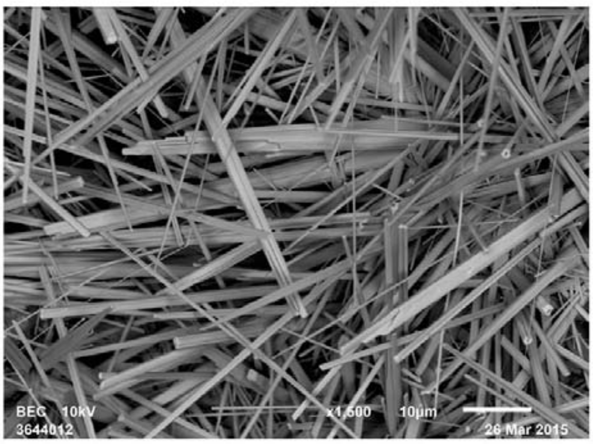
Butterfly valve

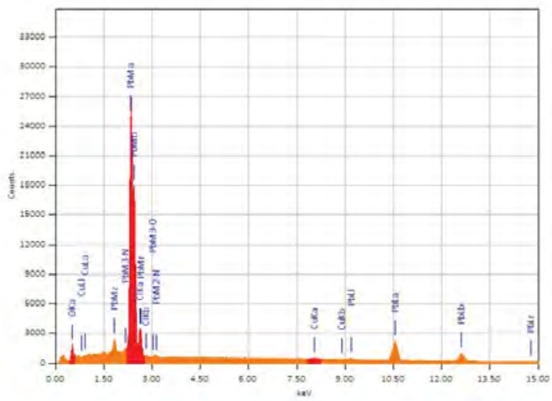
Tests with various materials



- Difference in scaling related to type of metal
- Influence of electrochemical potential
- Galvanic cel (salt water environment)

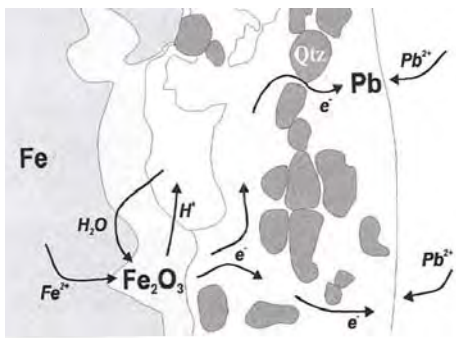
Microscopic view of scaling



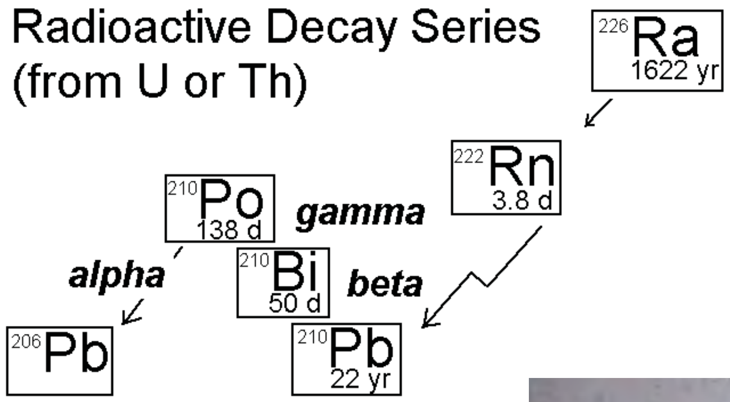


Energy Dispersive X-ray (EDX) spectrum of white deposit

- The element of lead
- Precipitation of lead from thermal water
- Electron exchance and relation with corrosion



Lead turned out to be NORM



- PB210, isotope
- Radio Active, beta emission
- Low radiation, but carefull treatement required
- Special working protocols developed

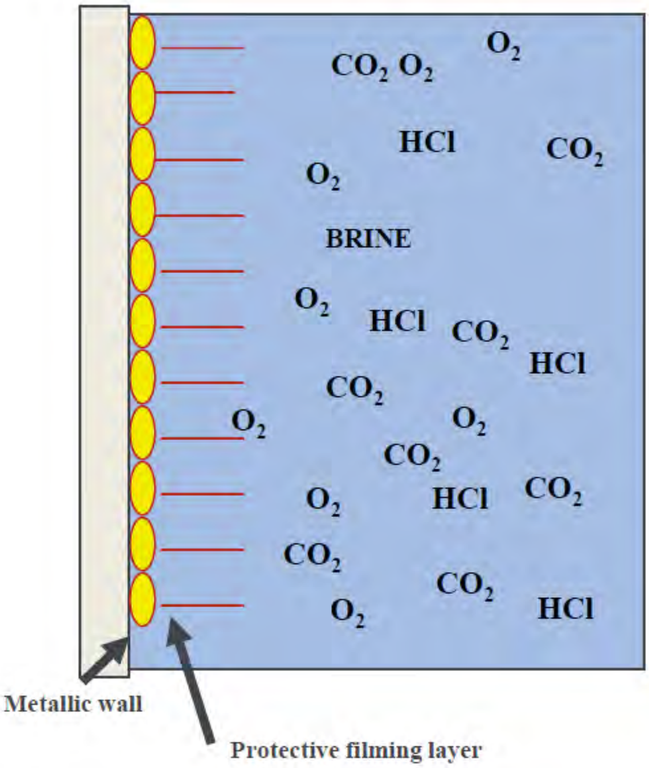
Possible strategies

- Alter the use (piping) materials (chromium)
- Avoid galvanic cel's in the installation (connection of two metals with a different electrochemical potential
- Remove the lead out of the water (precipition on en desired location)
- Coating of all liners/tubing
- Change pH to alkaline
- Start using (corrosion) inhibitor

And with all options intensive monitoring

Corrosion inhibitor

The film acts as a physical barrier between metal surfaces and corrosive thermal water, offering protection against the oxidation of the iron tubing.



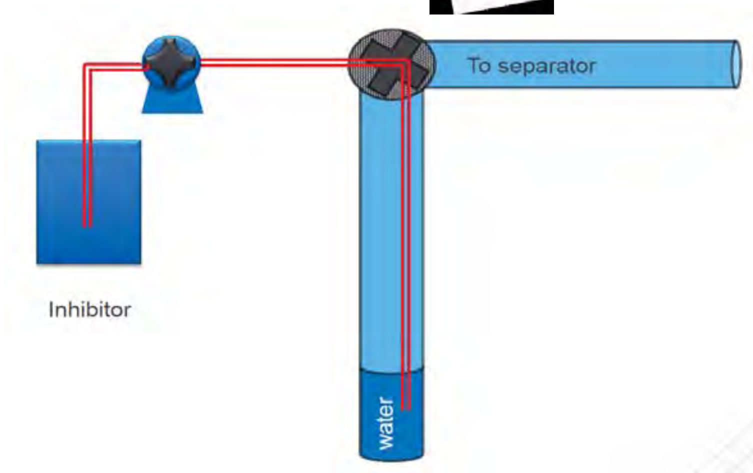
NALCO
An Ecolab Company

Corrosion inhibitor

- Filming amine:
  - Imidazoline
  - Quaternary Amine
- Filming amines have very long hydrocarbon chains and high molecular weight.
- One end of the molecule is hydrophilic (attracts water), and the other is hydrophobic (repels water).
- The hydrophilic end physically attaches itself to the metal surfaces of the system. As the density of the molecules on the metal surfaces increases, the hydrophilic ends create a monomolecular, non-wettable film on all metal surfaces that come in contact with the formation water.

Corrosion inhibitor dosing

- The injection is best done as deep as possible in the production well.
- Surface injection can be done by pareto dispenser



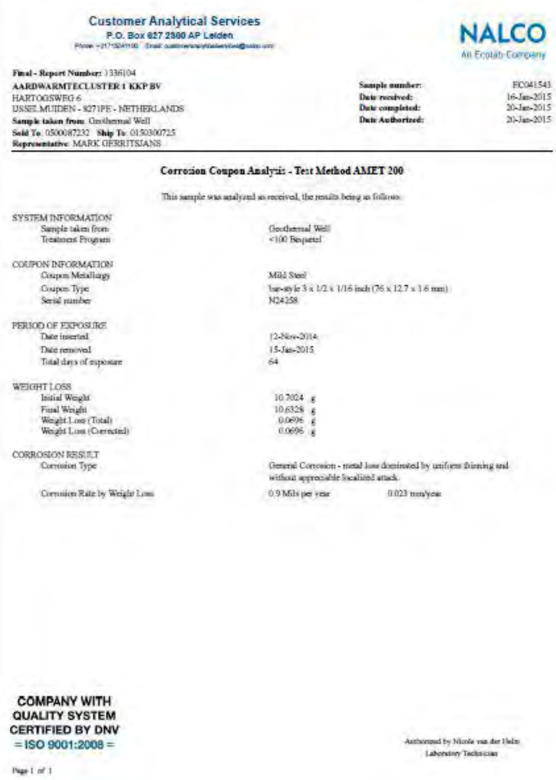
Corrosion monitoringsystem (1)

- Corrosion coupons, various types
- Similar flow speed
- Warm and cold
- Various types of metals
- Various periods of time in contact with thermal water

Corrosion monitoringsystem (2)

- Temperature measurement
- pH measurement
- Linear Polarization Resistance
- MPY calculation on the basis of Linear Polarization Resistance
- ORP measurement

Verification with real coupons



Customer Analytical Services
P.O. Box 627 2300 AP Leiden

NALCO
An Ecolab Company

Final - Report Number: 1336104
AARDWARMTECLUSTER 1 KKP BV
HARTOGSWEG 6
IJSSELMUIDEN - 8271PE - NETHERLANDS
Sample taken from: Geothermal Well
Sold To: 0500087232 **Ship To:** 0150300725
Representative: MARK GERRITSJANS

Sample number:	FC041543
Date received:	16-Jan-2015
Date completed:	20-Jan-2015
Date Authorized:	20-Jan-2015

Corrosion Coupon Analysis - Test Method AMET 200

This sample was analyzed as received, the results being as follows:

SYSTEM INFORMATION	
Sample taken from	Geothermal Well
Treatment Program	<100 Bequetel
COUPON INFORMATION	
Coupon Metallurgy	Mild Steel
Coupon Type	bar-style 3 x 1/2 x 1/16 inch (76 x 12.7 x 1.6 mm)
Serial number	N24258
PERIOD OF EXPOSURE	
Date inserted	12-Nov-2014
Date removed	15-Jan-2015
Total days of exposure	64
WEIGHT LOSS	
Initial Weight	10.7024 g
Final Weight	10.6328 g
Weight Loss (Total)	0.0696 g
Weight Loss (Corrected)	0.0696 g
CORROSION RESULT	
Corrosion Type	General Corrosion - metal loss dominated by uniform thinning and without appreciable localized attack.
Corrosion Rate by Weight Loss	0.9 Mils per year 0.023 mm/year

COMPANY WITH
QUALITY SYSTEM
CERTIFIED BY DNV
= ISO 9001:2008 =

Authorized by Nicole van der Helm
Laboratory Technician

Page 1 of 1

Alternative materials

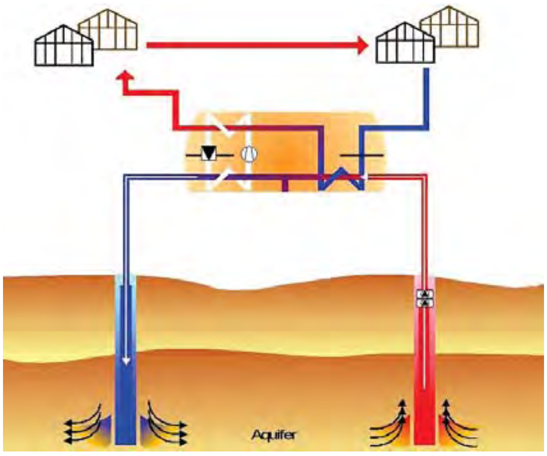
- GRE Glass Fibre Reinforced Epoxy
- Stainless Steel tubing
- Polypropylene
- Acquit material for casing

Conclusions

- Lead scaling and lead precipitation is likely to happen in thermal water from the Slochteren-Rotliegendes
- Lead has the risk to containing small amounts of PR210, which is NORM substance
- Redox-reactions can take place between the mild-steel parts of a geothermal installation and thermal water that contains dissolved lead.
- The use of corrosion inhibitor was found the most practical way of reducing the precipitation of lead in the geothermal installation in Koekoekspolder.
- Intensive monitoring of scaling and corrosion is very important, also in combination with the use of inhibitor and dosing.
- Composite materials should be considered in the design phase of a geothermal project.

Questions en discussion

Radboud Vorage
06-51431301
greenhousegeopower@hotmail.com



provincie Overijssel

GREENHOUSE GEO POWER Koekoekspolder

Kampen

Kas als Energiebron

DAGO Dutch Association Geothermal Operators

Thermal Decomposition of Barite scale by laser

Szanyi,J. – Bozsó,R. – Bozsó,T. – Bajcsi,P. – Molnár,G. – Czinkota,I. – Kovács,B. – Schubert,F. – Bozsó,G. – M.Tóth,T.

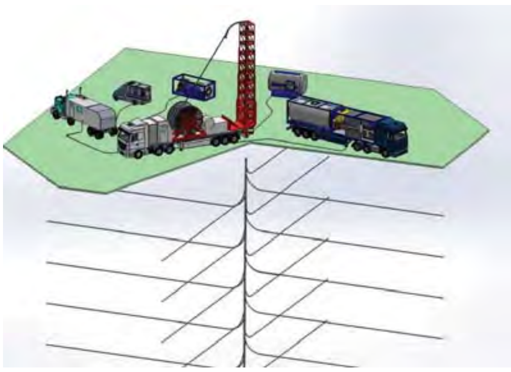
University of Szeged, Hungary
✉ szanyi@iif.u-szeged.hu

Geothermal ERA-NET Joint Activity "OpERA" – Vaals, 1-2 October 2015

Introduction

Department of Mineralogy, Geochemistry and Petrology

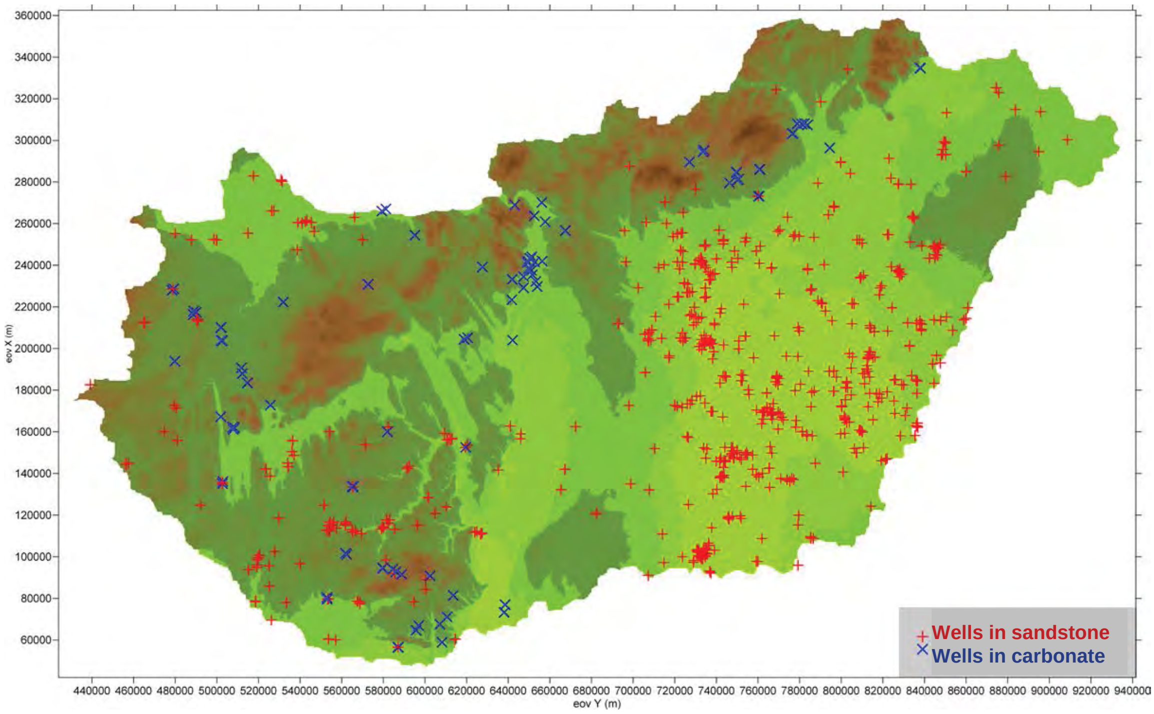
- Fractured Reservoir Research Group
- Geochemistry and Environmental Research Group
- Hydrogeological and Geothermal Research Group



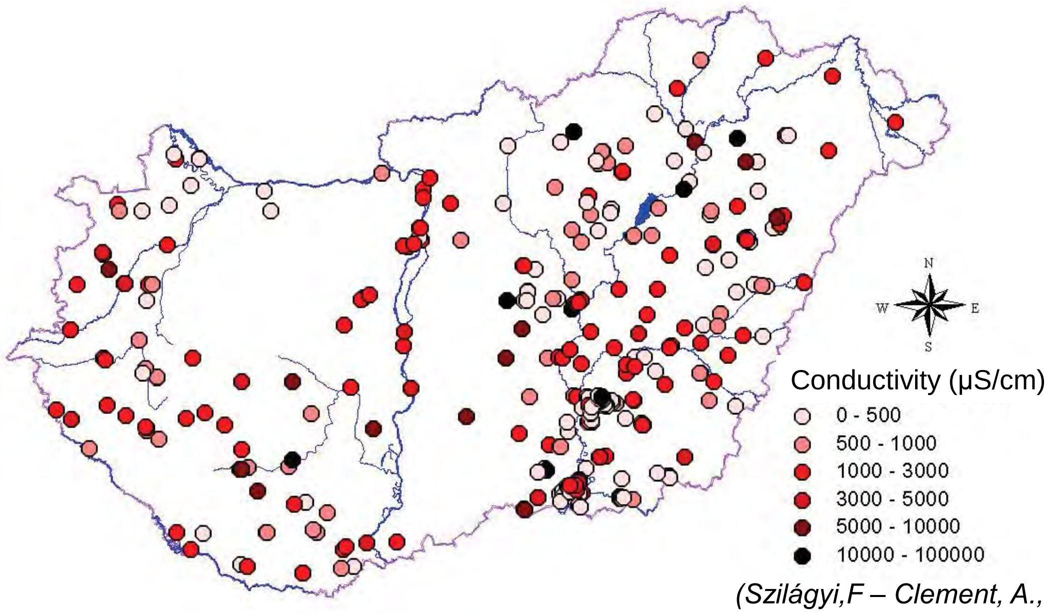
ZerLux Ltd

Development of laser technologies for geothermal and oil industry to give solution to some of the limitations inherent in conventional drilling
and scale removal methods, and open a wide range of new possibilities.

Background



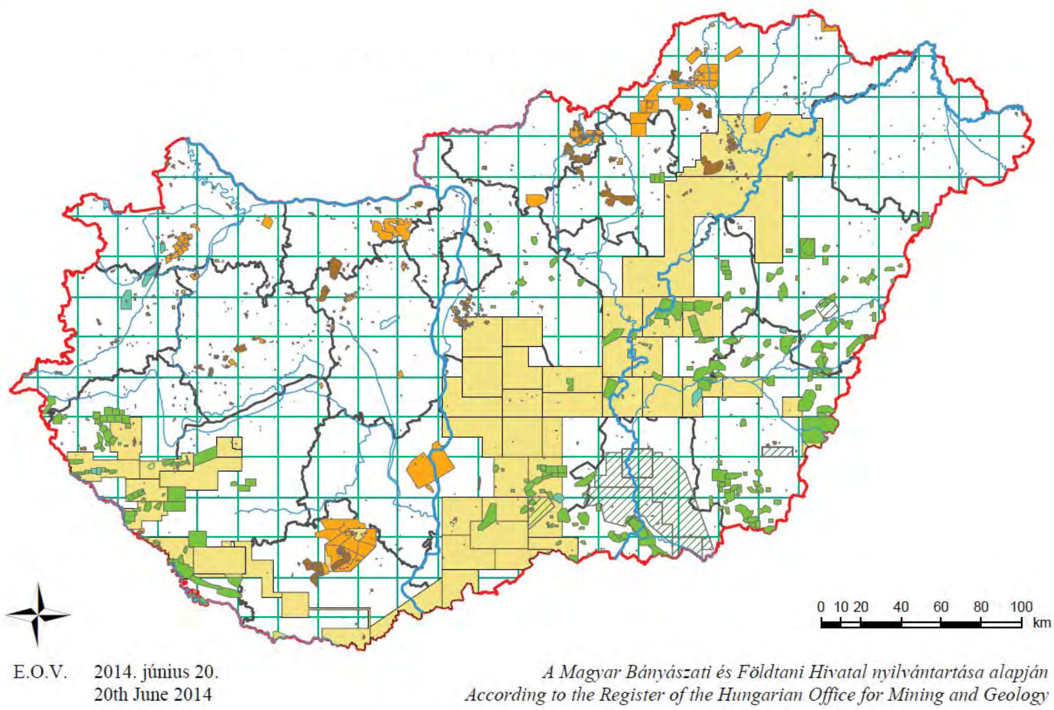
Chemical Pattern of Thermal Water



(Szilágyi,F – Clement, A., 2010)

Precipitation of hard scales can radically reduce the effective flow diameter of geothermal wells

Hydrocarbon mining territories in Hungary (green and yellow)



The Most Common Scale Types

- Calcite ($CaCO_3$)
- Barite ($BaSO_4$)
- Celestite ($SrSO_4$)
- Anhydrite ($CaSO_4$)
- Gypsum ($CaSO_4*2H_2O$)
- Pyrite (FeS_2)
- Halite (NaCl)

Exotic scales: calcium fluoride, zinc sulfide, lead sulfide mostly HT/HP wells

Scale Prevention Techniques

- **Pressure maintenance**
  closed system and extra energy need
- **Inhibitor using**
  relatively expensive, permanent dosage needed
- **Electromagnetic water treatment**
  „mystic", but some cases it works

Scale Remediation Techniques

- **Chemical dissolution**
  relatively inexpensive „acid washes" – problem: low solubility
- **Milling**
  one of the earliest methods – can demage the steel casing
- **Jetting**
  effective on soft scale, less effective on medium and hard scales

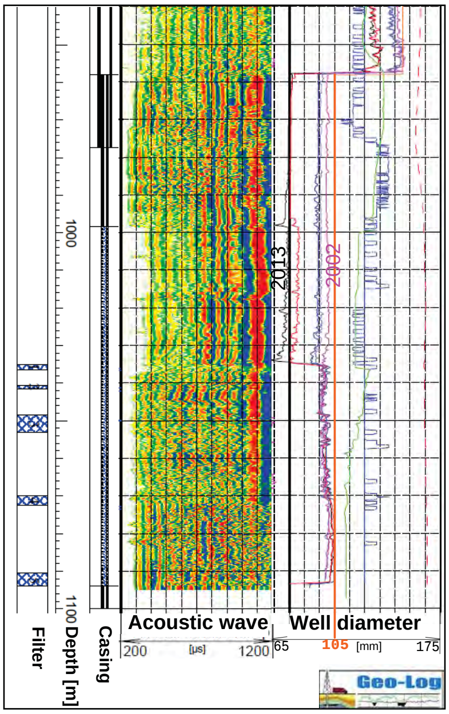
Difference between Carbonate and Sulphate Scales

- $CaCO_3$ - will become soluble by acid treatment - **easy to remove**
- $BaSO_4$ - , will require very high temperatures and a reductive environment to become soluble – **hard to remove**

Barium sulphate scaled-up tubing example
(Tom Grant and Johnny Smith, Gaither Petroleum, in Jonathan Bellarby, 2009, Well Completion Design)

Thermal Well with Barite

Bük-3 well (1972)	
Filter [m]	1033-1094
Yield [l/s]	12
Temp. [ºC]	55.7
TDS [mg/l]	7050
Barium [μg/l]	1100
Sulfate [mg/l]	170
CO_2 [l/m³]	15323

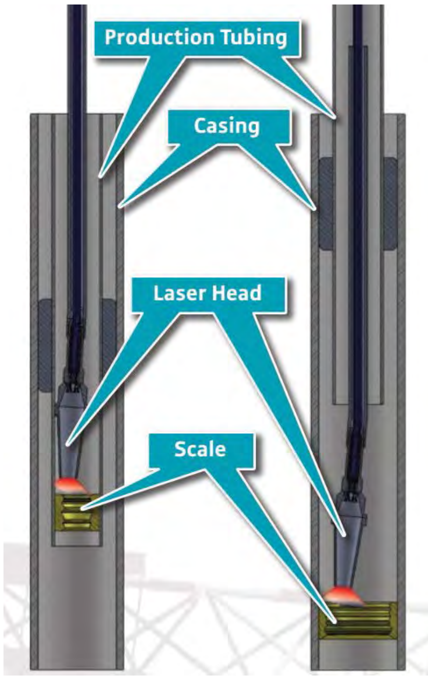


Principles of Laser Technology in Well Rework

ZerLux's Scale Removal Laser (SRL) enables us to use high power laser devices even in large depths via the standard high carrying capacity optical fibers.

The SRL will utilize cutting-edge, underbalance laser well rework and completion technology in fluid mining.

The tool is comprised of a surface located high power laser generator and a specially designed subsurface directional laser drilling head and uses nitrogen to displace all fluids during the drilling process.



The Purpose of Our Work

- Advanced stage experiments under way to remove scales by melting and thermal decomposition by high power infrared lasers
- The purpose of our effort is to analyse the solubility of various alkaline earth salt mixtures at a given energy laser treatment and draw conclusions on the melting efficiency of various mixtures

Materials

- The following mineral mixtures were used for the experiments (100 g each):

A. 100% $BaSO_4$
B. 75% $BaSO_4$ + 25% $CaSO_4*2H_2O$
C. 50% $BaSO_4$ + 25% $CaSO_4*2H_2O$ + 25% $CaCO_3$
D. 50% $BaSO_4$ + 25% $CaSO_4*2H_2O$ + 25% SiO_2

Thermal Decomposition of Barite

$BaSO_4 = BaO + SO_3$

$BaSO_4 = BaO_2 + SO_2$

Both can happen

$BaO + H_2O = Ba(OH)_2$

$BaO_2 + 2H_2O = Ba(OH)_2 + H_2O_2$

SO_2, SO_3 - gas

$Ba(OH)_2$ - soluble in water

Lab Laser Equipment

The samples were impinged by laser

Duration: 1 min, light capacity: 850 W, wavelength: 915 nm

Results and Evaluation

At a given laser light energy level:

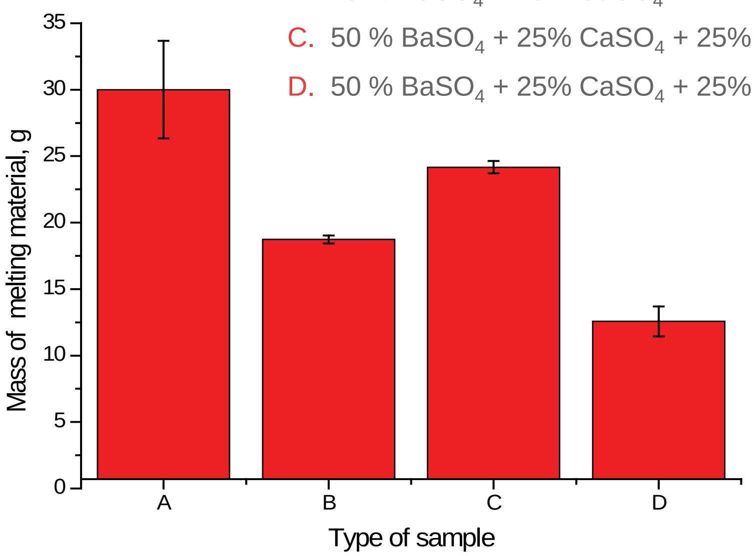
- The pure barite sample produced the largest amount of melt.
- The smallest mass was produced by the SiO_2 containing sample.
- The data also confirm that calcite will facilitate melting.

A. 100% $BaSO_4$

B. 75 % $BaSO_4$ + 25% $CaSO_4$

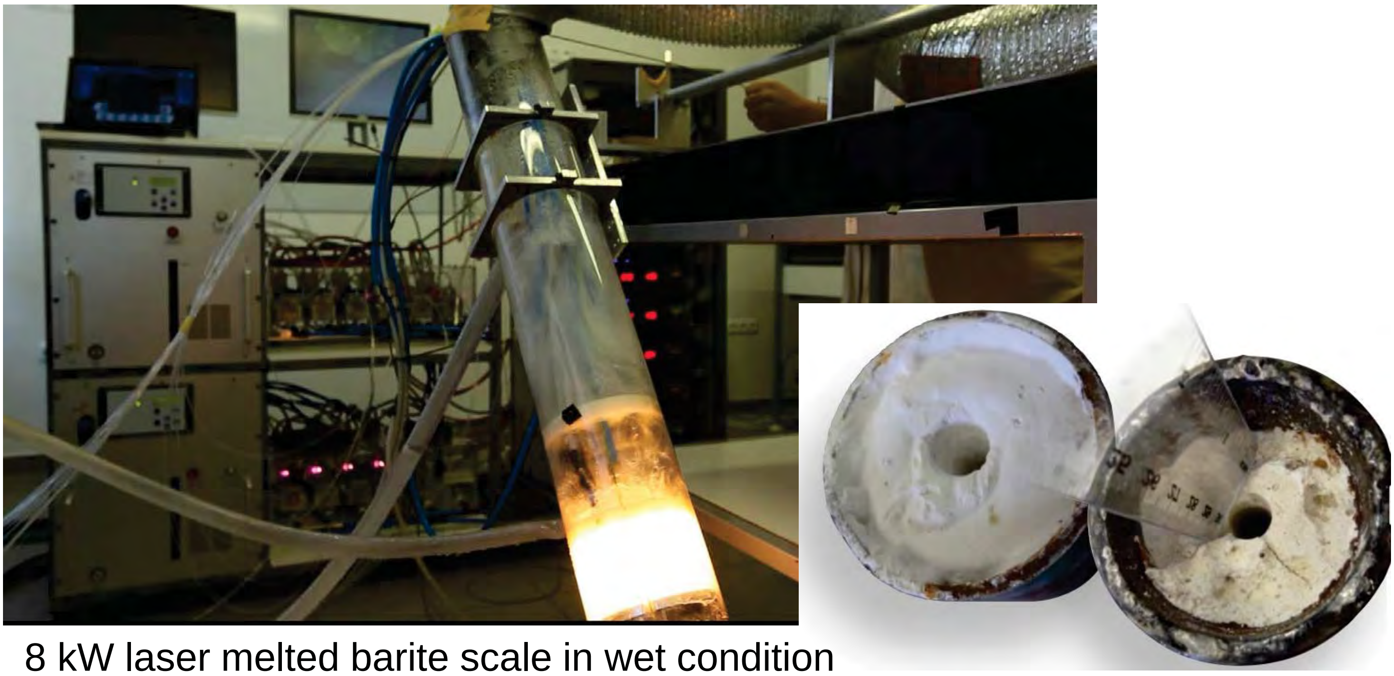
C. 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% $CaCO_3$

D. 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% SiO_2



Mass of molten substance of particular mixtures

Current Lab Testing



8 kW laser melted barite scale in wet condition
without damaging the tubing

Summary

- In all sample compounds it was clear that laser induced melting prompted the originally water insoluble alkaline earth sulfates to decompose to water soluble hydroxides and gas state water soluble sulphur dioxides.

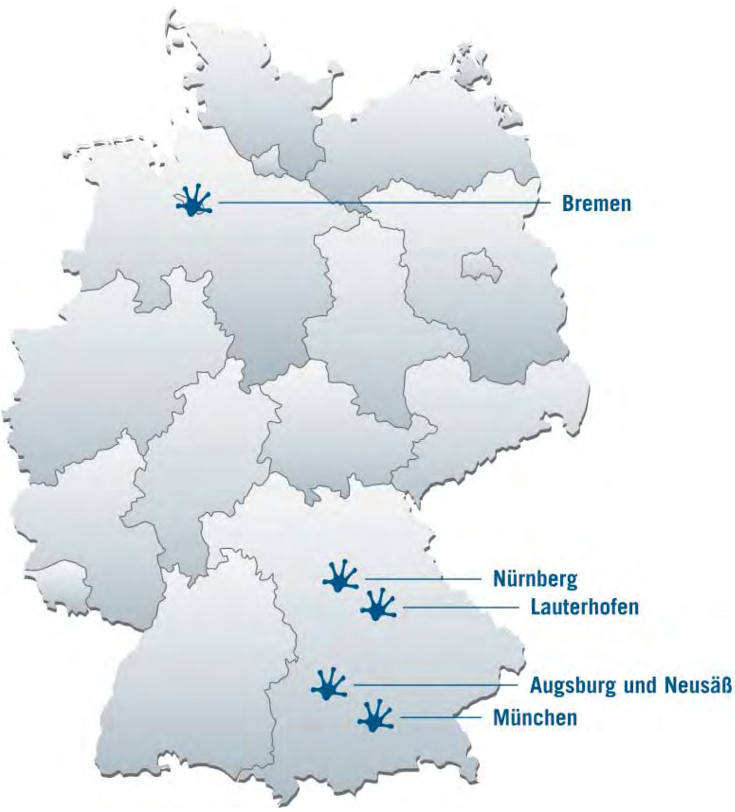
- The results of the experiments indicate laser induced heat treatment is a suitable alternative to effectively remove otherwise almost immovable deposits and scales from thermal water well pipes.

- Benefit of using Scale Removal Laser:
  - Non-mechanical force used
  - No vibration created
  - No explosives, toxic chemicals or other environmentally or logistically challenging components are required
  - SRL method assures scale deposit removal without overheating or damaging the metal tubing

Thank you for your attention!

PRV-GT – Avoidance of scaling and outgassing with a downhole pressure retention valve

Facts and Figures



- Establishment of our family business in 2007 focused on deep geothermal projects and drilling engineering research
- Management Geo
  Business Association
- ~ 25 employees
- more than 300 years engineering knowledge of our employees

Manager
Dipl.-Ing. Thorsten Weimann, MBA

Head Office
Bürgermeister-Wegele-Straße 6
86167 Augsburg

Business Units

gec-co Geothermal

- Drilling site construction
- Power plant construction
- Operational management
- ORC-/Kalina- cycle calculation

gec-co Drilling Technology

- Down Hole Tools
- Pipe Handler / Pipe Push Unit
- Vertical Drilling Equipment
- Horizontal Drilling Equipment

gec-co Plant & Equipment

- Mechanical Engineering and construction
- Coordination and calculation
- Simulations program IPSE Pro
- Plant design 3D

gec-co Flow Control

- Press- and volume- control valve
- Cavitation free pressure drop over a wide range of pressure
- Customization
- Extremely wear-resistant

gec-co Lobbying

- Management branch association (WFG
- Policy document
- Political network
- Renewable energies

gec-co Energy Communication

- Public relation
- Corporate communication
- Journalistic network
- Acceptance research

Overview

Pressure Retention Valve for Subsurface Applications

- Basic idea from geothermal experience
- Basic components and principle
- Detailed information
- Control mode and dimensions
- Materials, experience and prospect

R & D Project, government-cofounded by:

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Challenge in geothermal applications

Geothermal water

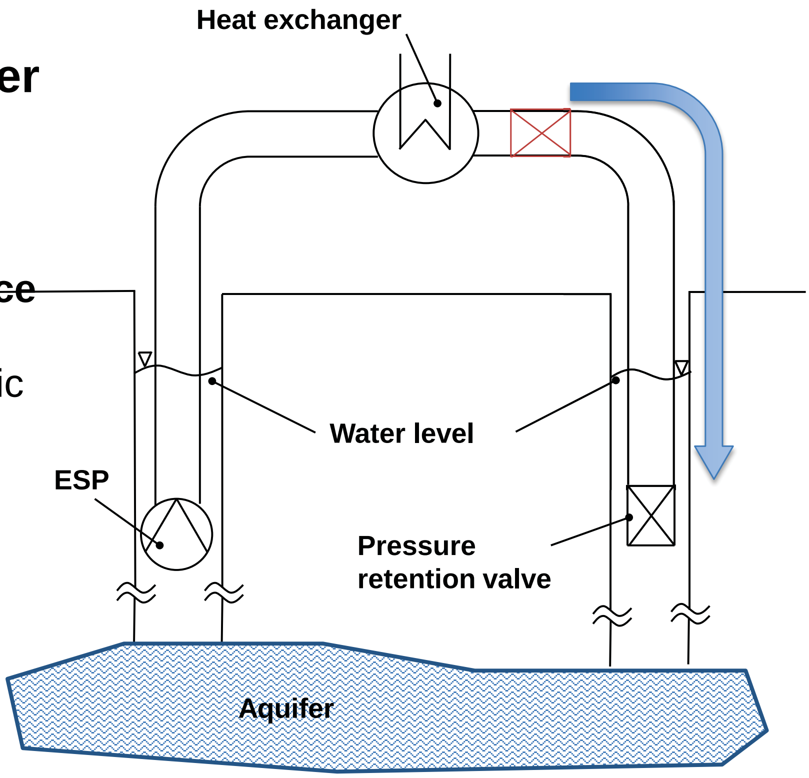
- **Degassing**
  - Two-phase-flow
  - declined heat transfer in heat exchanger
  - Stress on pipes and copmonents
- **New minerals formation**
  - Scaling
  - Corrosion
  - Higher energy consumption of ESP because of smaller pipe diameter
  - declined heat transfer in heat exchanger
  - Clogging of reservoir/aquifer
  - Abrasive erosion

(Quelle: Thomas Jahrfeld, Renerco)

Basic Idea/principle

Placement of pressure rentention below the water level of the injection well

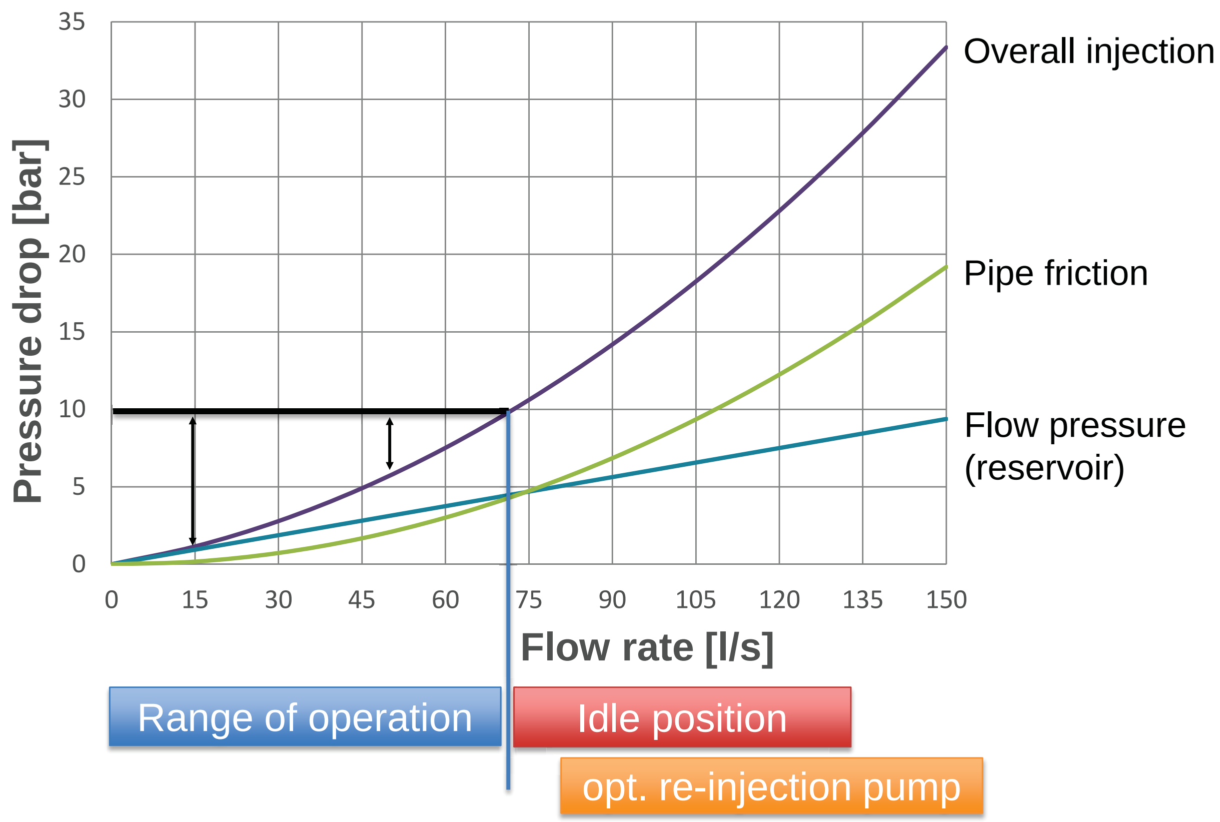
- State of the art: at surface;
  our development: subsurface
- Pressure release against static water head
- Same pressure level in the whole system



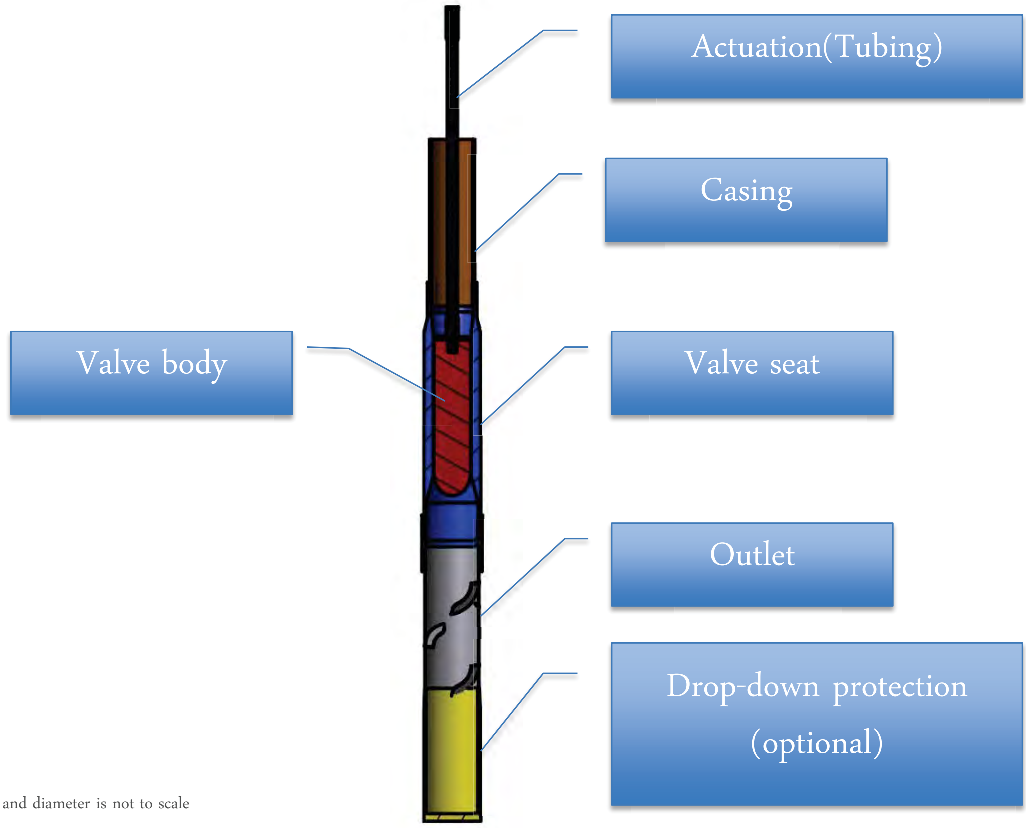
Advantage of the valve

- No cavitation
- No shearing of the fluid,
  due to no sharp edges in valve design
- Pressure in the whole system above the pressure
  where gas dissolves
- No local low-pressure areas
- Simple mechanical components and actuation
- Compensation of wear and scaling to a certain level
- Redundancy

Reservoir characteristic

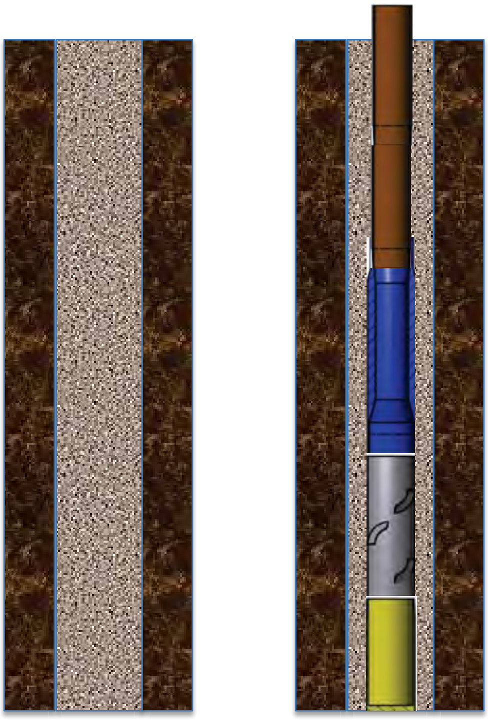


Valve components



Design in length and diameter is not to scale

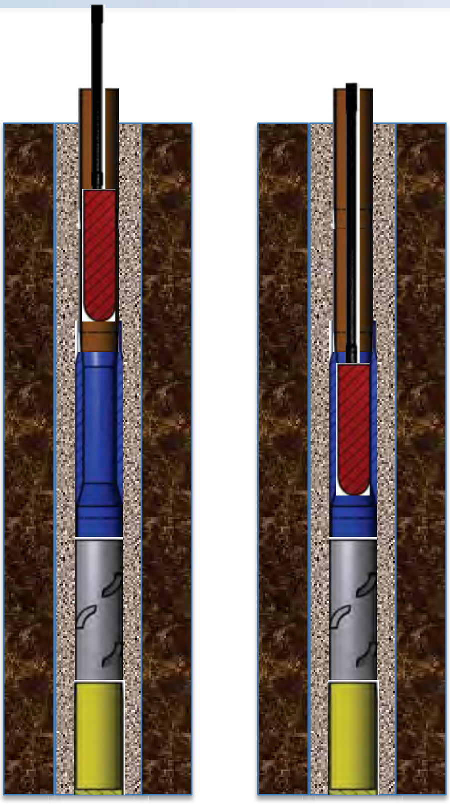
Installation in hole



- Installation of the valve seat together with injection pipes
- Handling with regular tongue, same used for assembaly of injection pipes
- Use of same tool-joints as used for injection pipes

Design in length and diameter is not to scale

Installation in hole



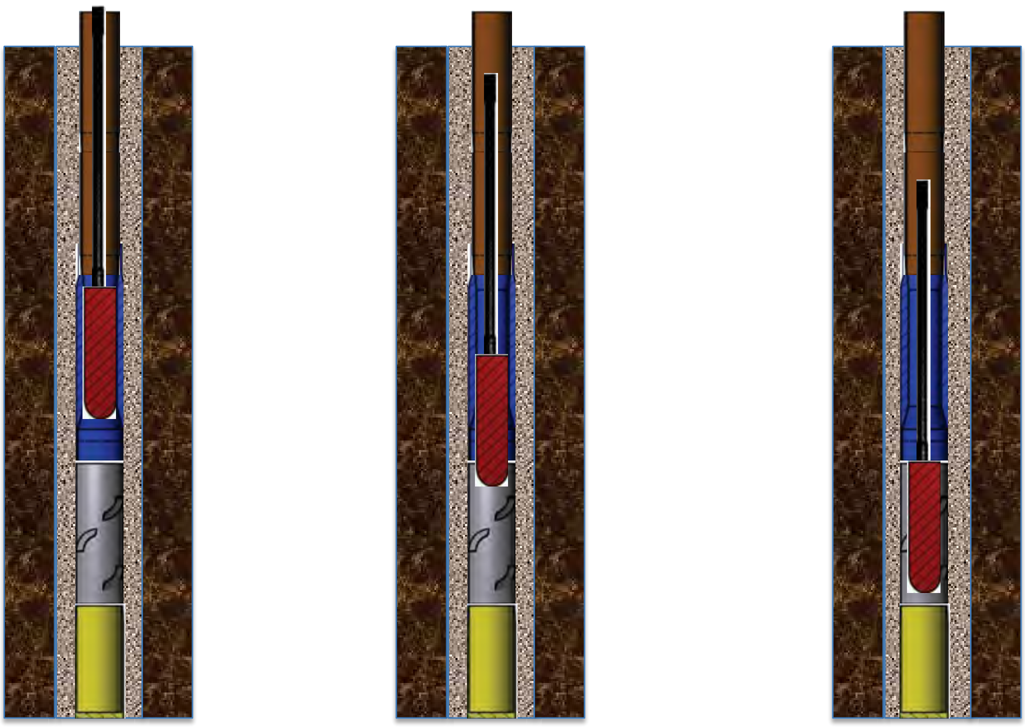
- Bring-in of the valve body at the end of a tubing into the valve seat
- Handling with regular tongue, spider, etc
- Assembly of surface installation
- Connecting with actiation and control device
- Start-up
- Appointment of normal control position

Design in length and diameter is not to scale

Working positions

Closed Working position Idle position

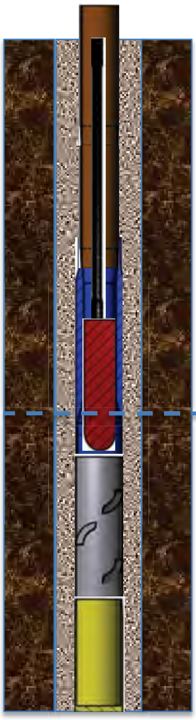
Valve is not sealing up



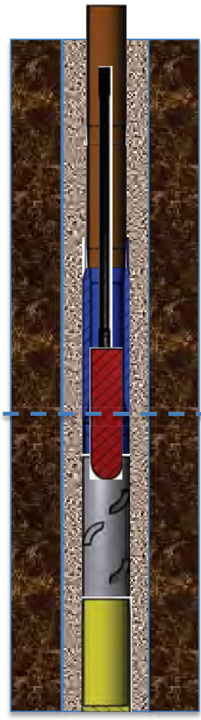
Design in length and diameter is not to scale

Wear/scaling compensation

Wear compensation | Normal position | Scaling compensation

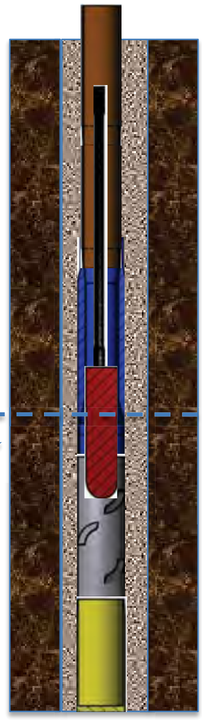


Erosion occurs in the valve body and not in the valve seat



➔ Both characteristics are basic principles of the valve design

➔ Only the position of the valve changes



Design in length and diameter is not to scale

Different installation types

Solid Body Type One-piece design

Pro	Con
Use of high-class materials possible	expensive
Smooth outer outline	
Exchange of components	

Multi Body Type Screwed design

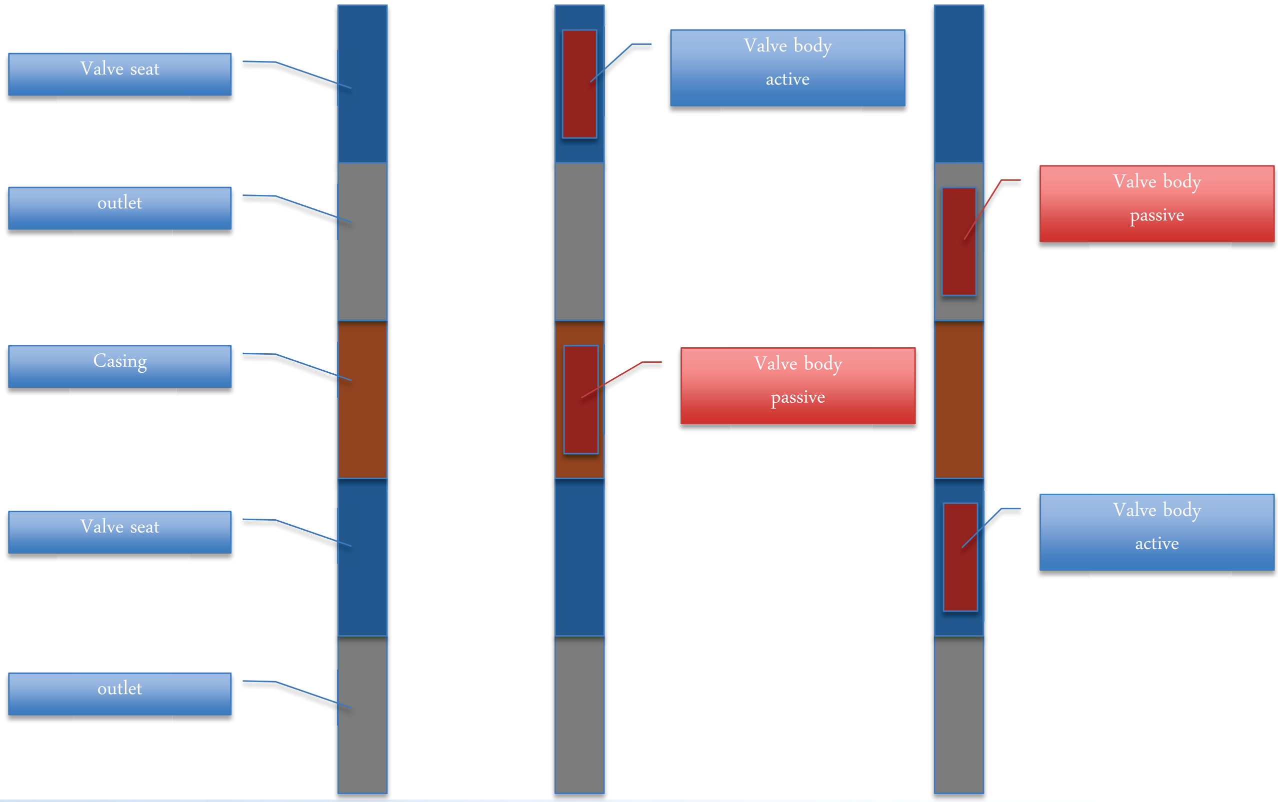
Pro	Con
Exchange of components	Normal budget
	Limited materials can be used

Welded Body Type Welded design

Pro	Con
Low budget	No exchange of components
	Only weldable materials
	Circular welding seams

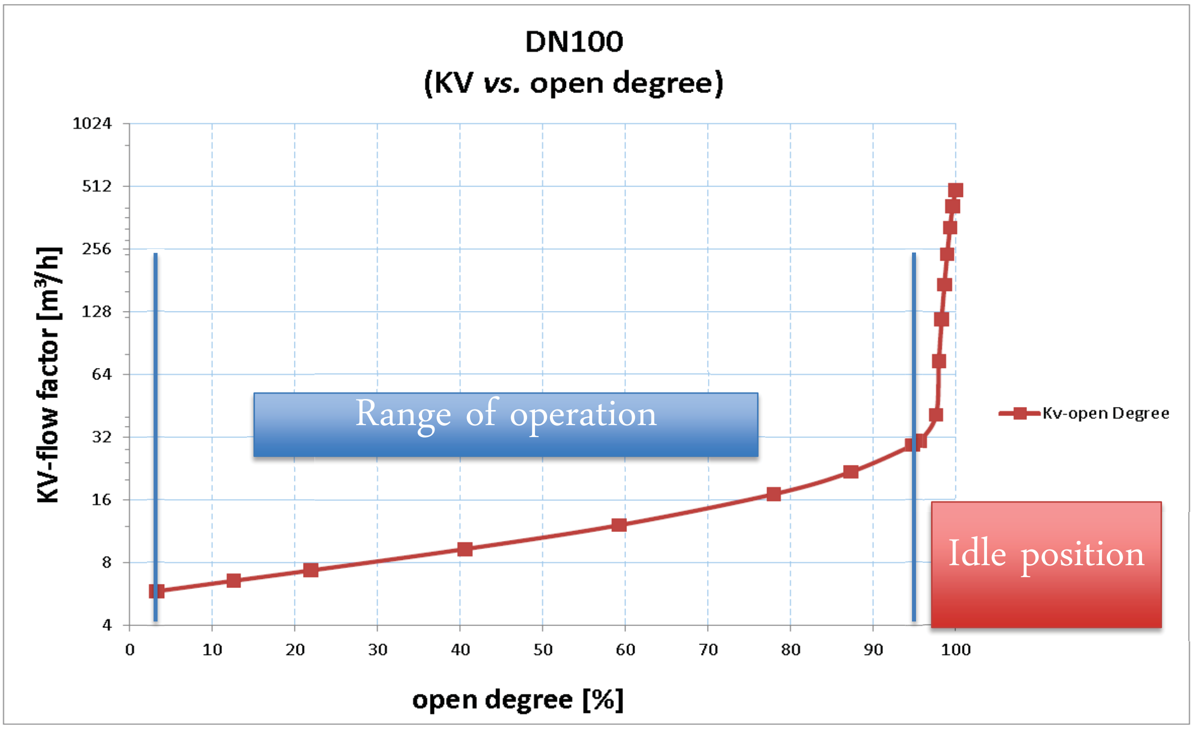
Redundancy

Schematic description of a single redundancy



Characteristic curve

Example of a KV-curve for 4“ / DN100

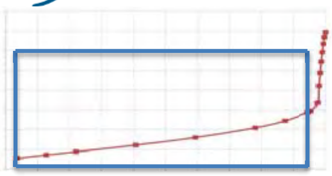


Characteristic properties

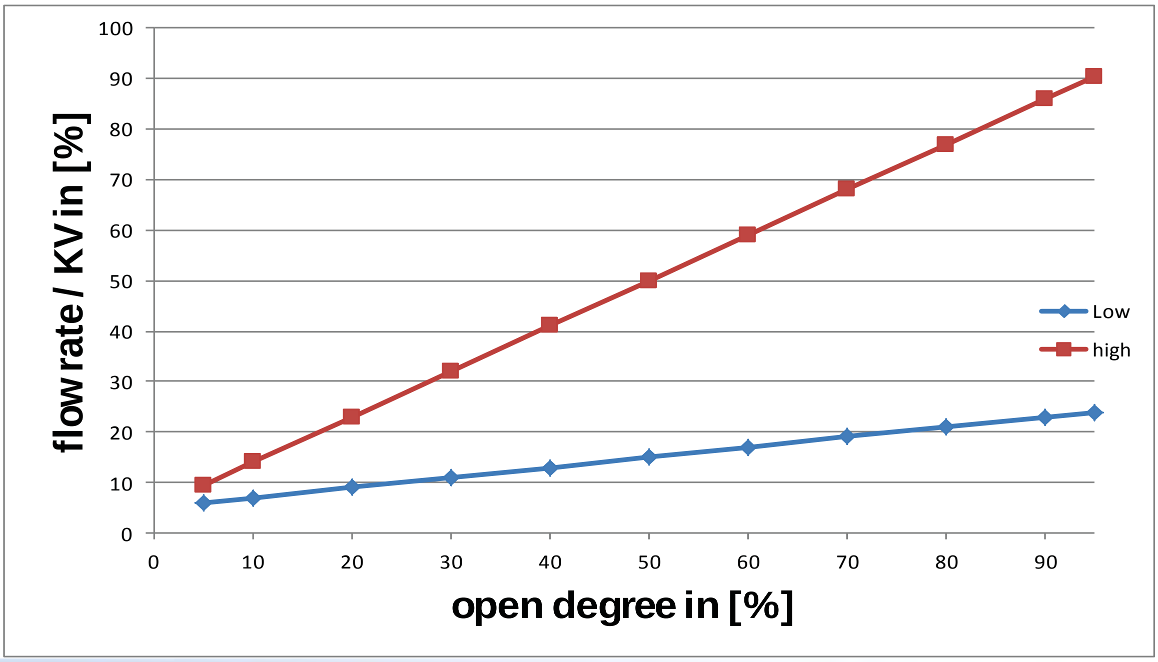
- Linear characteristic curve in range of operation
- Sensitive regulation
- Large control range
- High bandwidth of flow rate
- High flow rate at 100%-open with very low pressure drop
- Fast opening of the valve for max. flow rate

Individual characteristic curve

Specific curve for individual application in range of opera



- Flat curve, for sensitive regulation (blue)
- Steep curve for high bandwidth of flow (red)



Length of valves

Dimensions for geothermal applications

Casing-diameter Injection well [in]	Injection pipe diameter [in]	Valve diameter [in]	Valve length [m]	Pressure retention [bar]	Flow rate [l/s]
< 5“	On request				
5“ – 9 7/8“	3 ½“ – 6 5/8“	2 ½“- 5 1/2“	0,9 – 1,6m	Up to 40bar	20 l/s – 50 l/s
10 3/4“ – 13 5/8 “	7 5/8“ – 8 5/8“	6“ – 7 5/8“	1,3 – 2,2m	Up to 40bar	50 l/s – 100 l/s
14“ - 20“	8 5/8“ – 13 3/8“	7 5/8“ – 11 ¾“	2 – 3,5m	Up to 40bar	100 l/s – 200 l/s
> 20“	On request				

Materials

Material selection depends on:

- Fluid analysis
- Parameter of the environment
- …

Depending on the requirements different materials are possible

- Carbon steels
- Stainless steels
- Nickel-base alloy
- Titan-base alloy
- Synthetic materials

Project plan

Subsurface application

Laboratory test

Surface test

Subsarface test

Industrial application

concepts

Test of prototype

past — present — future

At your service…

Andreas Rauch
Team manager gec-co Flow Control
Dipl.-Ing. mechanical engineering

andreas.rauch@gec-co.de • www.gec-co.de

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

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„Common goals lead to common success.“

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Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Backup

Pressure-dependent deposition modeling

- Solubility of calcium carbonate (CaCO3) is dependent on the CO_2 content
- CO_2-solubilitiy is dependent from pressure

Henry´s law:

$$p_i = H_i * x_i \qquad H_{CO_2} = e^{-6{,}8346+1{,}2817\cdot10^4/T-3{,}7668\cdot10^6/T^2+2{,}997\cdot10^8/T^3}$$

p: pressure — x: mole fracton
H: Henry-constant — T: temperature

- Aquifer is under high pressure (several 100 bar)
- The result is carbon dioxide $CO_2 + H_2O \leftrightarrow H_2CO_3$
- Carbonic acid dissolves limestone $H_2CO_3 + CaCO_3 \leftrightarrow Ca^+ + (HCO_3^-)_2$

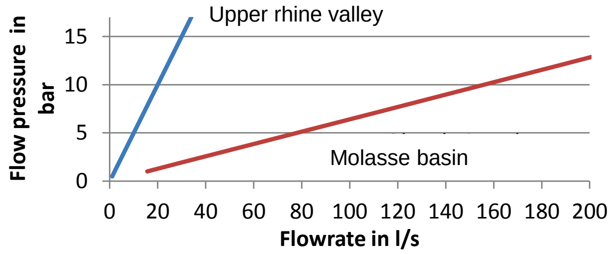
Pressure development

$$WL_{recovery} = SWL - WL_{flow} - WL_{pf}$$

$$\Delta p_i = \rho_i \cdot g \cdot h_i$$

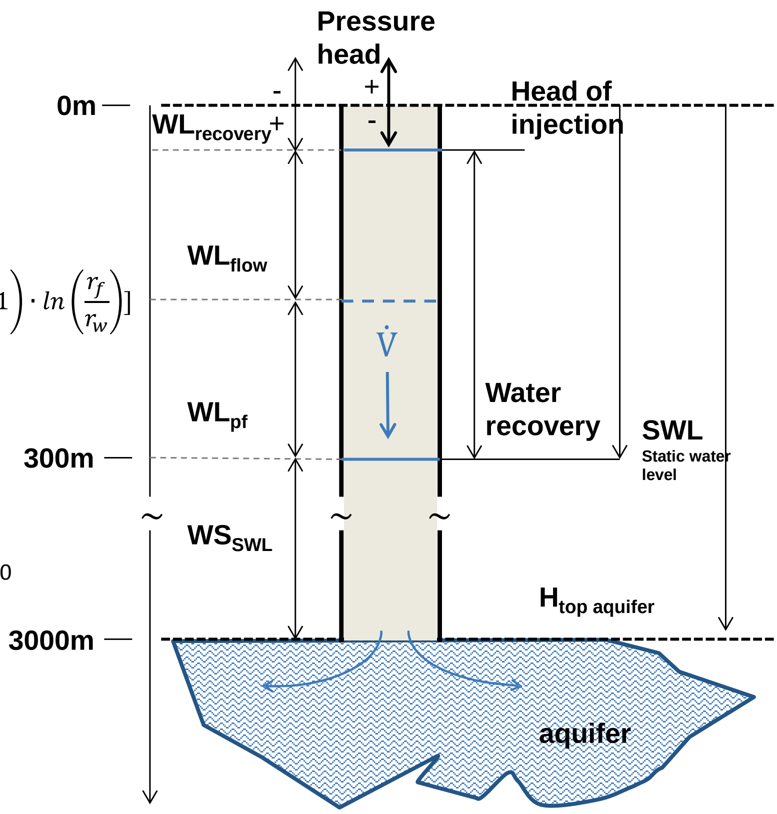
$$\Delta p_{Kopf} = \Delta p_{flow} + \Delta p_{pf} - \Delta p_{recoveryWL}$$

$$\Delta p_{fließ} = \frac{\dot{m}\cdot\eta_r}{2\cdot\pi\cdot\rho_r\cdot k_f\cdot H}\left[ln\left(\frac{D-r_w}{r_w}\right)+\left(\frac{\eta_k\cdot\rho_r}{\eta_r\cdot\rho_k}-1\right)\cdot ln\left(\frac{r_f}{r_w}\right)\right]$$



$$\Delta p_{pipe\ friction} = \lambda \cdot \frac{L}{D}\cdot\frac{\rho}{2}\cdot v^2$$

$$\Delta p_{recoveryWL} = \rho(T_i)\cdot g\left(h - h_0\cdot\frac{\rho(T_0)}{\rho(T_i)}\right)$$



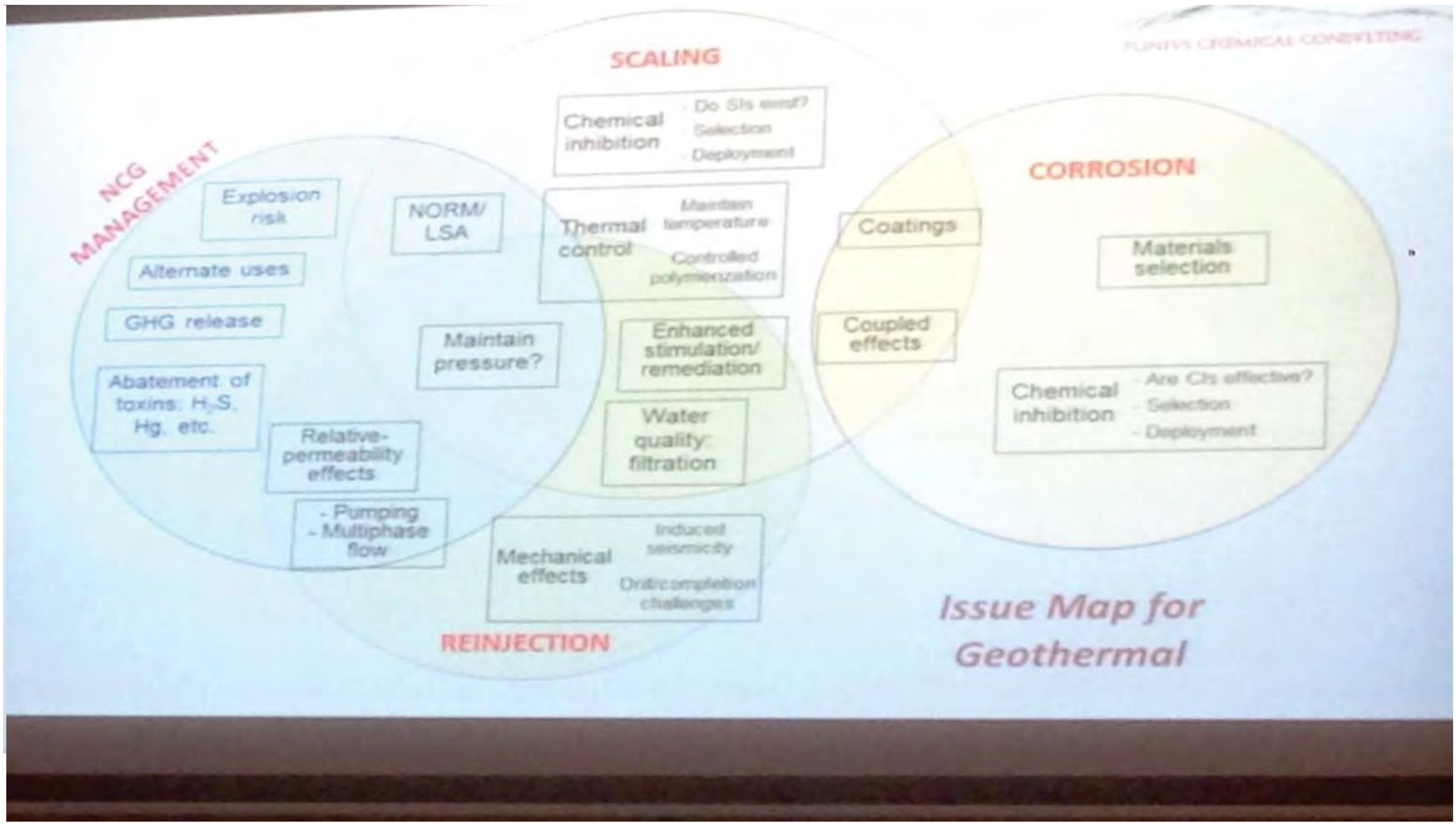
Carbonate Scaling and the Role of Degassing in Geothermal Systems in The Netherlands: Causes, Effects and Remedies

Dr. Niels Hartog
niels.hartog@kwrwater.nl

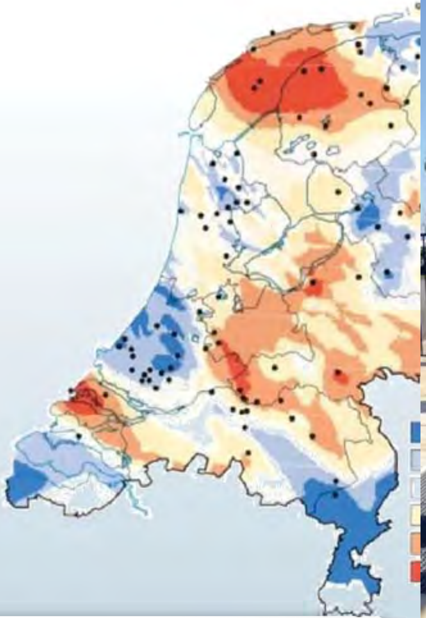
Workshop “OpERA”
Operational Issues of Geothermal Installations in Europe
1-2 October 2015, Vaals

Geothermal ERA-NET

KWR Watercycle Research Institute



Geothermal Heat in The Netherlands



Physical and thermodynamic properties

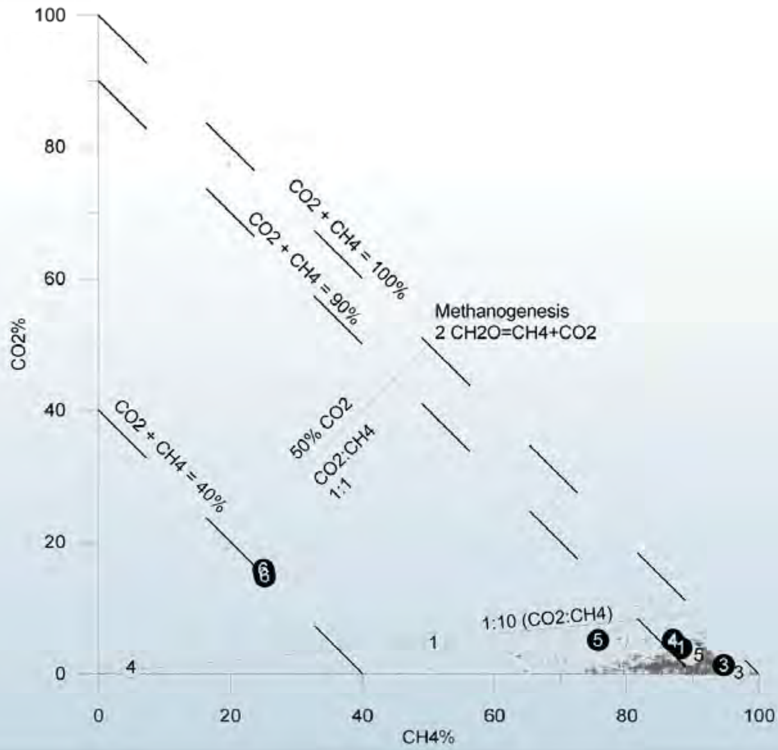
niels.hartog@kwrwater.nl

ITEM \ SITE	1	2	3	4	5	6	6
Wellhead temperature WHT (°C)	70	60	66	70	84	60	57
pH @ 20°C	6.08	6.45	6.07	6.25	5.84	5.74	6.01
Chloride Cl^- (mg/l)	77	62	68	78	84	-	50
Suspended particle concentration (mg/l)	42	16	22	114	24	106	-
Small particle (<0.45 µm) Concentration (% of total)	70	54	58	67	54	2	-
Bubble point BP (bar)	12.5	8.5	12.7	>1.4	>3.7	5.0	4.5
Gas liquid ratio GLR (%)	30	48	14	-	-	9	5

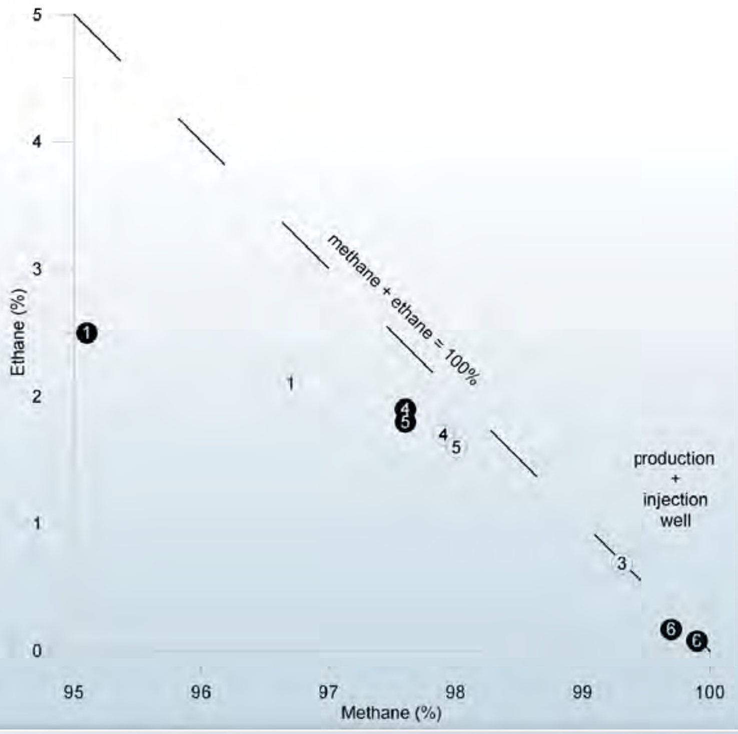
Gas compositions: CH4 vs. CO2

Watersamples taken at surface

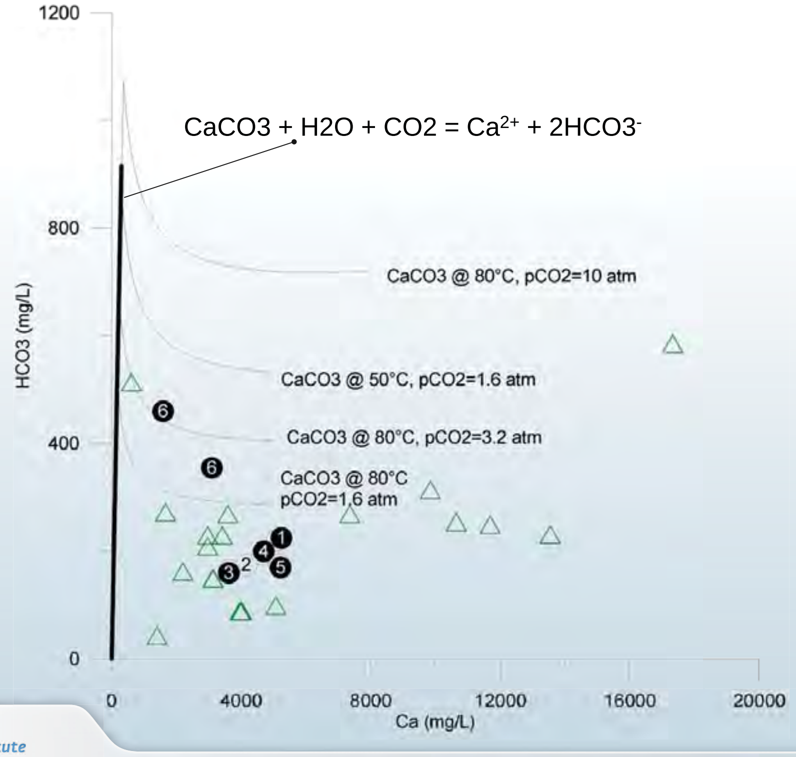
1. Production
2. Injection



Gas composition: Methane vs. Ethane



Carbonate equilibrium, pCO2



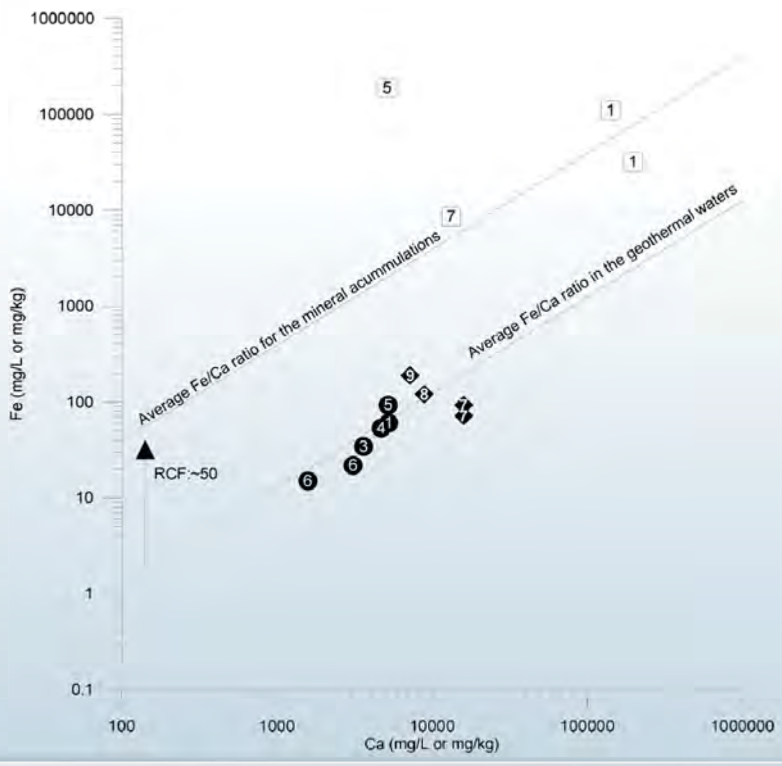
Elemental scale analysis (HNO3 destruct.)

Rank	1 Scalant		1 Filter		5 Filter		7 Scalant	
	Element	wt. %	Element	wt. %	Element	wt. %	Element	wt. %
1	Ca	19,7	Ca	14,1	Fe	18,8	Pb	56,1
2	Fe	3,2	Fe	11,1	Cl	5,6	Cl	4,0
3	SO4	2,2	SO4	2,2	Na	3,4	Na	2,2
4	Cl	0,5	Cl	1,2	Mn	1,9	Ca	1,3
5	Mg	0,5	Na	0,7	SO4	1,7	Fe	0,9
6	Na	0,3	Mg	0,4	Ca	0,5	SO4	0,1
7	Sr	0,2	Mn	0,3	Pb	0,5	Mg	0,1

Scaling and Filter material

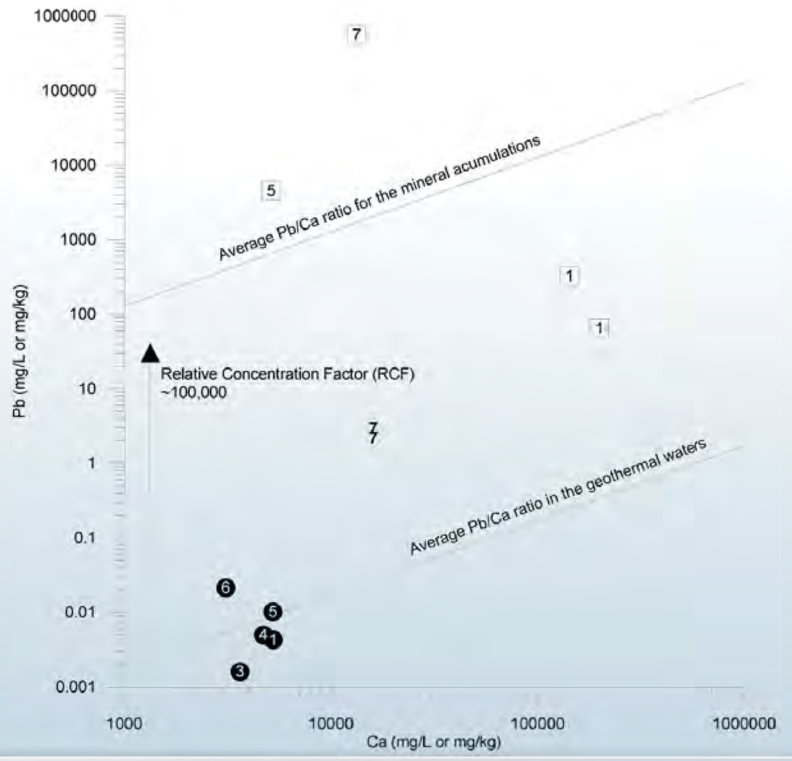
Type	Water %	Acid Test	Residue		Carbonate phase	
			Present	Aceton solvable	Main	Minor
Scalant	7.4	+	yes	yes	CaCO3	FeCO3
Filter	17.3	+	yes	yes	CaCO3	FeCO3
Filter	72,1	-	yes	yes	FeCO3	MnCO3
Scalant	35,2	++	no	-	PbCO3	CaCO3

Enriched in precipitates, Fe
Comparison with aqueous



Enriched in precipitates, Pb

Comparison with aqueous



Degassing induced carbonate scaling

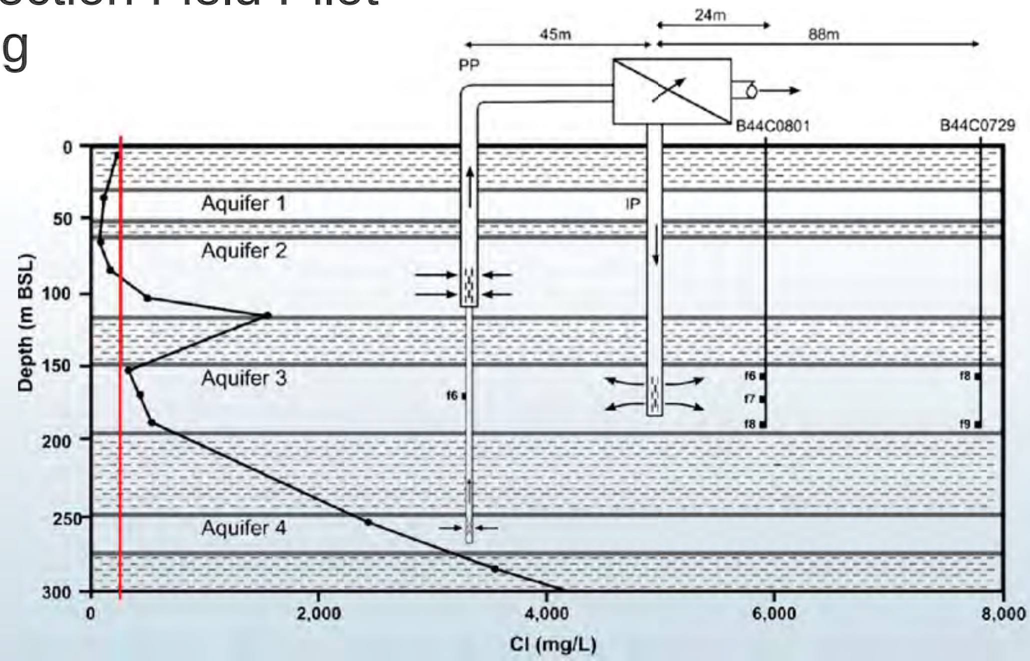
Solutions?

CO2 is fraction of gaspressure but key to scaling management

1. Prevent degassing → maintain pressure above bubble point… high system pressures required
2. Collect produced gas and re-use in injection well (e.g. at depth below bubbling point) → may help prevent injectivity issues due to scaling, but scaling issues in above ground system remain
3. Degass, utilize methane if possible (convert to CO2), dose required pCO2 to maintain carbonate (sub)saturation after degassing

niels.hartog@kwrwater.nl

Concentrate injection Field Pilot with CO2-dosing



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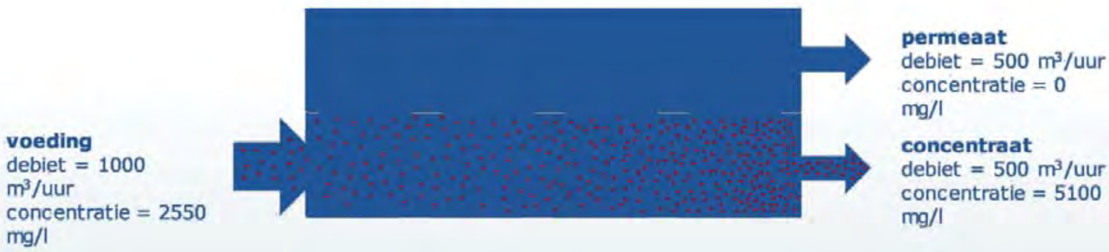
Reverse Osmosis

recovery = 50 %

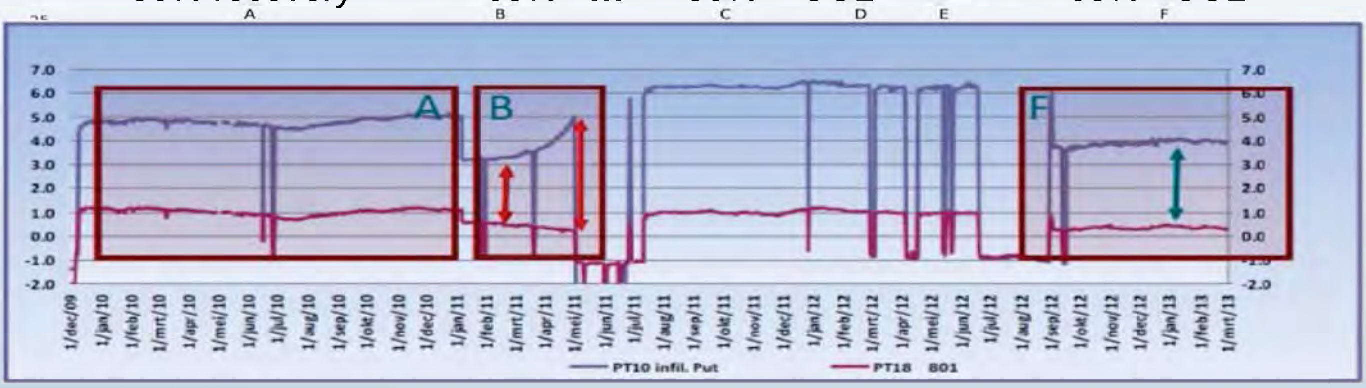


recovery = 65 %

CO2 dosing to prevent injectivity problems

Phase	Settings	Feed water ($m^3 h^{-1}$) Aquifer 2	Feed water ($m^3 h^{-1}$) Aquifer 4	Injection ($m^3 h^{-1}$) Aquifer 3	Start	End	Time (days)
A	50 % recovery	49.2	0.8	25.0	11-12-'09	06-01-'11	391
B	65 % recovery	49.2	0.8	17.5	07-01-'11	02-04-'11	115
C	50 % recovery	49.2	0.8	25.0	13-07-'11	17-01-'12	188
D	50 % + CO_2	49.2	0.8	25.0	17-01-'12	05-04-'12	79
E	50 % + CO_2	50.0	0.0	25.0	20-04-'12	19-06-'12	60
F	65 % + CO_2	50.0	0.0	17.5	01-09-'12	20-04-'13	231

50% recovery 65% !!! 50% + CO2 65% +CO2

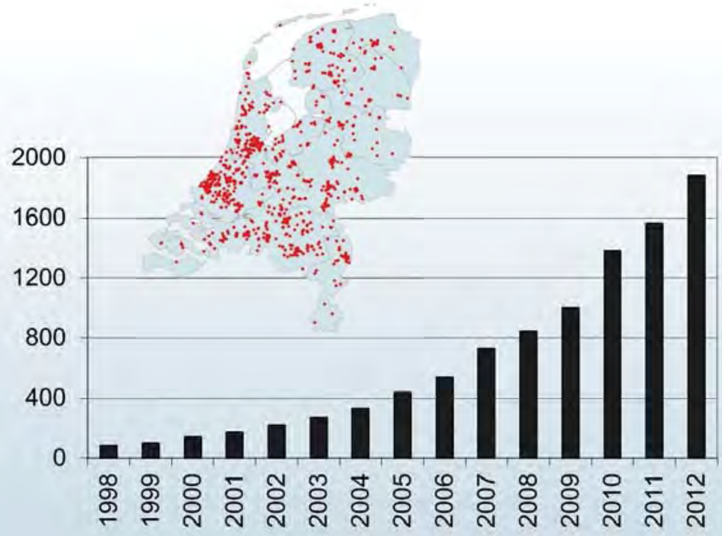


Conclusions

- Carbonates are main component in precipitates and scaling
- Degassing of CO2 is main cause for carbonate precipitation
- Variably these carbonate fases are Ca-rich, Fe-rich or Pb-rich
- CO2 gas pressure management is main control mechanism
- Limited CO2 (<10 bar) dosing could be viable option to minimize scaling and prevent carbonate induced injectivity issues
- “To prevent is better than to cure”, acid jobs to restore injectivity are much less effective and inefficient.

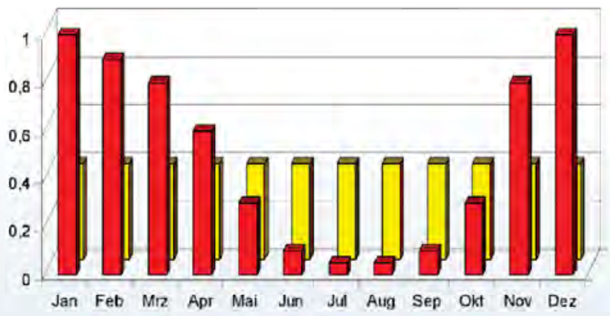
Seizoenale WKO in NL en de wereld

Storage temperatures < 25 °C

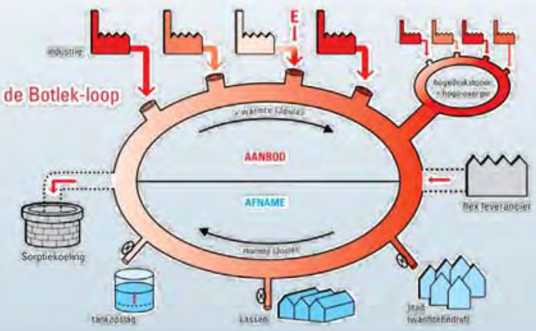


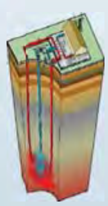
World Potential for Aquifer Thermal Energy Storage
Bloemendal et al (2015).
Science of The Total Environment, 538: 621-633.

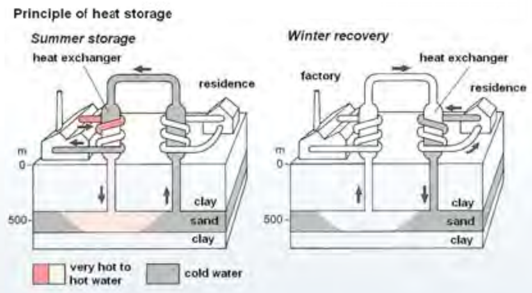
Temporele mismatch tussen aanbod (constant) en vraag (variabel)



Seibt and Kabuz (2007)



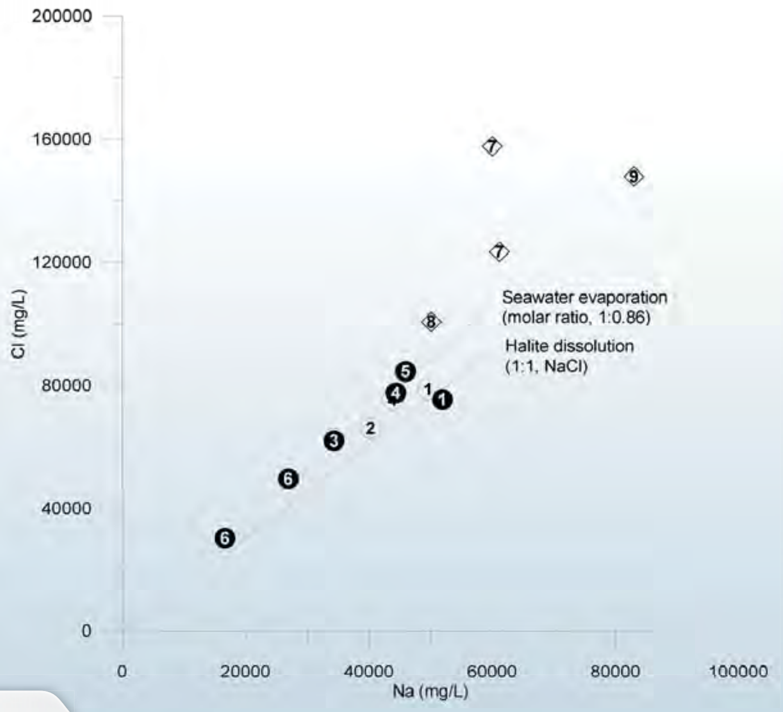




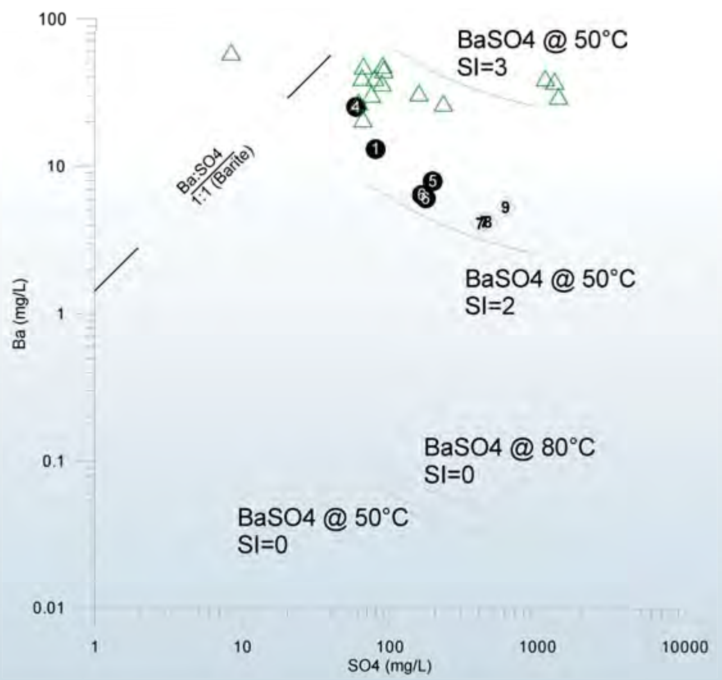
Hoge Temperatuur Opslag faciliteert:

- Tijdelijke Warmte **Opslag**→ optimalisatie
- Warmte **Voorraad** → Back-up faciliteit

Salinity, Sodium-Chloride

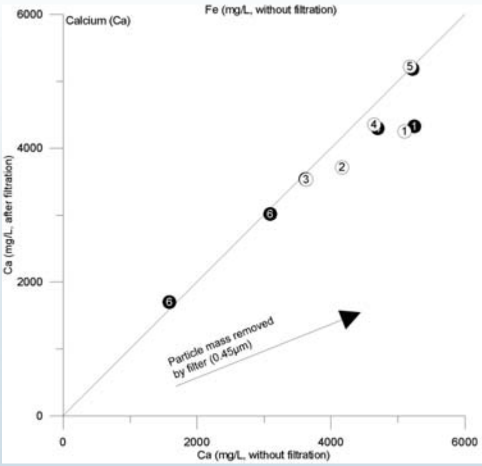


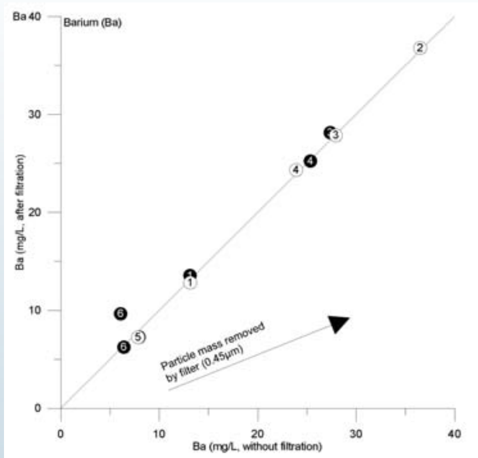
Barite supersaturation



Filtration: Dissolved vs. particulate?

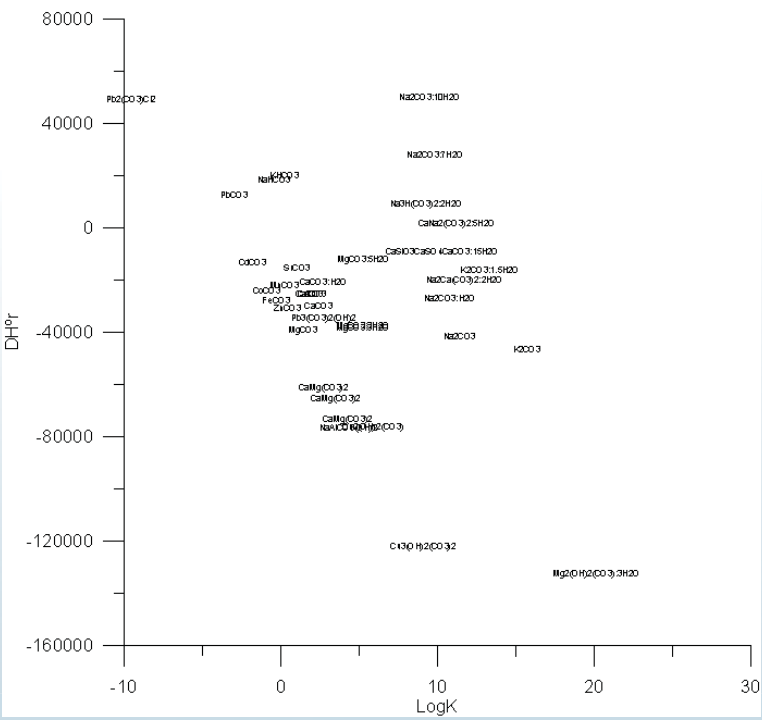
Exclusion size: 0,45 µm





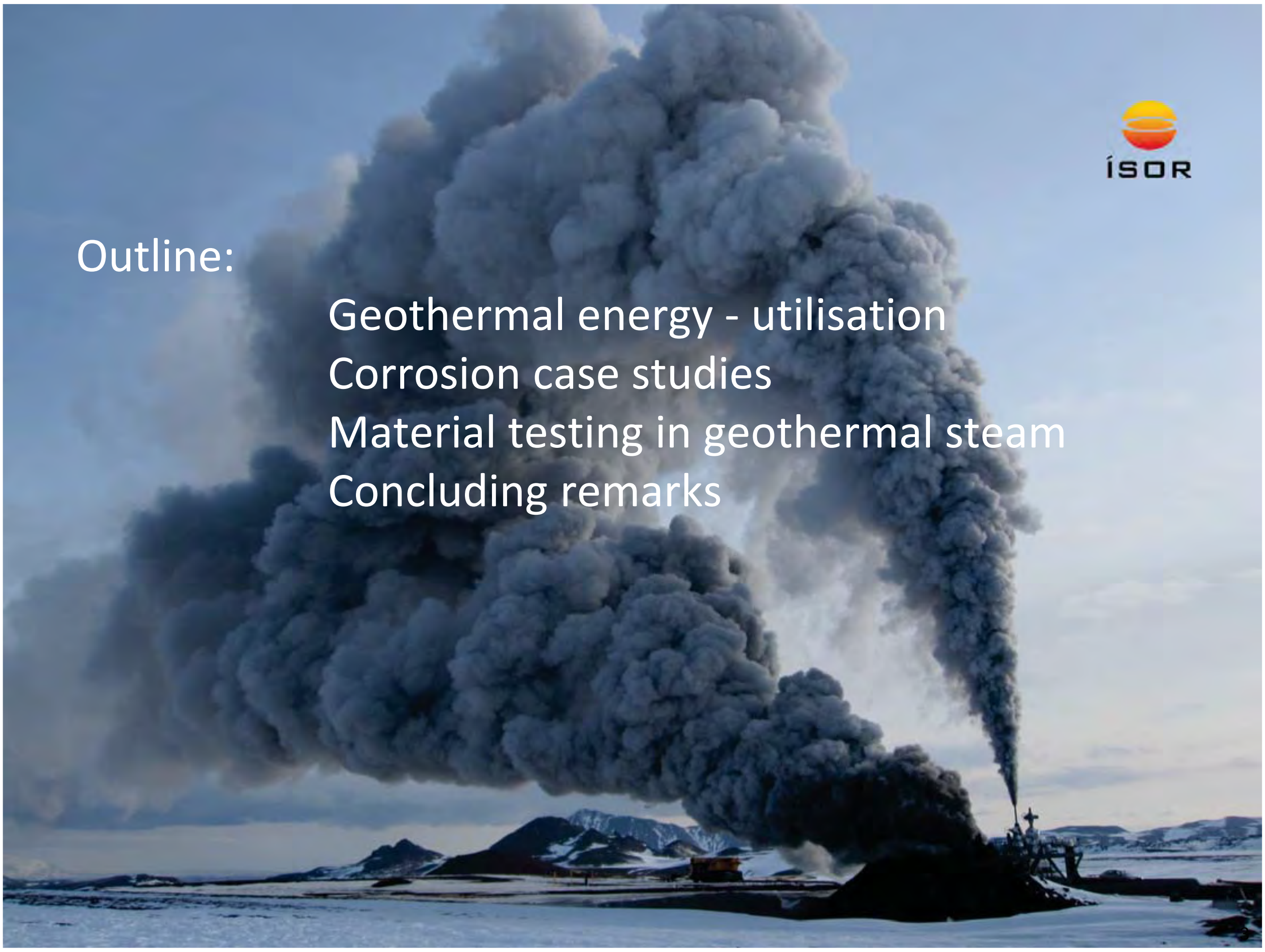
Carbonate thermodynamic characteristics

Database Thermodem (BRGM)



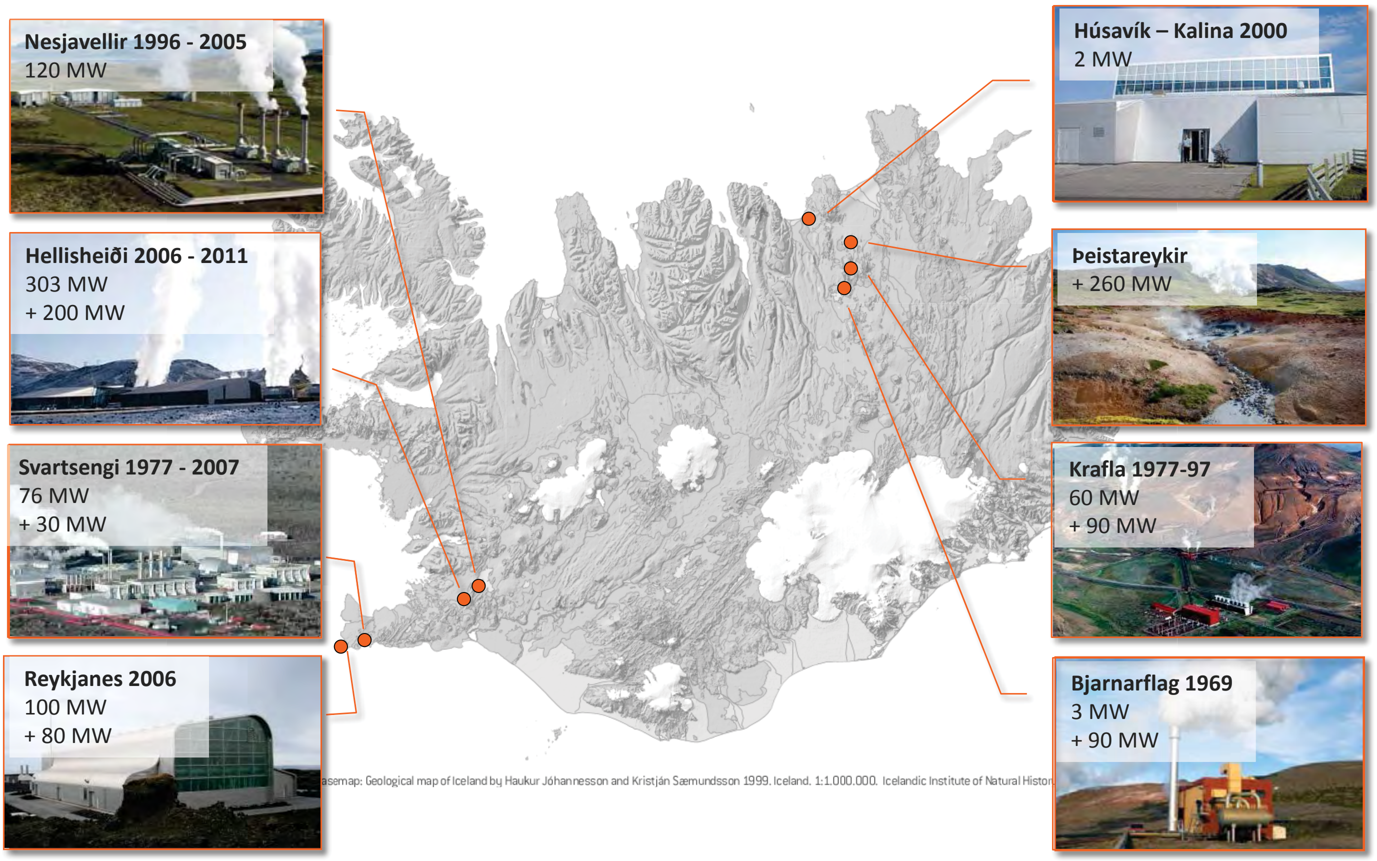

ÍSOR
ÍSOR – Iceland GeoSurvey
Ingolfur Thorbjornsson
Head of Geothermal Engineering
Sigrún Nanna Karlsdóttir
Associate Professor, University of Iceland


ÍSOR
Materials for high temperature geothermal utilisation
opERA workshop 2015.



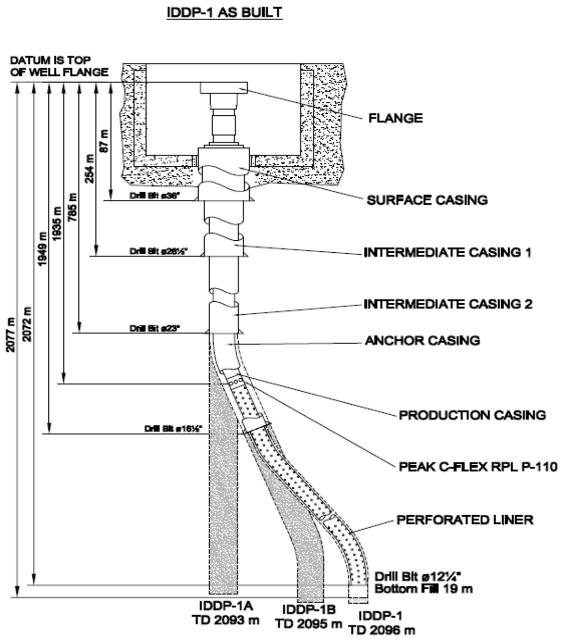
Activities in Iceland

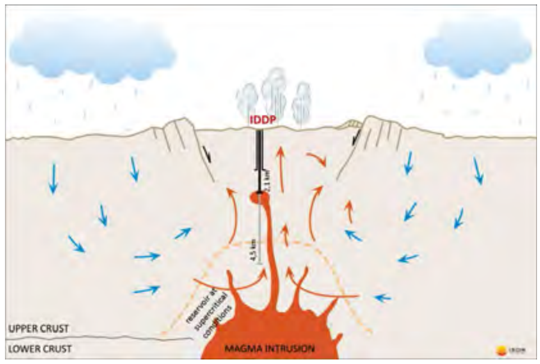
Exploration, drilling consultancy, resource assessment and management



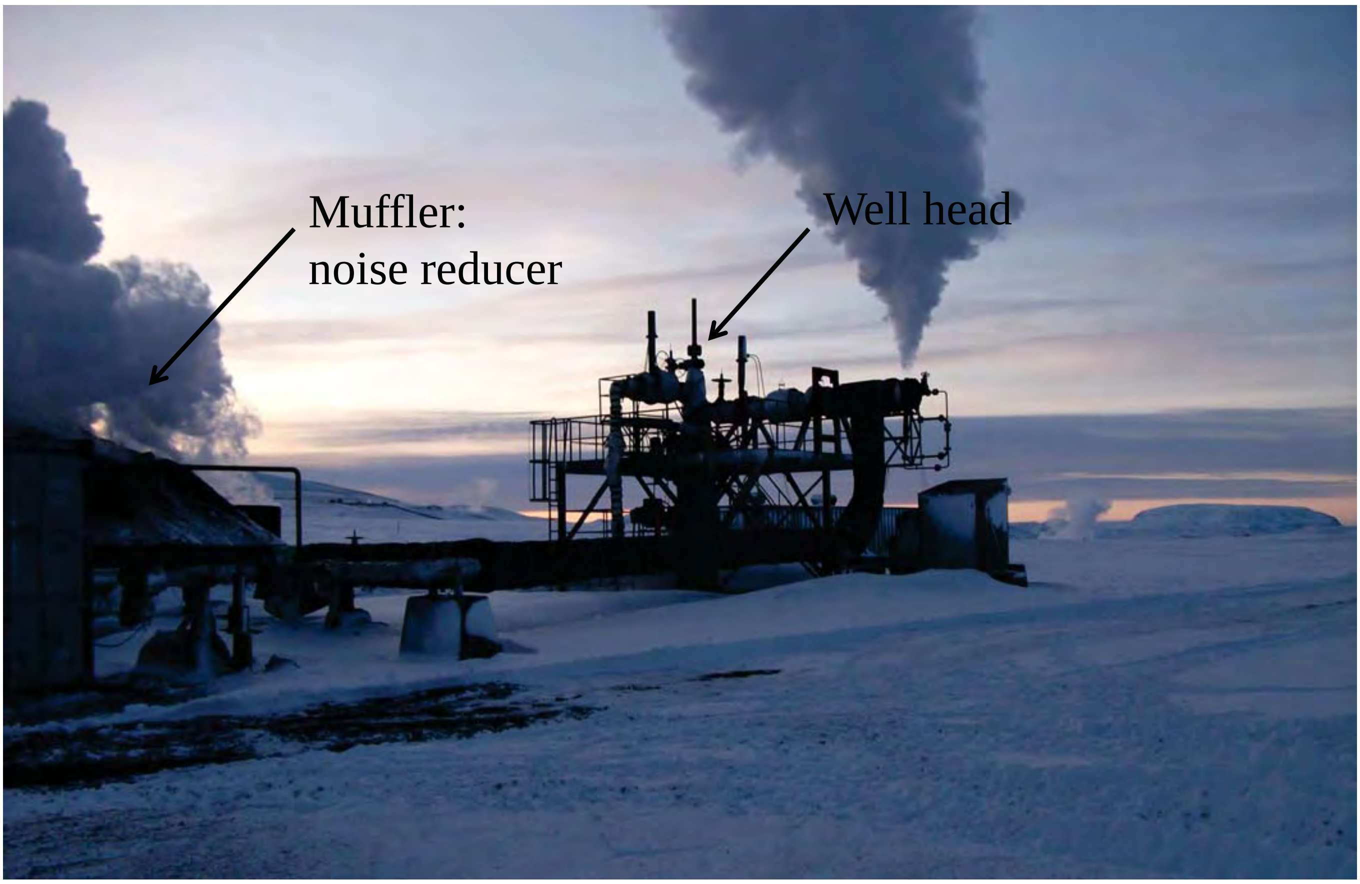
Case Study - The IDDP-1 well

- IDDP-1 well is situated in the Krafla area in NA Iceland
- Planned for depth of 3.5-4.5 km into supercritical conditions
    - Intersected magma at 2.1 km
- ***450°C*** and ***140 bar at wellhead*** with 12 kg/s of superheated steam
- Contains HCl and HF
- Condensate very corrosive (pH 2.6-3.5)
    - CO_2: 732 mg/kg, H_2S: 339 mg/kg, H_2: 10 mg/kg, Cl: 93 mg/kg and F: 5.0 mg/kg
    - Also dissolved silica and silica particles





The IDDP-1 well



Corrosion in well head components

ÍSOR

8HM10048

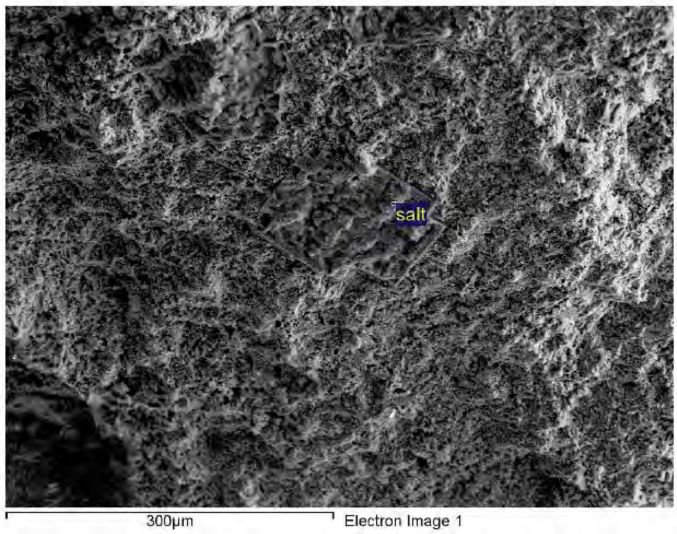
19.8.2010 18:33:31

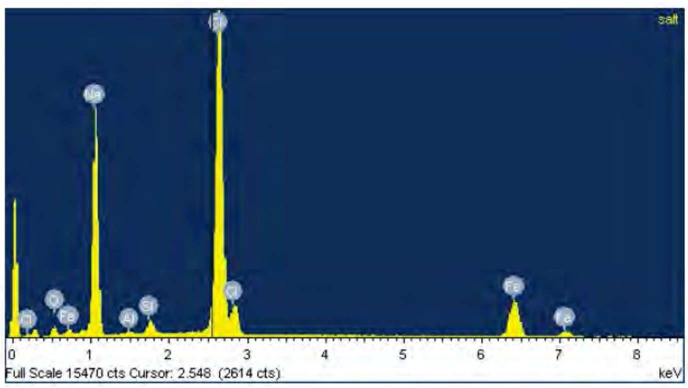
Spectrum processing :
No peaks omitted

Processing option : All elements analyzed
Number of iterations = 3

Standard :
O SiO2 1-jún-1999 12:00 AM
Na Albite 1-jún-1999 12:00 AM
Al Al2O3 1-jún-1999 12:00 AM
Si SiO2 1-jún-1999 12:00 AM
Cl KCl 1-jún-1999 12:00 AM
Fe Fe 1-jún-1999 12:00 AM

Element	Weight%	Atomic%
O K	5.14	10.54
Na K	30.32	43.26
Al K	0.19	0.24
Si K	1.35	1.58
Cl K	38.70	35.80
Fe K	14.62	8.59
Totals	90.32	





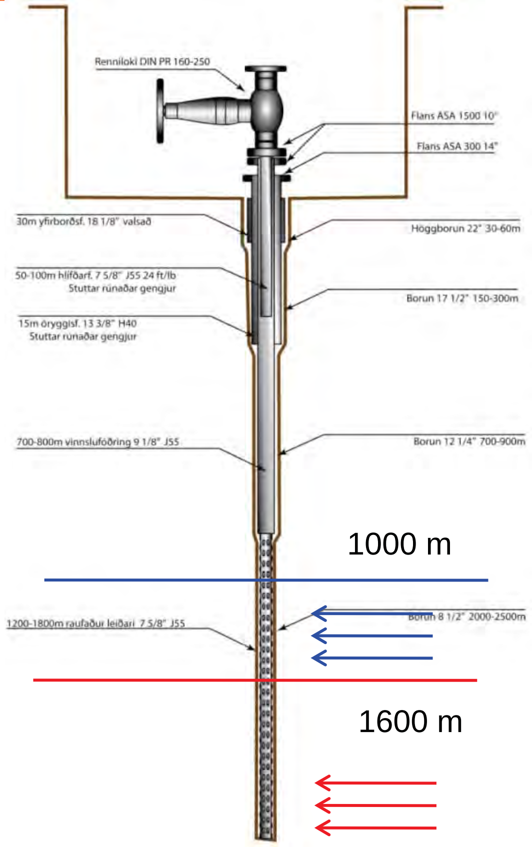
Project: 8HM10048
Owner: jonmatt
Site: Site of Interest 2

Sample: Útfelling við gat Svört
Type: Default
ID:

Case study: Krafla – Well KJ-39 - 2009

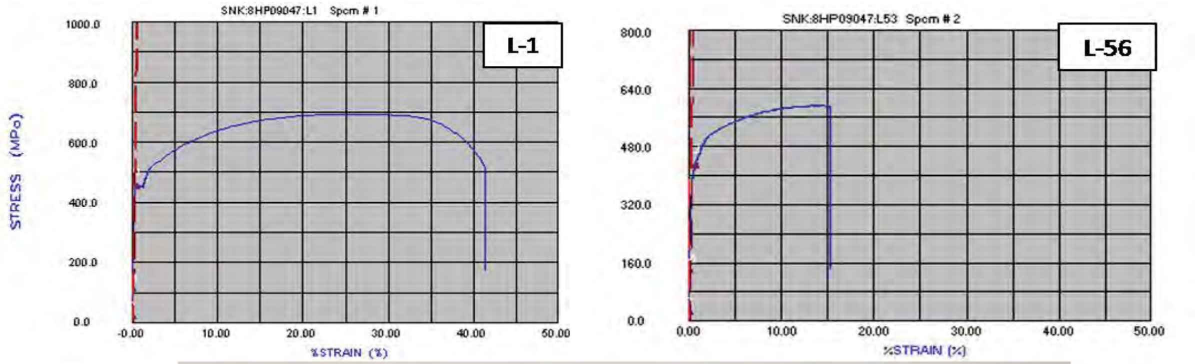
- Pieces from the slotted liner came up during cleaning of the well.

  Material: Steel K-55.
- Measurements indicated two fluid types in the well, an upper system at 1100-1600 m and a lower system at >1600 m.
- Lower system: Superheated dry steam (T>300°C) containing HCl, H_2S og CO_2.
- Upper system: Wet steam at a lower temperature (T≈260°).



The liner was removed from the well after approx. 1,5 months operation.
The last unit obtained was L56 at approx. 1600 m.

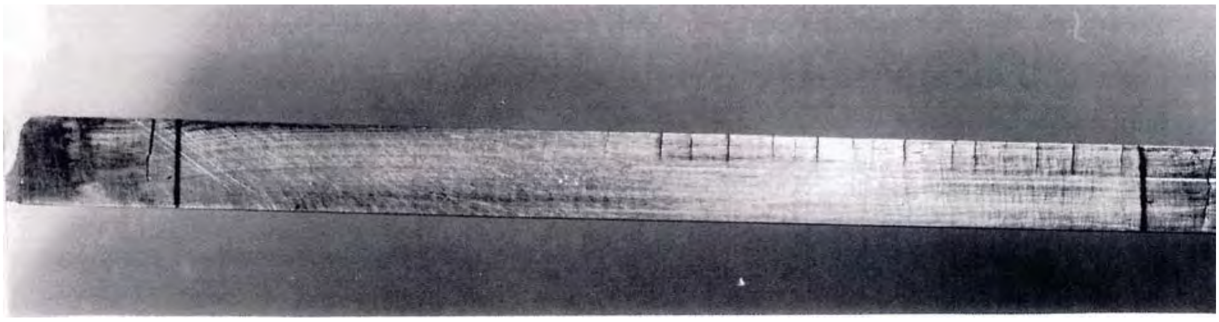
Tensile testing showed decreased ductility of the well liner (K-55) down the well.



L-1	First liner unit. Unaffected steel
L-53/56	Maximum exposure to sulfide corrosion

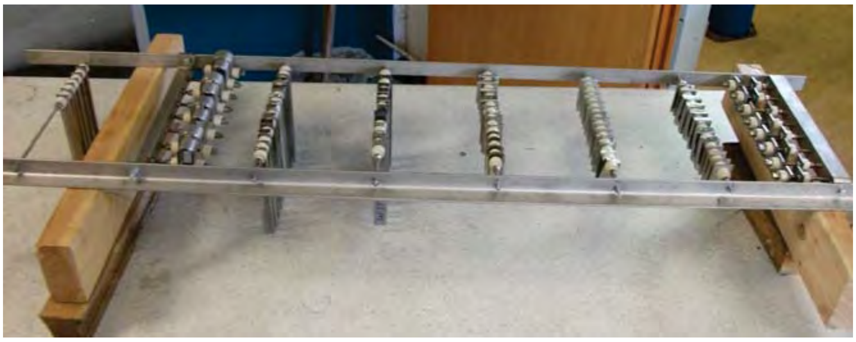
Hydrogen affected brittleness.

Mechanical testing of J-55 wellheads after use at Nesjavellir and Reykjanes, Iceland.



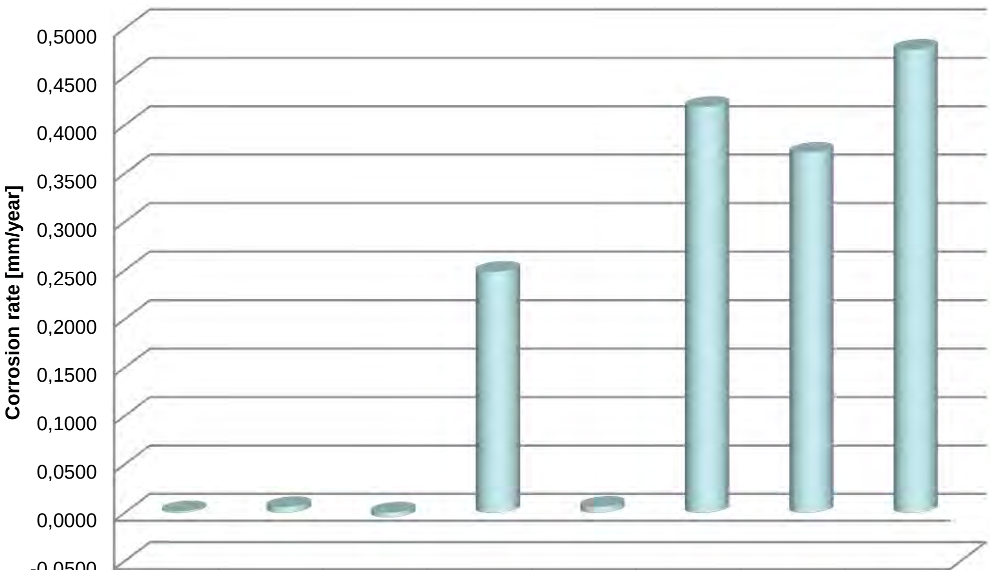
Transverse cracking of a tensile test piece from the Nesjavellir wellhead. The crack formation indicates that the steel is affected by hydrogen.

Extensive corrosion test on selected materials.



Corrosion rate from IDDP- 1

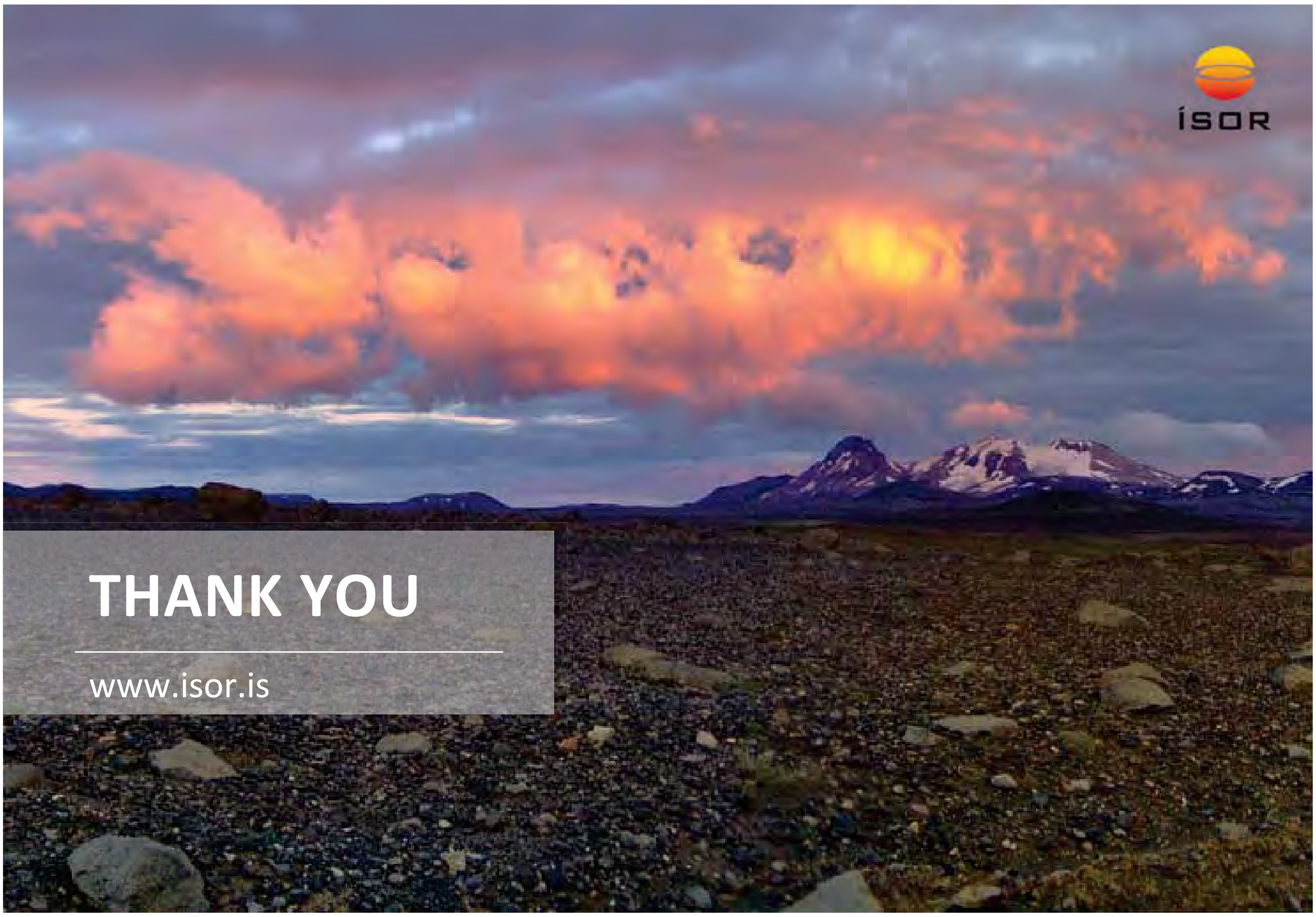
Corrosion rate: IDDP-1



	SAF 2507	254SMO	SM2550	13Cr	316L	K55	TN95	S235
mm/year	0,0014	0,0056	-0,0045	0,2482	0,0059	0,4186	0,3713	0,4777

– Concluding remarks.

- Liner and casing materials K55 and L 80 has been used for long time in Icelandic geothermal wells.
- K55 and L 80 has shown to last in Icelandic non-acidic geothermal wells.
- Material problems occur in acidic conditions although it is not problem free in non-acidic conditions.
- Materials with higher alloying content, Nickel alloys, Titanium, High Austenitic and Duplex stainless steels have been extensively tested.
- Proper material choice has to take into consideration the geotermal conditions, economic validations and type of corrosion occuring/expecting.



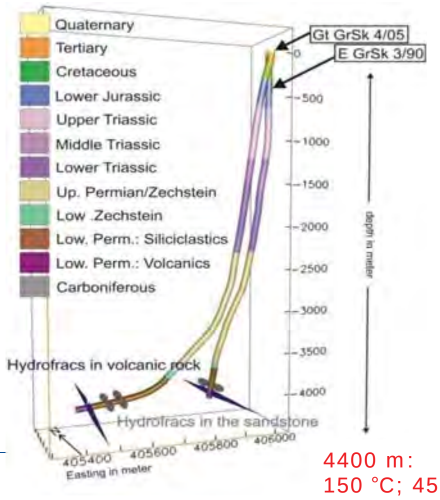
Corrosion monitoring –

Experience from the *in situ* geothermal research platform Groß Schönebeck (Germany)

Simona Regenspurg, Ali Saadat

Background: The geothermal research platform Groß Schönebeck

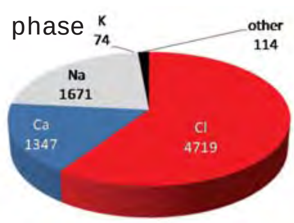
Groß Schönebeck



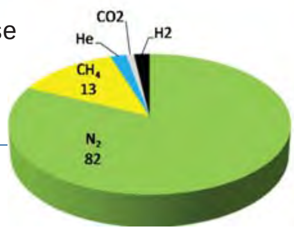
4400 m:
150 °C; 45 MPa

fluid composition:
liquid:gas ~1:1

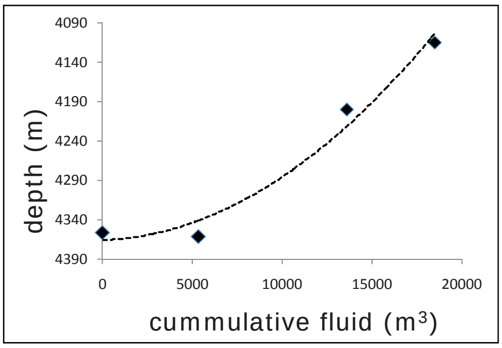
liquid phase (mM)



gas phase (vol-%)



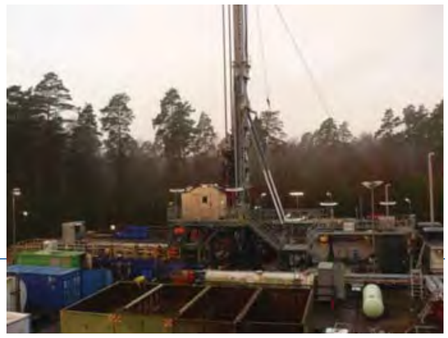
Groß Schönebeck circulation tests (2011-2013)



1. Reduced production rate and change of total depth over time.

2. Bailer sampling indicated: filling of the production well (native copper, magnetite, barite...)

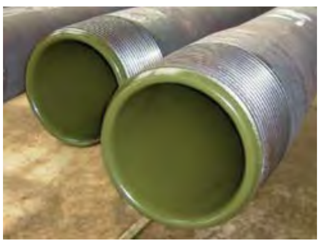
3. Two work-over operations:
   1. Coiled tubing
   2. Work-over rig



Blöcher et al., 2015; Reinsch et al., 2015; Regenspurg et al., 2015

Chemical monitoring – during and after circulation tests

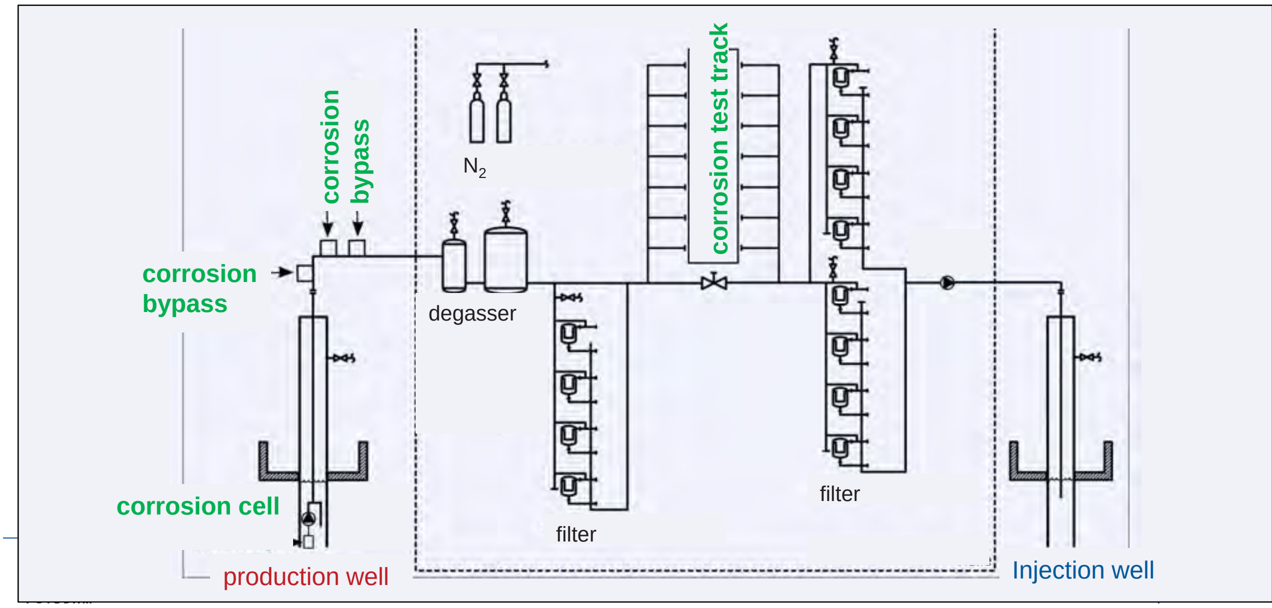
- Thermal water composition
  Feldbusch et al., 2013
- Gas composition
- Solid phase composition
- **Corrosion**



Material protection: epoxy resin

- Non-polar, electric isolating coating
- Temperature restistivity: 200 °C
- thickness: < 250 µm

Corrosion monitoring



Corrosion monitoring

1. Corrosion test track (bypass)
2. Component bypass
3. Corrosion cell (below production pump)

planned

4. Coating stability (tubing)
5. Wellbore: electrochemical corrosion

unexpected

1. Monitoring corrosion test track

S+C materials (cast and modeling treatment)

alloy	corrosion
G 45 Mo	no pitting corrosion
G 45 Mo mod.	
A59	
A 254 SMO	matted but no pitting
A625	
A825	
A31	
G625	
316 L	pitting corrosion
C80L	general corrosion

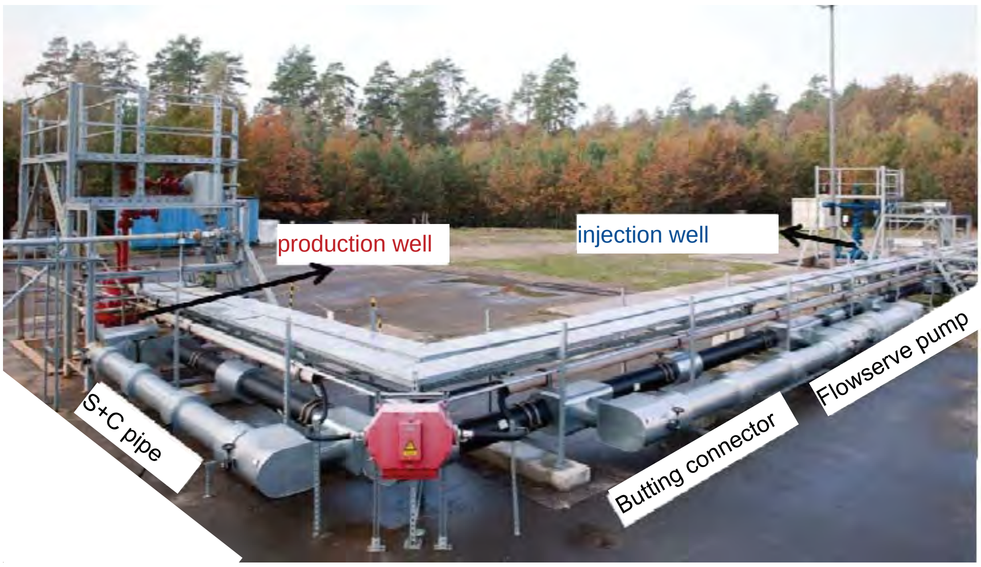
corrosion resistant

limited stable

unstable

HELMHOLTZ ASSOCIATION

2. Components (bypass)



GFZ Helmholtz Centre Potsdam

HELMHOLTZ ASSOCIATION

2. Results components (bypass)

alloy	corrosion
Duplex cast material 1.4469	No corrosion
Superduplex 1.4501	
Austenitic cast steel 1.4408	
CrNiMo steel 1.4418	
Carbon steel parts	general corrosion (< 0.2 mm/a)

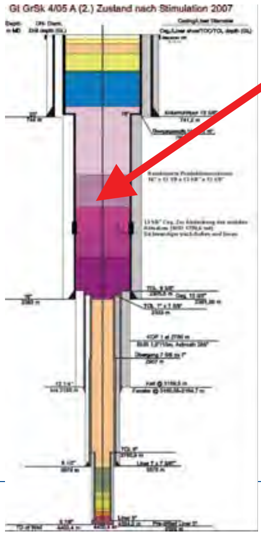
corrosion resistant

unstable

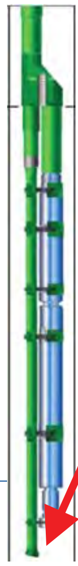
vane housing

3. Corrosion test cell below the production pump

Production well



ESP in 1200 m



Corrosion test cell

3. Results: corrosion-tests below the pump

- austenitic CrNiMo-steel A
- austenitic CrNiMo- Stahl B
- titanium gr. 12
- alloy 625
- alloy 59
- alloy 31
- alloy G45 Mo (7%)
- alloy G45 Mo (9,5%)

Example sample after 3 years exposure

→ all samples were corrosion-resistant

Unexpected corrosion reactions

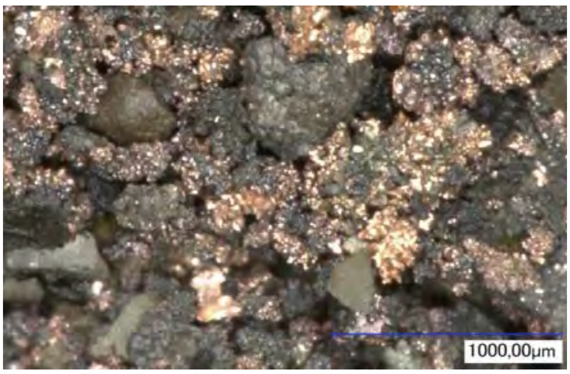
4. Coating instability: Epoxy resin

Tubing above ground: scaling *(barite),* intact coating; adherence > 20,68 Mpa

Tubing (<1200m) below ground:

some tubes: coating removal → decreasing adhesion between topcoat and primer (red) → defect of manufacturing

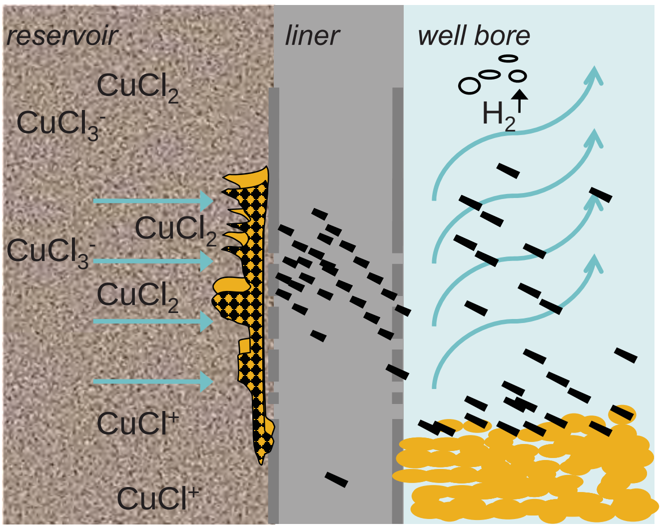
5. Electrochemical corrosion in the well bore/ liner wall



Corrosion products: High amounts of

- native copper (Cu)
- magnetite (Fe_3O_4)
- hydrogen gas (H_2)

5. Electrochemical corrosion in the well bore/ liner wall



$Cu^{2+} + 2e^- \rightarrow Cu_0$ $E_0 = 0.34\ V$

$Fe_0 \rightarrow Fe^{2+} + 2e^-$ $E_0 = -0.44\ V$

$Fe_0 + 2H_2O \rightarrow Fe(OH)_2 + H_2$

$3Fe(OH)_2 \rightarrow Fe_3O_4 + H_2O + 2H_2$

$Cu^{2+} + 3Fe_0 + 4H_2O \rightarrow Cu + Fe_3O_4 + 8H_2$

Conclusion

- Most tested materials (apart of carbon steel) proved to be corrosion resistant within the installations.
- Main risk: Electrochemical corrosion of carbon steel with dissolved Cu → possible clogging of the pores of the well-near region of the reservoir.

Outlook

Groß Schönebeck: → New production well und application of a different liner/ casing material resistant against electrochemical corrosion with Cu → Remove Cu above ground.

Thank you

- Günter Schmitt, Institut für Instandhaltung und Korrosionsschutztechnik GmbH (IFINKOR)
- Schmidt & Clemens

References

Blöcher, G., Reinsch, T., Henninges, J., Milsch, H., Regenspurg, S., Kummerow, J., Francke, H., Kranz, S., Saadat, A., Zimmermann, G., Huenges, E. (2015) Hydraulic history and current state of the deep geothermal reservoir Groß Schönebeck. Geothermics; online first.

Regenspurg, S., Feldbusch, E., Byrne, J., Deon, F., Driba, L.D., Henninges, J., Kappler, A., Naumann, R., Reinsch, T., Schubert, C. (2015) Mineral precipitation during production of geothermal fluid from a Permian Rotliegend reservoir. Geothermics 54, 122-135.

Reinsch, T., Regenspurg, S., Feldbusch, E., Saadat, A., Huenges, E., Erbas, K., Zimmermann, G., Henninges, J., Pfeil, S. (2015) Reverse clean-out in a geothermal well - Analysis of a failed coiled tubing operation. SPE Production & Operations.

Feldbusch, E., Regenspurg, S., Banks, J., Milsch, H., Saadat, A. (2013) Alteration of fluid properties during the initial operation of a geothermal plant: results from in situ measurements in Groß Schönebeck. Environmental Earth Sciences 70 (8), 3447-3458.

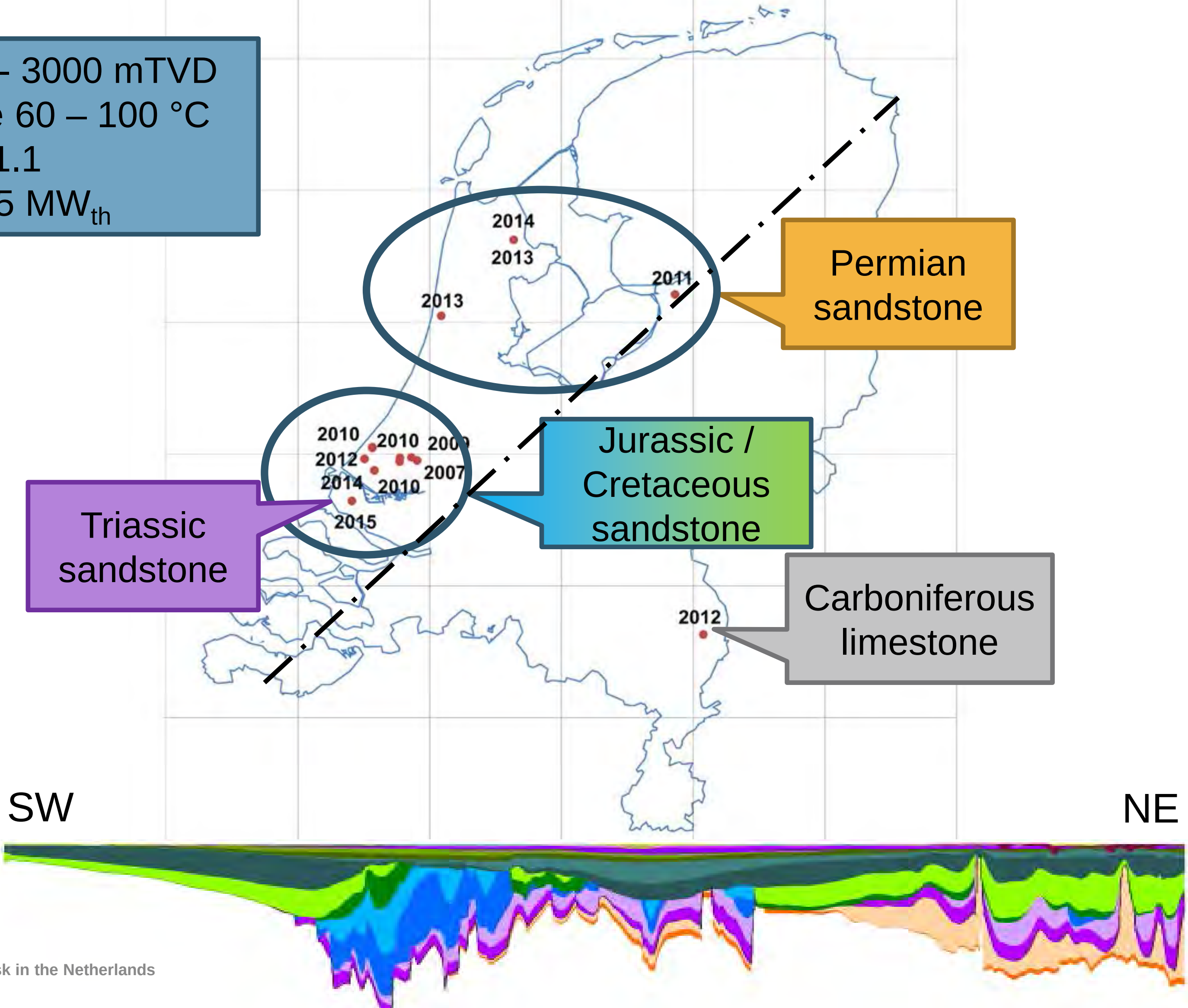
IDENTIFICATION OF CORROSION RISK IN THE NETHERLANDS

ERANET workshop October 2, 2015 | Hans Veldkamp, Tanya Goldberg, Peter Bressers, Frank Wilschut

TNO innovation for life

DOUBLETS IN THE NETHERLANDS

Depth 1600 - 3000 mTVD
Temperature 60 – 100 °C
GWR 0.3 – 1.1
Power 5 – 15 MW_{th}



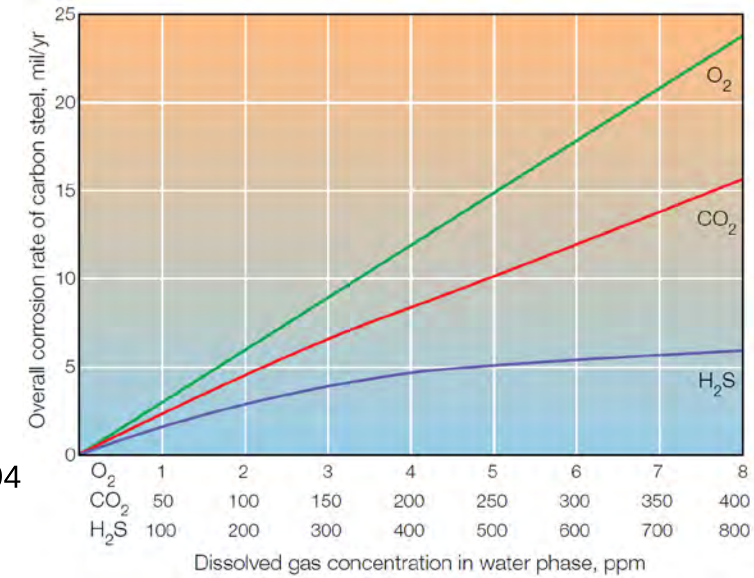
WELL INTEGRITY – QUESTIONS ASKED BY DUTCH GEOTHERMAL OPERATORS

- Can corrosion of unprotected steel be expected?

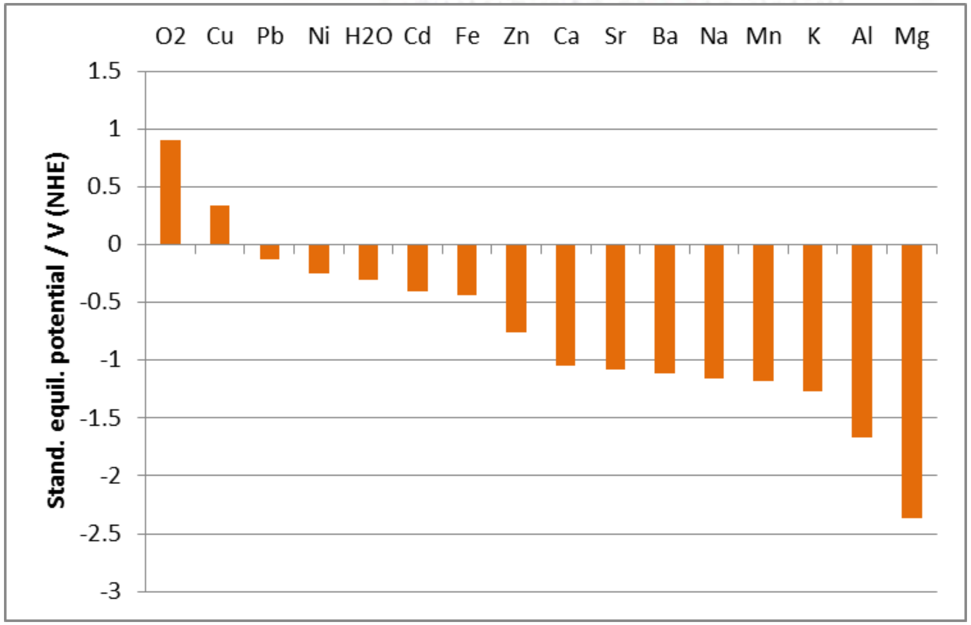
- Is it reasonable to expect that conditions exist where corrosion in geothermal wells is limited by natural protection mechanisms like oil films or iron carbonate scaling?
- At which locations in a geothermal well can the corrosion rate be expected to be relatively high and / or low?
- In which ways can the corrosion rate be lowered, either by design, or by the application of inhibitors?
- If corrosion should be expected, which monitoring techniques are available / effective / achievable / applicable?

CORROSIVE ELEMENTS

- oxygen (O_2)
- carbon dioxide (CO_2)
- hydrogen sulphide (H_2S)
- chloride (Cl^-)
- ammonia (NH_3)
- sulphate (SO_4^{2-})
- base metals (esp. Cu, Pb, Ni)

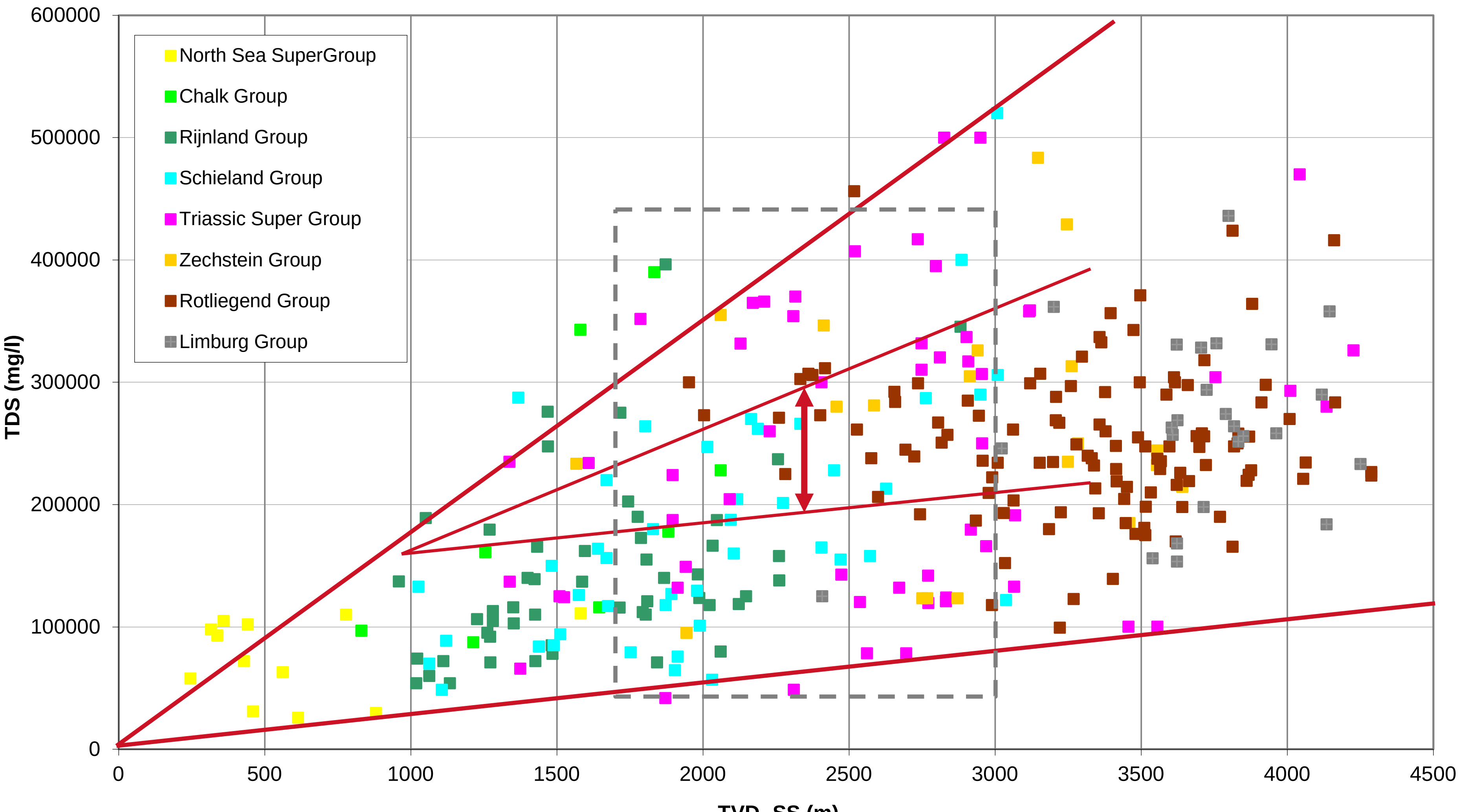


Brondel et al. 1994



Bressers et al. 2014

SALINITY



source: www.nlog.nl

	Cl				SO_4				HCO_3				Fe			
	n	min	avg	max	n	min	avg	max	n	min	avg	max	n	min	avg	max
KN/SL	24	46	63182	85000	23	54	221	2469	18	35	150	260	22	1	34	111
RO	26	86000	131669	160000	15	185	438	610	21	14	301	670	34	26	139	730
DC	1	48000	48000	48000	1	15	15	15	1	360	360	360	1	29	29	29

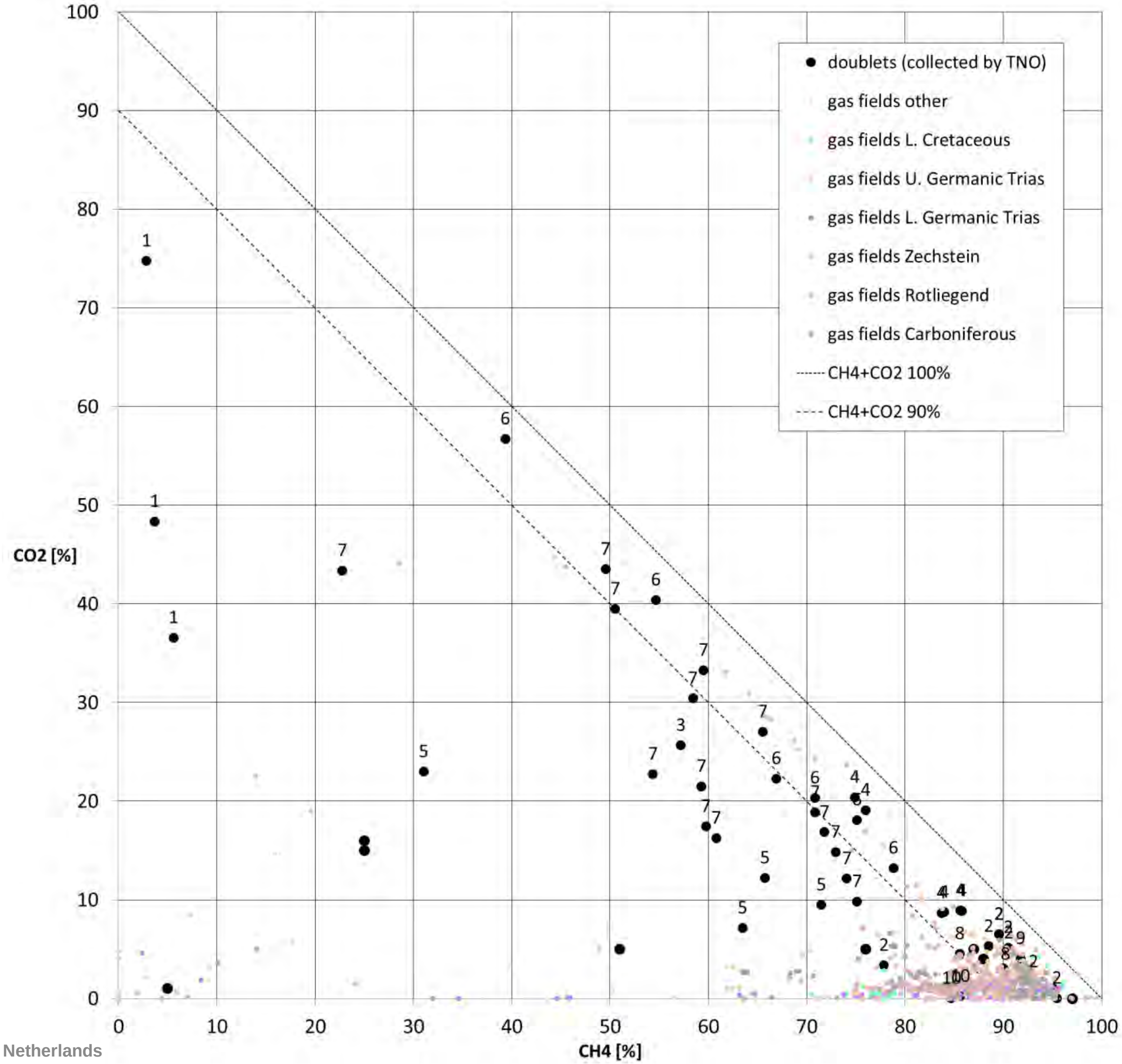
	Ca				K				Pb				Na			
	n	min	avg	max	n	min	avg	max	n	min	avg	max	n	min	avg	max
KN/SL	25	4	4849	8300	24	177	10698	92818	0	-1	-1	-1	25	41	29914	40000
RO	34	7200	9953	16600	34	650	1406	2400	1	4	4	4	34	43000	64088	87000
DC	1	3580	3580	3580	1	1600	1600	1600	0	-1	-1	-1	1	23800	23800	23800

Table 2 Minimum and maximum concentrations of some key elements and compounds in the formation water of Dutch geothermal wells. Concentrations are given in ppm.

	n	CH_4			CO_2			N_2			O_2		
		min	avg	max	min	avg	max	min	avg	max	min	avg	max
KN/SL	25	39.3	82.6	95.8	0.0	11.0	56.7	0.4	3.0	13.4	0.00	0.23	0.51
RO	12	22.8	55.9	75.1	7.2	25.4	43.5	3.0	12.5	38.6	0.07	0.09	0.12
DC	3	2.9	4.1	5.6	36.6	53.2	74.8	6.8	32.0	57.6	-	-	-

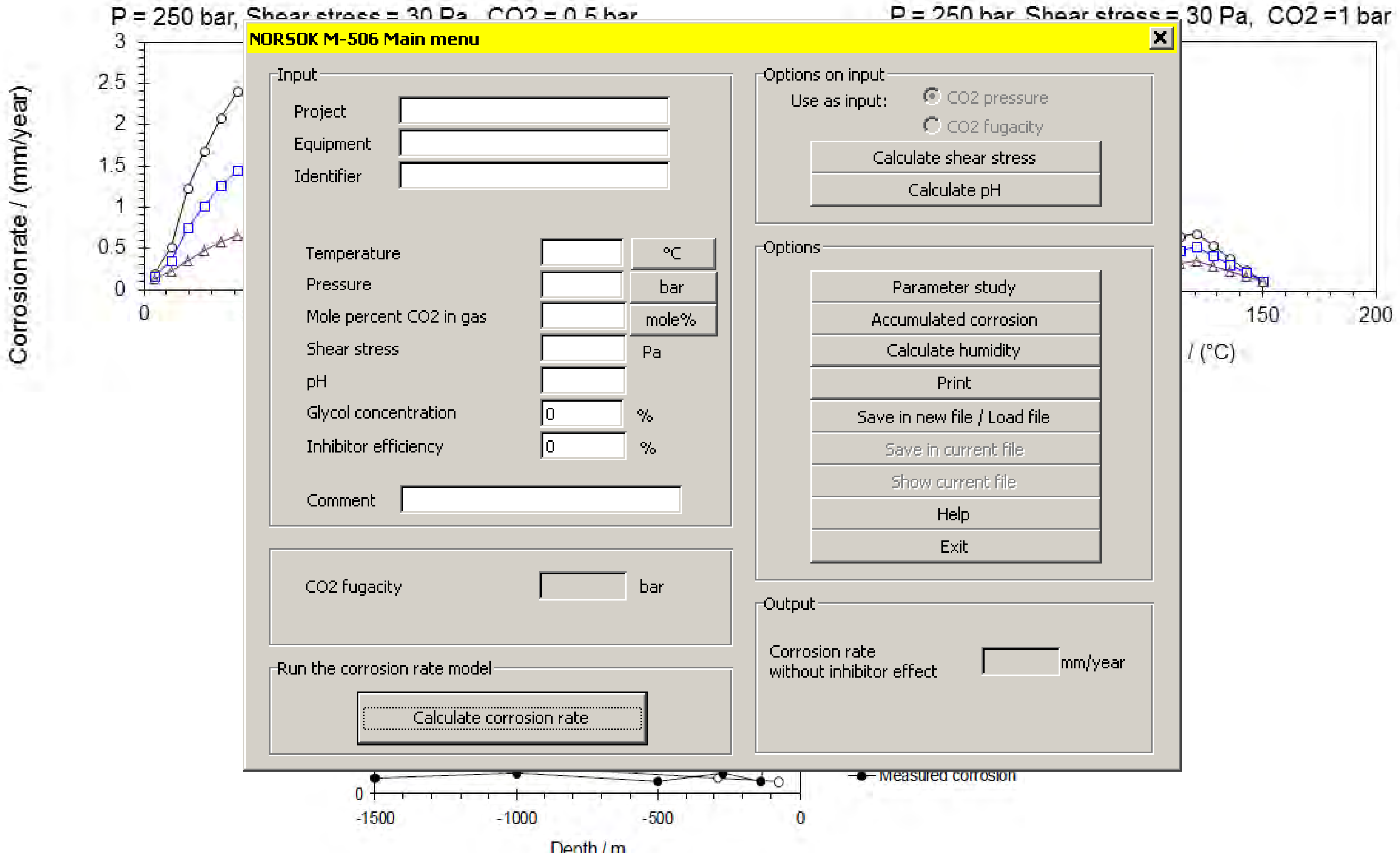
Table 3 Minimum, average and maximum concentrations of major gas components in the formation water of Dutch doublets. Concentrations are given in mole%. All available samples used.

CH_4 - CO_2 RATIOS



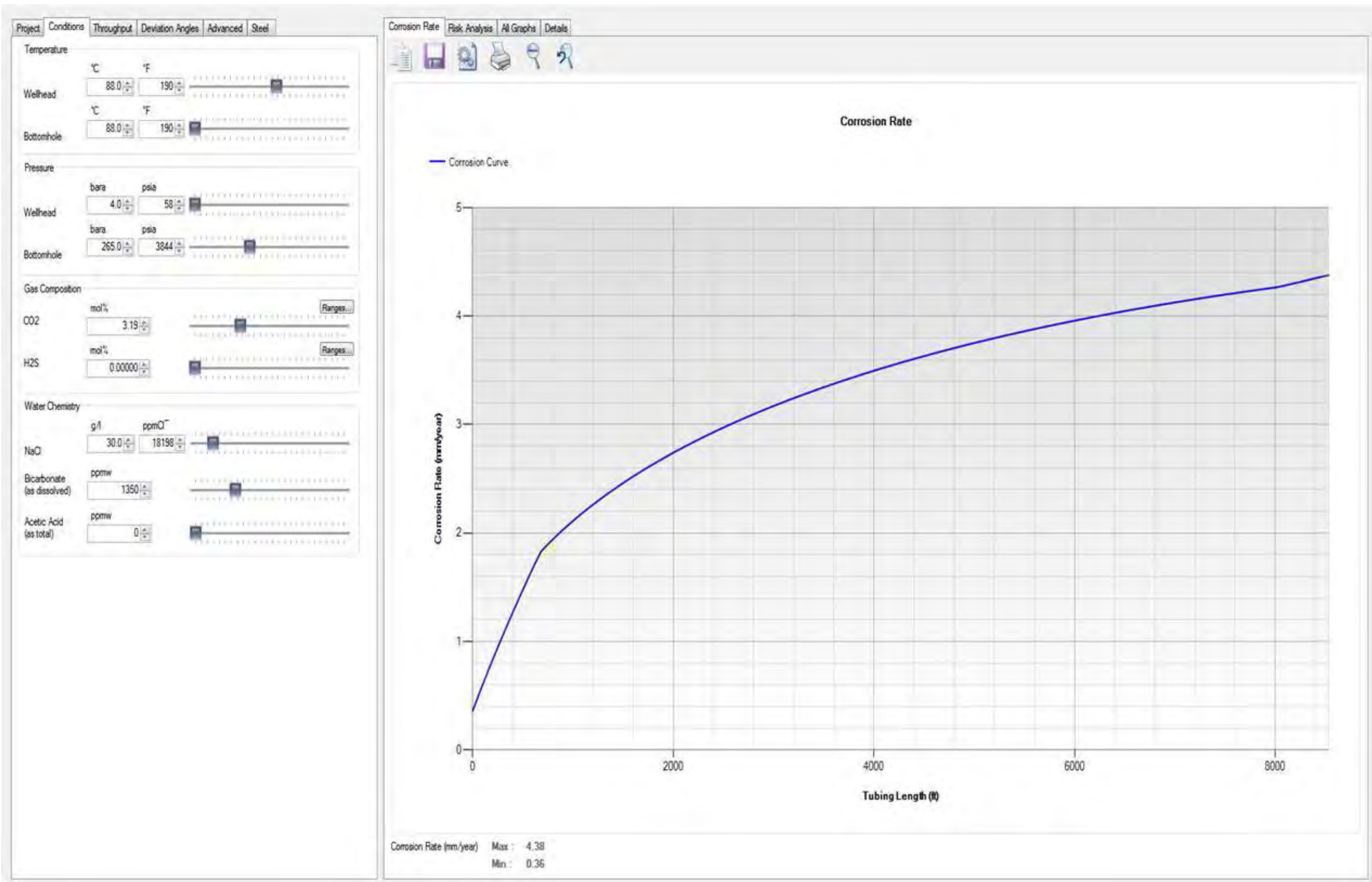
sources: www.nlog.nl,
dutch doublets

CORROSION MODELS



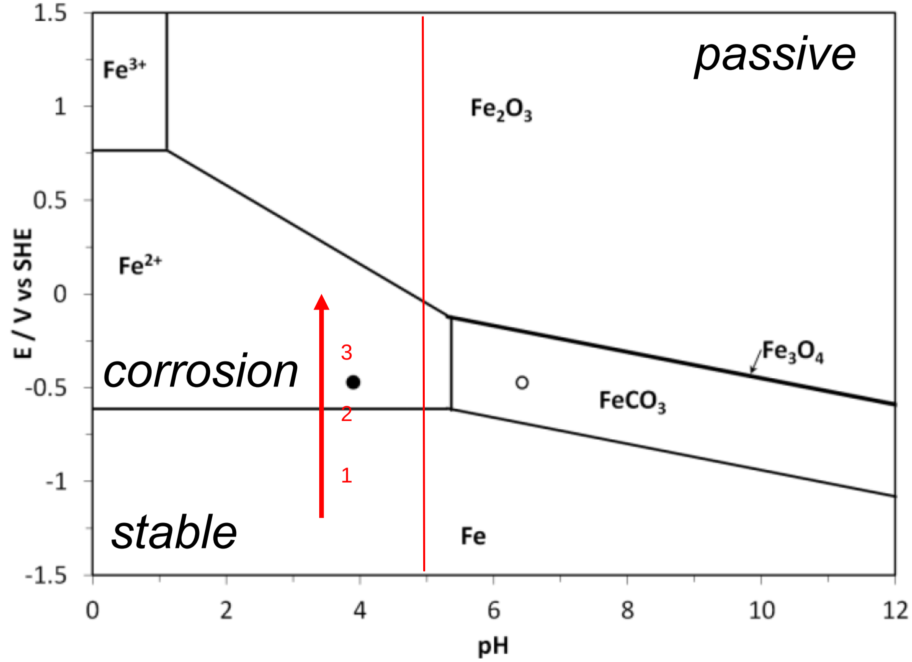
NORSOK, Olsen (2003) Nyborg (2010).

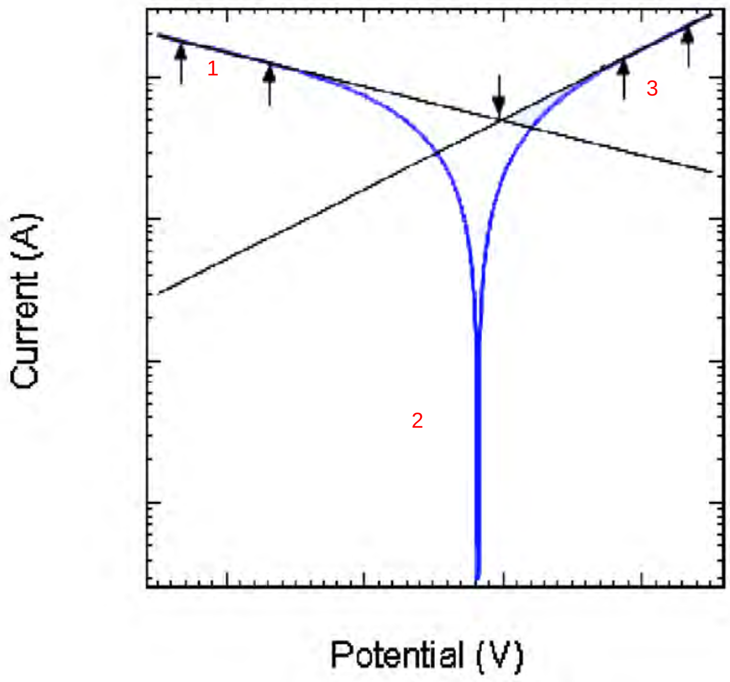
CORROSION RATE CALCULATION



source: ECE calculation by O&G consultant

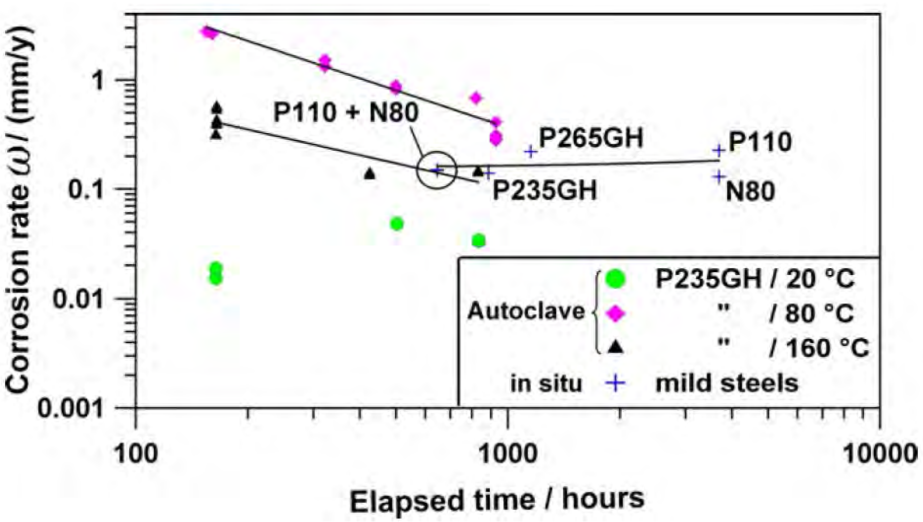
POURBAIX DIAGRAM AND TAFEL PLOTS



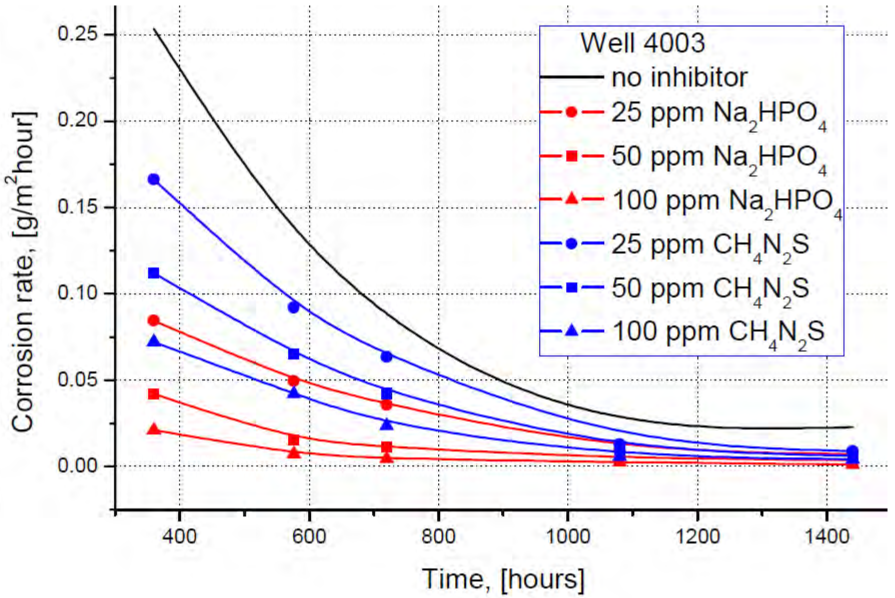


Tanupabrungsun et al. 2012

IMPORTANCE OF MONITORING



Mundhenk et al. 2013 (Soultz, mild steel, low enthalpy



Stanasel et al. 2010 (Romania, stainless steel, low enthalpy)

PRESCO: PREVENTION OF SCALING AND CORROSION

- Focus on sedimentary basins, contribution to other WP's
- Understanding scaling and corrosion
  - Salinity, heavy metals, degassing, pH, T
  - Literature, sampling, analyses
  - Geochemical database and regional trends (mapping)
- Test/improve predictive models of scaling
  - Calibration/validation with field data
  - From model to risk management
- Field testing and implementation of scaling and corrosion mitigation measures and materials (of partners) in field labs
  - Dutch sites, build on site testing facility, tests and sampling
  - Low cost early warning system (practical monitoring)

CONCLUSIONS

- Likely risk of CO_2 corrosion

- Need for good, reliable data
- Need for proper monitoring program

Following steps will be

- Understanding the actual cause of corrosion (it may not necessarily all be due to CO_2)
- Correct mitigation of the corrosion

‘[This futfeeder] is quite simple’, said the old man, ‘you just connect the hose to the gnom and you stick it into the ground. Then the zapl will come out by itself and make the wheel go round. Very handy, an ever turning wheel. You can do a lot with it, like, pumping water from a well, and, I don’t know what all’

Marten Toonder (1963) The Top Bosses

THANK YOU FOR YOUR ATTENTION

TNO innovation for life

Floricultura Geothermal Project

Injectivity of gas containing medium in a closed loop geothermal system

Floricultura

- Specialist in breeding, selection and propagation of orchids
- Global market leader in orchid propagation material
- Offices in Netherlands, India, USA and Brazil
- Around 1000 employees (550 in Heemskerk)

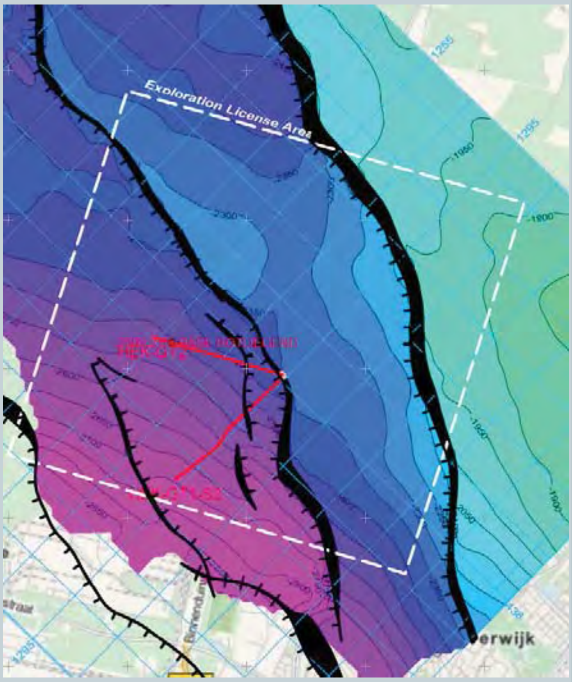
Project location

Objective

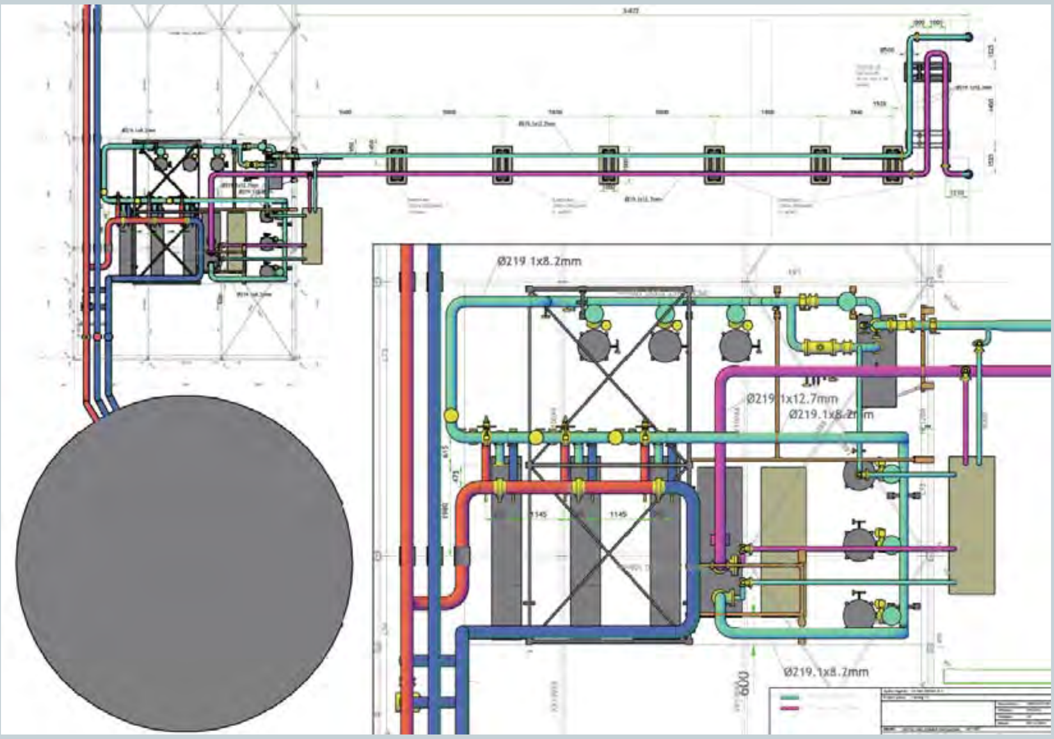
- Stable heating costs
- Annually avoiding the use of 5 million m3 of gas
- Locally decreasing the CO_2-emission with 9000 tons

Well

- Production well 2728 meters TVD
- Injection well 2599 meters TVD
- Reservoir thickness 200 meters
- Water and gas
- 7 inch no screens Injection well



Lay-out system



Geothermal heating system

Capacity

- About 100 m3/h with 99 degrees Celsius
- Injection temperature about 40 degrees
- Heating capacity of the water
- Current demand 7,1 hectare from -10 to 28 degrees Celsius

Injectivity

- No degassing
- Temperature effect on flow versus pressure
- Tubing injection well
- Bubble point versus injection pressure
- Back pressure gas injection well versus water flow

In operation

Geothermal ERA-NET

OpERA

Operational Issues
of Geothermal Energy Installations in Europe

Expert Workshop
1 + 2 October 2015
Vaals (NL/D)

Rock mechanical and formation damage aspects of reinjection into Upper-Pannonian sandstones

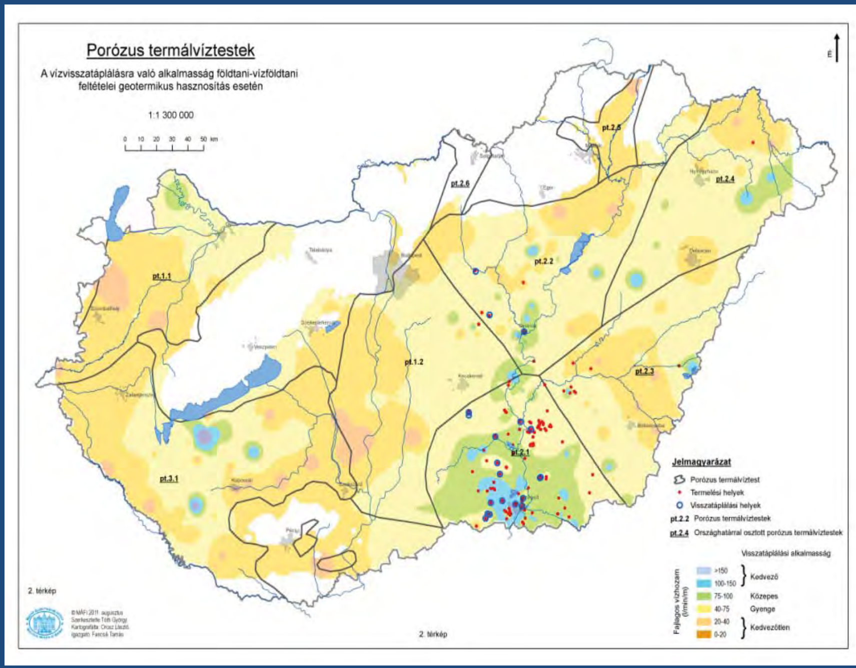
Miklós Hlatki

Contents

- Characteristics of Upper-Pannonian thermal aquifers and sandstones
- Basic reinjection mechanisms
- Pore pressure influence on fracturing pressure in normal fault stress regime
- Effect of temperature on fracturing pressure
- Reasons of failure in the injection tests/projects in Upper-Pannonian sandstones
- WellTech projects
- Summary

Upper-Pannonian thermal aquifers

- Upper-Pannonian thermal aquifers are the main source of geothermal energy production in Hungary
- Max. formation temperature is 130-150 ^{0}C
- ~200 production and 20 injection wells are in operation for direct use



Upper-Pannonian thermal aquifers

J. Szanyi, B. Kovács / Geothermics 39 (2010) 357–364 363

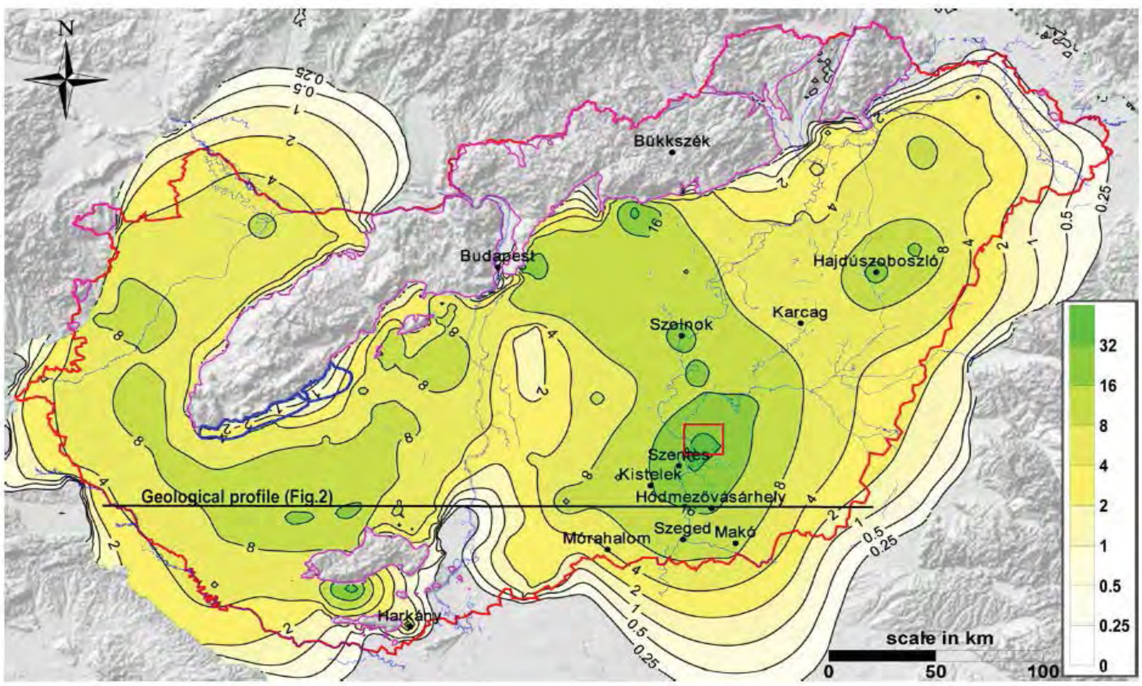


Fig. 7. The calculated drawdown (meters) at the bottom of the Upper Pannonian sequences (Tóth, 2009). Also shown is the location of the geothermal sites discussed in the paper and geological profile of Fig. 2.

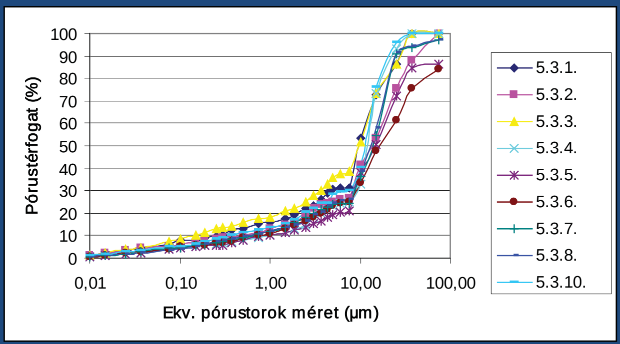
Significant formation pressure decrease is observed in several UP aquifers – Szanyi-Kovács. „Utilization of Geothermal Systems in South-East Hungary" Geothermics, 39 (2010) 357-364.

Characteristics of Upper-Pannonian sandstones

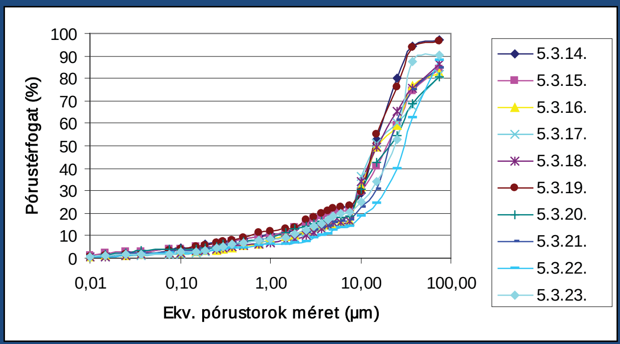
- UP sandstones are heterogeneous, of low strength, often unconsolidated, poorly sorted, and have relatively high clay content. Due to these features, reinjection into UP sandstones can be difficult.
- Reinjection is a problem in soft, or unconsolidated sandstones all over the world. It is not a Hungarian problem, e.g. Gulf Coast, offshore Italy, etc. /E.g. SPE 60901, SPE 64297 /

Pore structure of Upper-Pannonian sandstones

Poorly cemented samples



Unconsolidated samples



Complexity of reinjection into soft, unconsolidated sandstones

To study and to solve the reinjection difficulties the following disciplines/aspects are necessary to take into consideration:

- ***Hydrogeology/Reservoir geology: reservoir characterization, hydraulic connectivity between production and injection wells.***
- ***Rock mechanics: TIF, wellbore stability/sand production, sandstone/gravel pack/fluid flow interactions***
- ***Petrophysics: formation damage characterization, prevention and removal***
- ***Water chemistry: thermal water/brine analysis/content, precipitation/scale characterization and inhibition***
- ***Well completion engineering: proper and high quality well completion, gravel packing or frac packing, stimulation of formation damage***
- ***Process engineering and operation: proper surface technology design, diagnostics…***

Basic reinjection mechanisms

- **Matrix injection: severe injectivity declines have been observed. /e.g. SPE 60901/ Matrix injection is possible, but it is proven by field and laboratory experiences that matrix reinjection is a formation damage sensitive process. Formation damage – permeability decrease - can be arisen due to external and internal filtering, fines migration, scaling, precipitations, clay swelling, clay deflocculation, microbial metabolites: polimers, etc. /Pet. Soc. of CIM, Paper No 94-60/**
- **Fracture injection. /Temperature Induced Fracturing, TIF/ /E.g. SPE 20898, SPE 108238/ Long term sustainable injection option. Heterogeneity has large impact on TIF, and on injectivity. /SPE 112944/**

Pore pressure influence on fracturing pressure in normal fault stress regime

(Valkó-Economides, 1997; Zoback, 2007.)

$$S_{hmin} = \frac{\nu}{1-\nu}\left(S_v - \alpha P_p\right) + \alpha P_p$$

$$\Delta S_{hmin} = \left(\alpha - \frac{\alpha\nu}{1-\nu}\right)\Delta P$$

$$P_b = 3S_{hmin} - S_{Hmax} - P_p + T_0$$

Effect of temperature on fracturing pressure

/TIF coefficient, thermal stress coefficient/

SPE 10080 (Perkins-Gonzalez, 1981)

In case of a short injecton period, the radius of the cooled zone is small with respect to its height:

$A_T = \alpha_T * E / 2*(1-v)$

In case of a long term injection, the radius of the cooled zone is very large

$A_T = \alpha_T * E / (1-v)$

SPE 112944 (Santarelli et al., 2008)

E ≥ 10 GPa - Perkins-Gonzalez

E ~ 5 GPa - A_T = 3 bar/⁰C

E ≤ 2 Gpa - *A_T < 3 bar/⁰C*

Reasons of failure in the injection tests/projects in Upper-Pannonian sandstones

Unsuccessfull reinjection tests, projects: *Szarvas, Szeged-Felsőváros, Algyő, Orosháza*

- Sand production of the injection wells was the main problem /wellbore instability, collapse/
- Inadequate well completions and well completion technology /lack of gravel pack, completion fluid damages, etc./
- Unfavorable rock mechanical and petrophysical parameters of UP sandstones
- Incomplete and poor ducumentation

WellTech-I project

Objectives of the project:

- Development and testing of a laboratory device suitable for long term formation damage and gravel pack selection measurements.
- Development and testing of a dynamic fracture conductivity measurement instrument for frac packing investigations.

Project leader: Mecsekérc
www.mecsekerc.hu

WellTech-2 project

Objective of the project phase-II:

To develop low cost well completion technologies /gravel packing and frac packing/ for the long term sustainable geothermal energy utilization from Upper-Pannonian sandstone aquifers

WellTech-2 project

- Formation damage measurements: investigations on damage mechanisms and the effects of different damages on matrix injection in UP sandstones, particularly of fines migration; to determine the effect of different water content/different water filtering, static and dynamic precipitation/scaling tests, etc.

- Gravel packing measurements: to determine the best gravel size design method for UP sandstones, testing cheaper well completion fluids additives/components, etc.

- Dynamic fracture conductivity measurements: long term testing of frac & pack completion technology, testing low cost frac fluid additives, etc.

Summary

- Reinjection into decreased pressure formations is a good injection strategy in Upper-Pannonian sandstones

- It is necessary to determine the temperature influence on fracturing pressure in Upper-Pannonian sandstones

- Low cost and long term reliable well completion technology is one of the key elements of sustainable reinjection into Upper-Pannonian sandstones

- It is essentially important to establish a reinjection database, which contains all relevant information and data in detail on reinjection projects and processes

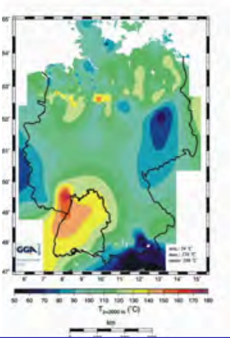
Fluid Injection Induced Seismicity at Insheim Geothermal Site (Palatinate/Germany)

Dr. L. Küperkoch, **M. Schindler**

Geothermal ERA-NET - OpERA Workshop, Vaals, 1. & 2.10.2015

Location and Background

"Südpfalz", Rhineland-Palatinate

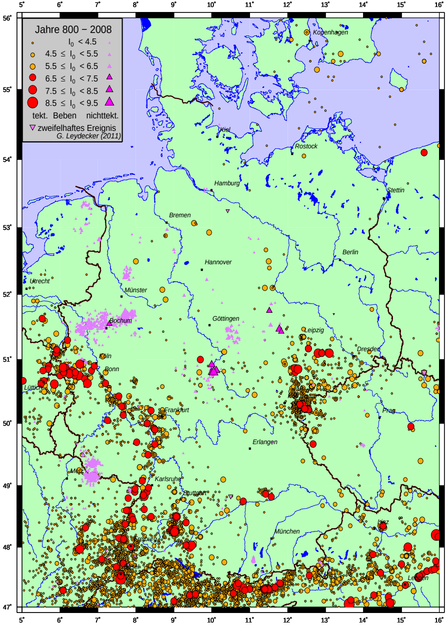


Insheim Power Plant

Insheim Power Plant

- Startup: October 2012
- Geothermal water temperature: $> 160^o C$
- Flow rate: $40 - 85 l/s$
- Power:
  - electrical: $\approx 4.8\ MW$
  - thermal: $\approx 6\ MW$
- 2 wells: 1 production & 1 injection well with multilateral completion to reduce microseismicity

Seismicity: Natural events

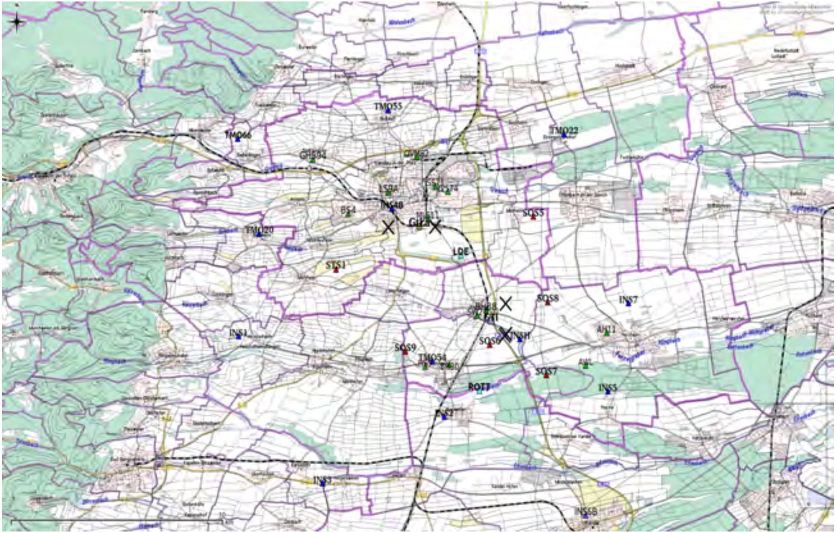


Map of earthquake epicenters in Germany and adjacent areas for the period from AD 800 to 2008 (Leydecker, 2011).

Upper Rhine Valley:
EQ zone I (DIN4149).

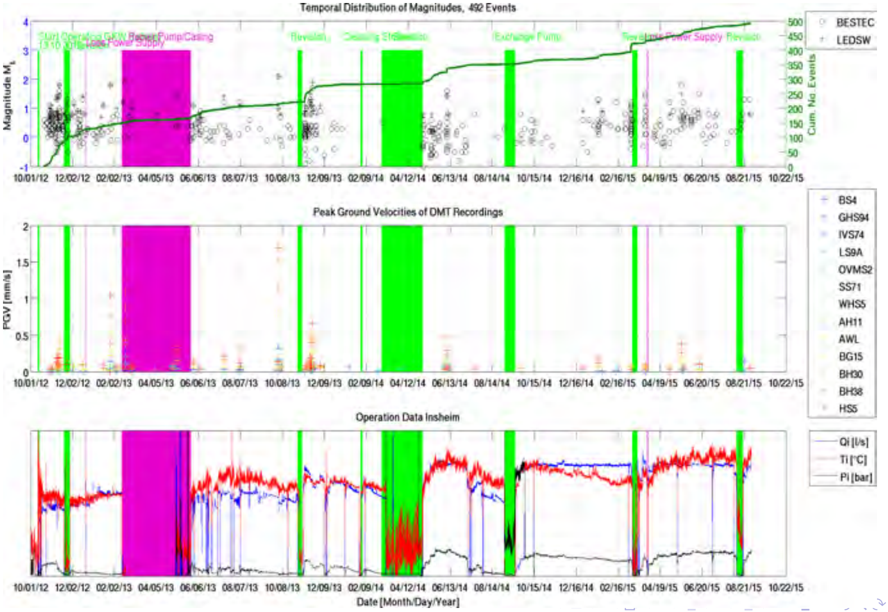
Seismic Monitoring

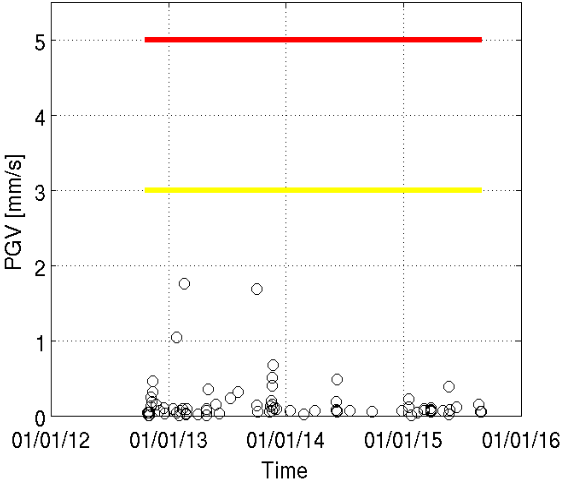
Seismic Network: Emission and Immission Network



△ permanent stations of operator, △ temporary stations of BGR,
△temporary stations of DMT, △ permanent stations of LGB RLP

Seismicity: Fluid Injection Induced Seismicity



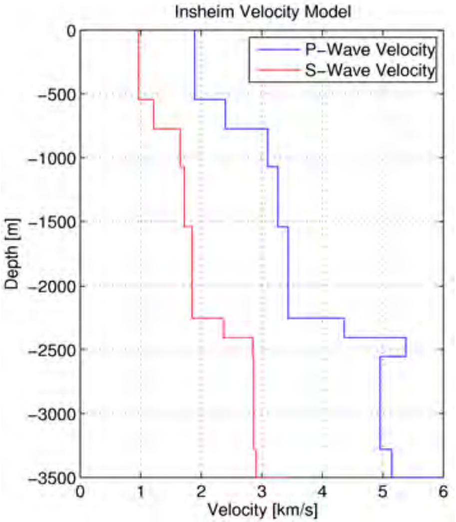


DIN (German Industrial Standard) 4150: Maximum allowed PGV up to where no damages are to be expected. Ordinary buildings (apartments, ...), special buildings (frame houses, ...).

Locating Microseismicity: Velocity Models
VSP Measurements

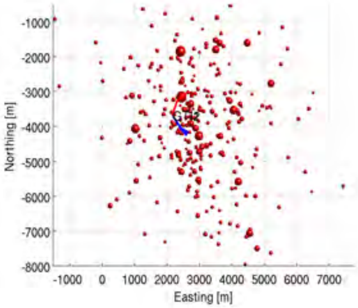
Locating Microseismicity: Initial Velocity Model

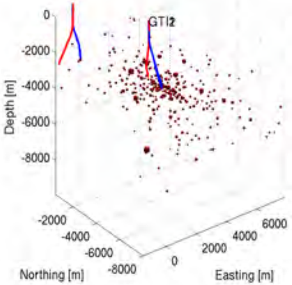
10-layer 1-D Velocity Model



Locating Microseismicity: Routine locations of seismic events

HYPOSAT, correction for elevation (P: 1.45 km/s, S: 0.49 km/s), no station corrections, velocity model derived from VSP measurements, RMS=0.12 s





Insufficient location accuracy due to complex velocity heterogeneities
⇒ Advanced data processing!

VELEST and hypoDD - advanced processing

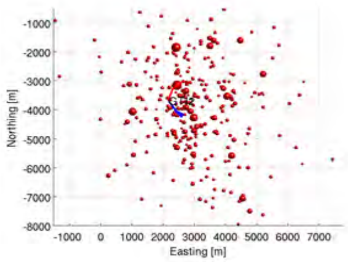
VELEST: Best approximation of a 1D-velocity model to the 3D-subsurface structures

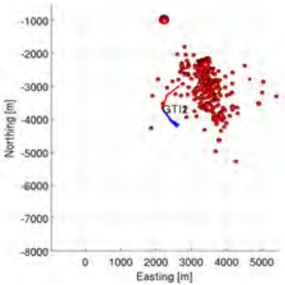
- Solves iteratively the coupled, non-linear problem hypocenter determination - velocity model
- Good starting model needed $\Rightarrow$ 1D-model from VSP measurements

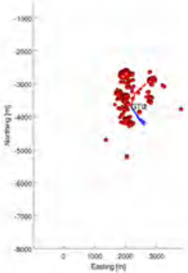
hypoDD: Improves the relative location accuracy

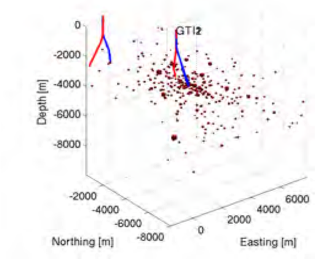
- a double-difference earthquake location algorithm
- RMS is reduced by a factor of 10, relative accuracy improved, but absolute accuracy stays

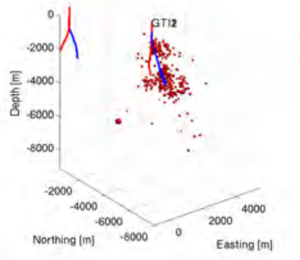
Working towards highly accurate locations: HYPOSAT ⇒ VELEST ⇒ hypoDD








GTI2
0
-2000
-4000
-6000
-8000
Depth [m]
-2000
-4000
-6000
-8000
Northing [m]
0
2000
4000
6000
Easting [m]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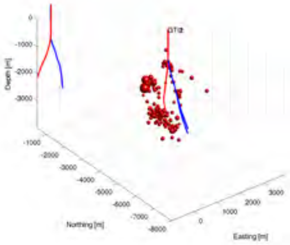


Conclusions

- Correlation between fluid injection and seismicity, but ...
  - No unique correlation with up- and down times
  - No unique correlation with pressure level or injected volume
- 3 years of experience in Insheim show that overall seismicity drops down in size and quantity
- Experience from Soultz and Insheim: avoid rough operations (instantaneous ups and downs)!
- Induced microseismicity in Insheim is below legal restrictions
- Although we do not consider microseismitiy an operational error, the aim of the power plant in Insheim is clearly to avoid felt seismicity during operation.
- Sophisticated data processing is needed for accurate microearthquake location in areas with complex subsurface heterogeneities (e.g. Upper Rhine Valley)
- 1D-velocity model derived from 2D-seismics is not sufficient!

Thank you very much for your attention!

Das Verbundprojekt **MAGS2** - Mikroseismischen Aktivität geothermischer Systeme - **Vom Einzelsystem zur großräumigen Nutzung** wird durch das Bundesministerium für Wirtschaft und Energie (BMWi) aufgrund eines Beschlusses des Deutschen Bundestages gefördert und betreut vom Projektträger Jülich.

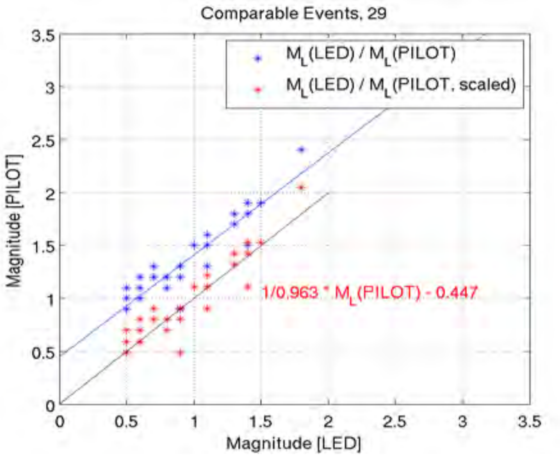
Förderkennzeichen: 0325662A-G

Projektträger für

Bundesministerium für Wirtschaft und Energie

Skalierung der Magnituden

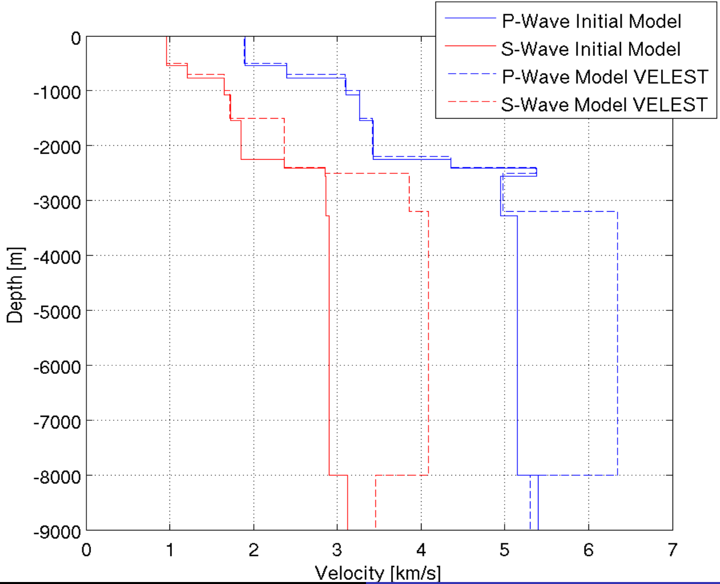
Skalierung der Wood-Anderson-Magnitude nach Stange (2006) [1]:
$M_L^{PILOT} = log(A) + 1.11 \cdot log(r) + 0.00095 \cdot r - 2$



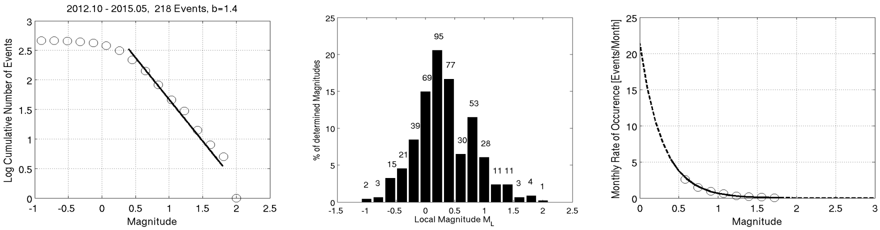
[1] Stange, S., 2006. M_L determination for local and regional events using a sparse network in Southwestern Germany, J. Seismol., 10, 247-257.

Absolute re-locations: VELEST

Improvement of velocity model: Minimum-1D-velocity model



Magnitude Statistics
Gutenberg-Richter and Recurrence Intervals



VELEST (Kissling et al., 1994 [a])

A program to derive a "minimum-1D velocity model"

[a] Initial reference models in local earthquake tomography. *J. Geophys. Res.*, *99*, pp 19635-19646.

Best approximation of a 1D-velocity model to the 3D-subsurface structures

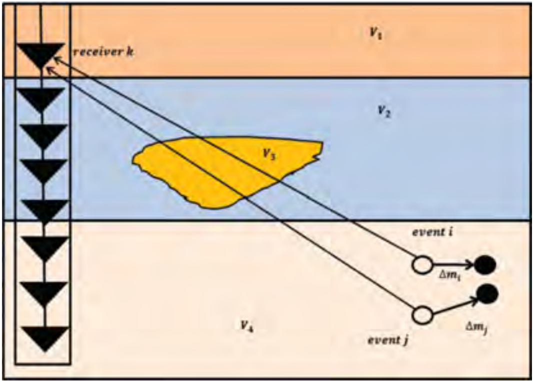
- FORTRAN77-routine to derive 1D-velocity models and initial reference-velocity models for seismic tomography
- Solves iteratively the coupled, non-linear problem hypocenter determination - velocity model
- Iteration:
  - Solving the "forward problem" (determination of arrival times for direct, refracted, and reflected waves using a ray-tracer)
  - Solving the inverse problem (determination of a velocity model by full inversion of the least-squares (Jacobi) matrix
- Solving iteratively the non-linear problem

Good starting model needed ⇒ 1D-model from VSP measurements

hypoDD (Waldhauser, F., & Ellsworth, W.L., 2000. [a])

A program to compute double-difference hypocenter locations

[a] A double-difference earthquake location algorithm: Method and application to the northern Hayward fault, California, *Bull. Seism. Soc. Am.* **90**, pp 1353-1368.



- Hypocentral seperation between two earthquakes is small compared to the event-station distance and to scale length of velocity heterogenities
- ⇒ Assumption of homogenious velocities within source region

Guralp acquisition system:

- CMG6T 1Hz-seismometer
- CMG-D24 data logger
- CMG-EAM (embedded acquisition module)
- near-real time processing via GSM modem, CMG-NAM (network appliance module), and InSite software (ASC)
- 100-Hz data transmitted to data center (Landau), continuous recording of 400-Hz data

Petrol Geoterm d.o.o.
Mlinska ulica 5
9220 Lendava, Slovenija
www.petrol-geoterm.si

PETROL GEOTERM d.o.o.- dr. Evgen Torhač

Geothermal district heating with reinjection in Lendava, Slovenia

19/10/2015

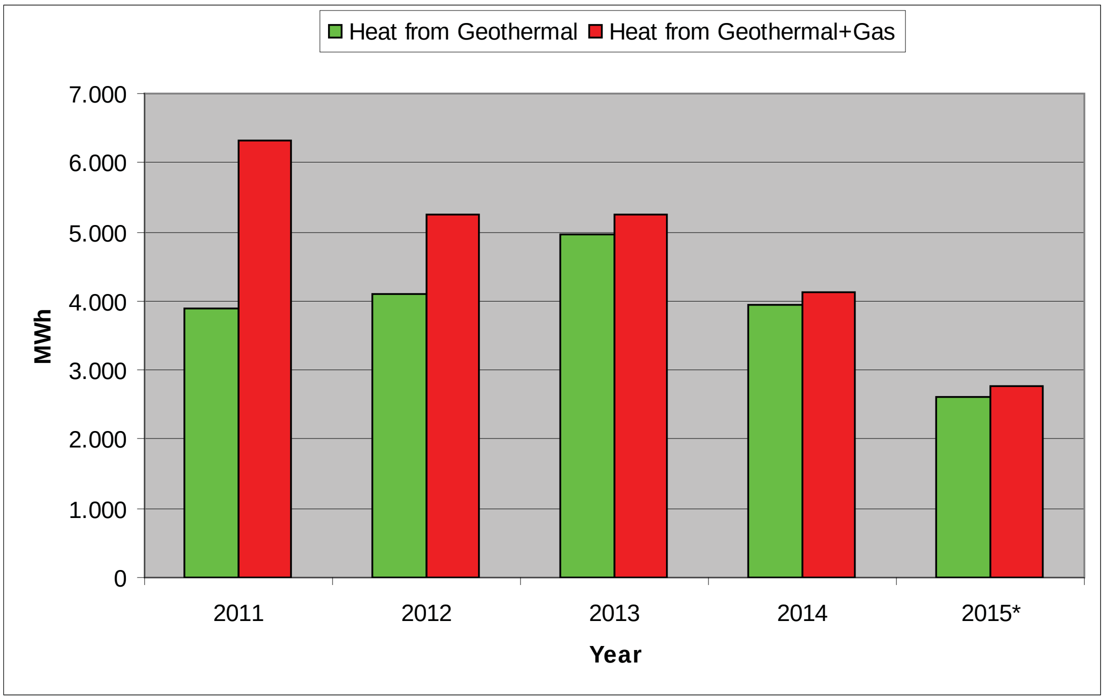
Geothermal district heating with reinjection in Lendava, Slovenia

GEOTHERMAL PIPELINE:
Length of pipeline
2.000 m
DISTRICT HEATING PIPELINE:
Length of pipeline
3.200 m
HEATED AREA:
ca. 55.000 m^2
INSTALLED CAPACITY
7,5 MW

PEAK LOAD COVERAGE

- High temperature heat pump (500 kW)
- Two gas boilers Buderus (2 x 1.320 kW)

ANNUAL HEAT PRODUCTION



PRODUCTION WELL LE-2g

Depth: **1503 m**

Wellhead temperature: **66˚C**

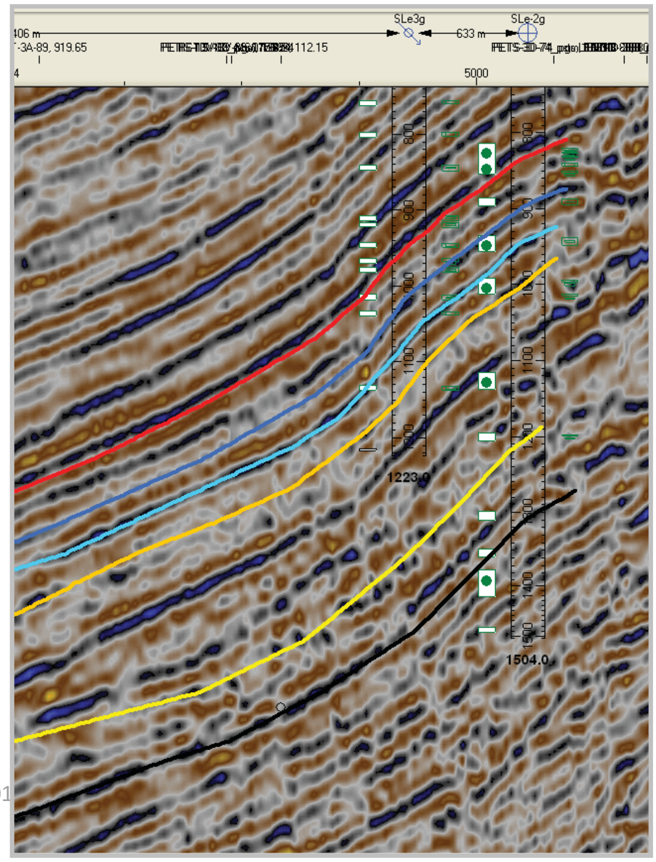
Max. productivity: **90 m3/h or 25 l/s**

Dynamic water level at max. productivity:
-25 m

REINJECTION WELL LE-3g

The well was intentionally constructed for reinjecting water into aquifer.

PRODUCTION/REINJECTION WELL SEISMIC LINE



REINJECTION WELL LE-3g

Depth: **1223 m**

Construction:
- Johnson screens
- gravel pack
- selective activation of all water layers
- other very significant details,…

The greatest challenge - how to reinject all water into fine to medium grain sands and sandstones?

REINJECTION SYSTEM

CONCLUSION / IMPROVING POSSIBILITIES

- CHEMICAL STIMULATION OF REINJECTION WELL

- PERIODICAL CLEANING OF WELL WITH COMPRESSOR

- VERY IMPORTANT IS THE CASCADE USE OF GEOTHERMAL WATER (water must be well cooled)

Thank you for your attention!

› OpERA „Operational Issues across Europe“

Next Steps

WP4: Development of Joint activities
Dr. Stephan Schreiber
Project Management Jülich
Geothermal Energy and Cross-cutting Programs

Overview

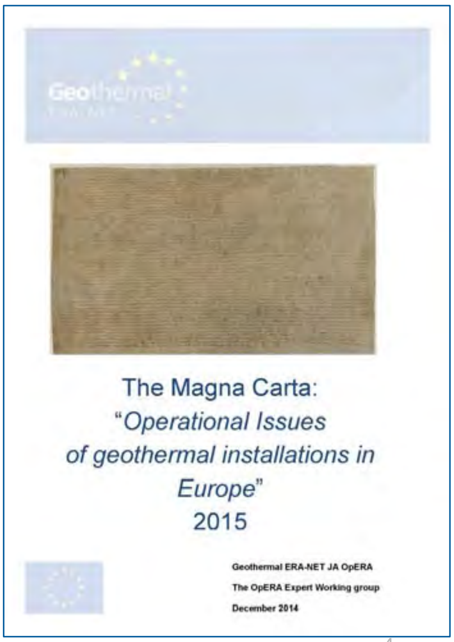
- › The Publication
- › The OpERA Expert Working Group
- › Follow-up Joint Activities

The Publication

- …should summarize the results of the last two days
- …should give an overview of the existing solutions for operational issues in 2015
- …should give an overview of the most urgent operational issues which have to be solved

The Publication

- Est. 20-30 pages
- Geothermal ERA-NET Publication
- Available via the Geothermal ERA-NET website
- Promoted by the country representatives of the ERA-NET Members



The Publication - Structure

1. Introduction (Approach, concept etc.)
2. Status of operational issues in Europe
   a) Country A
   b) Country B
   c) …
3. Corrosion issues
   a) General, solved and unsolved issues
   b) Examples from different countries
4. Scaling issues
   a) General, solved and unsolved issues
   b) Examples from different countries
5. Gas issues
   a) General, solved and unsolved issues
   b) Examples from different countries
6. Re-injection issues
   a) General, solved and unsolved issues
   b) Examples from different countries
7. Conclusions
8. Recommendations for support of specific RD&D topics

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Geothermal ERA-NET
Federal Ministry for Economic Affairs and Energy

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The Publication – Workload and Timeframe

- Request for contributions (country- or topic-specific)
  - Mid October 2015
- Estimated only ca. 1-2 pages per expert
- Submission of your contribution
  - End of November 2015
- Review
  - December 2015
- Publication
  - January-February 2016

PtJ Projektträger Jülich Forschungszentrum Jülich
Geothermal ERA-NET
Federal Ministry for Economic Affairs and Energy

The Expert Group

Geothermal ERA-NET: Paul & Stephan
Annamária
Andrej
Hjalti Páll
Adele

Søren ?
Martin ?
Florian ?
Christian ?
Bernd ?
Gregor ?

+ Experts for specific topics & Examples:

- ENEL, IT
- Low T°C expert, IC
- You ?
- You ?
- You ?
- You ?
- …

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Follow-up: Future JA

- Discussion and decision on the next steps (JA2/JA3)
  - Next week
- Implementation of follow-up JA
  - Until April 2016
- Start
  - April 2016
- All activities related to a follow-up JA will be in parallel to the work of the expert group

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Geothermal ERA-NET

Federal Ministry for Economic Affairs and Energy

What do you think?

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