Economic and Environmental Aspects of CHPM technology

Vojtěch Wertich, Lari Shanlang Tiewsoh, Günter Tiess
MinPol GmbH – Agency for International Minerals Policy
vojtech.wertich@minpol.com
Máté Osvald, János Szanyi, Tamás Medgyes, Balázs Kóbor
University of Szeged, Department of Mineralogy, Geochemistry and Petrology
osimate@geo.u-szeged.hu

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WP5 - Integrated sustainability assessment

Start: M18 / End: M42

WP leader: University of Szeged (Hungary)

Task leader (5.2, 5.3, 5.4): MINPOL GmbH. (Austria)

Deliverable		Due date
D5.1	Integrated sustainability assessment framework (USZ)	24
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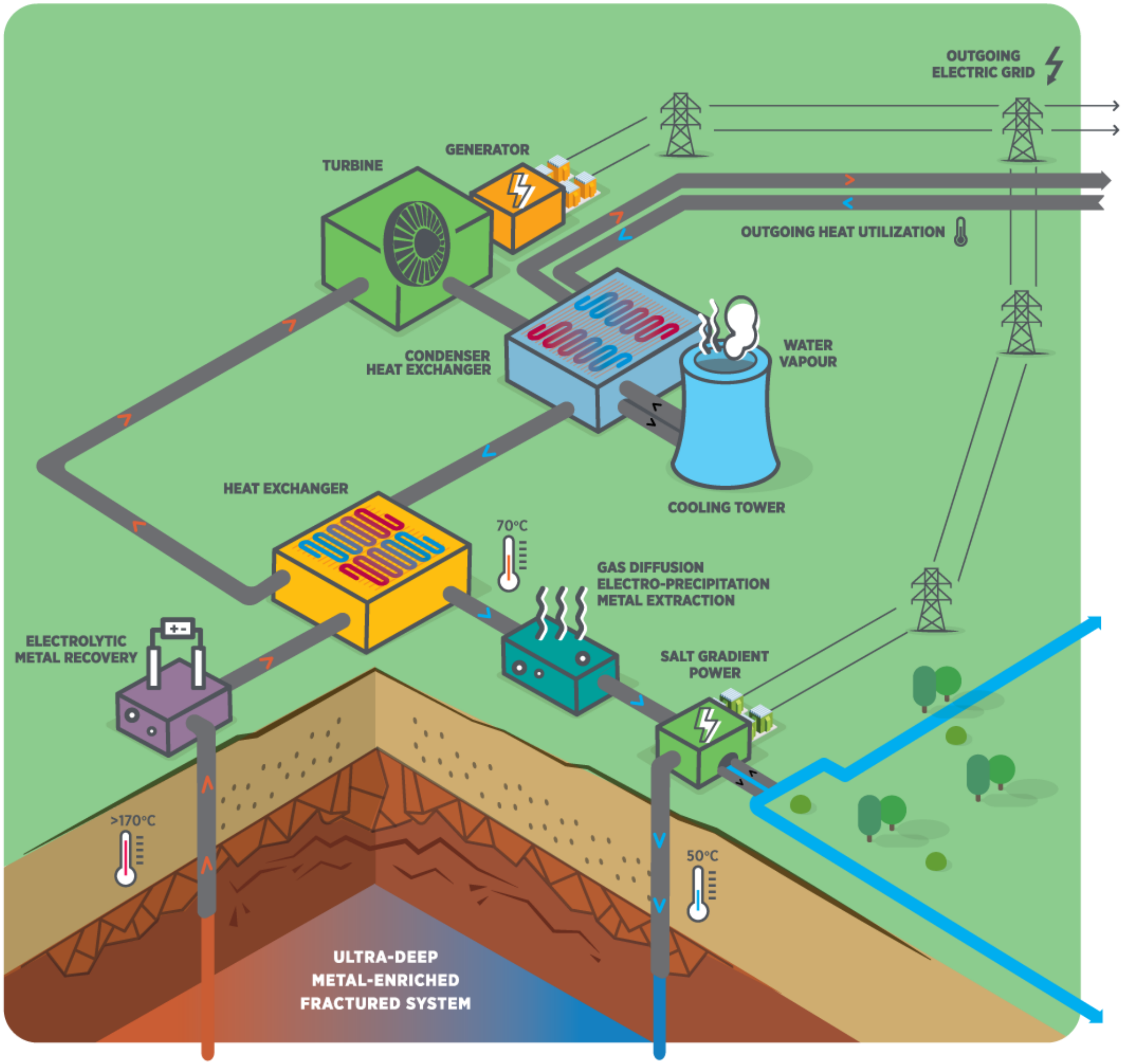
D5.2 – Economic feasibility assessment methodology (Task leader MinPol)

The Energy Level

The Metal Extraction Level



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The Energy Level – position of geothermal energy in Europe:

Geothermal energy – electricity generation and direct use of heat.

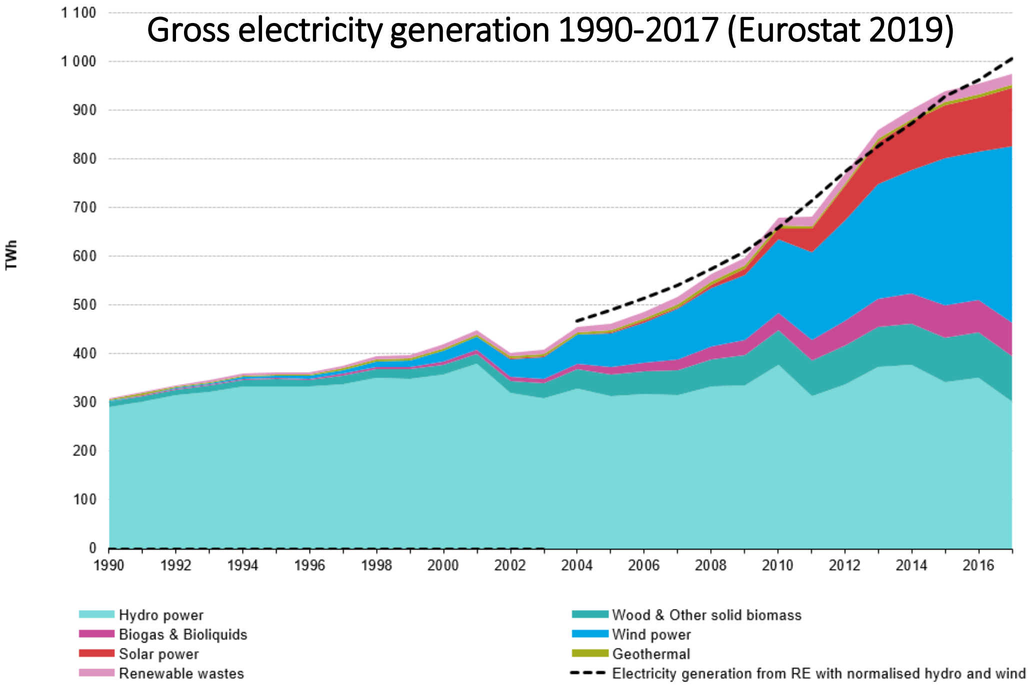
Renewables takes about 25% of EU-28 electricity production, but only 0.2%, about 1 GWe installed capacity is share of geothermal energy (4 EGS in production, rest is conventional with the largest share of Italy, Tuscony region).

Installed capacity of geothermal electricity generation outside the EU-28: U.S. 3.5 GWe, Philippines 2 GWe, Indonesia 1.4 GWe, Mexico 1 GWe, New Zealand 1 GWe, Iceland 700 MWe.

Higher installed capacity in direct use of heat – especially in the Northern and Central European countries.

70% of world geothermal electricity production is run by only 20 companies (ENEL Green Power, Ormat Industries or e.g. Calpine Corporation).

Direct use of heat – many smaller companies (greenhouses, spas), municipalities, individual households



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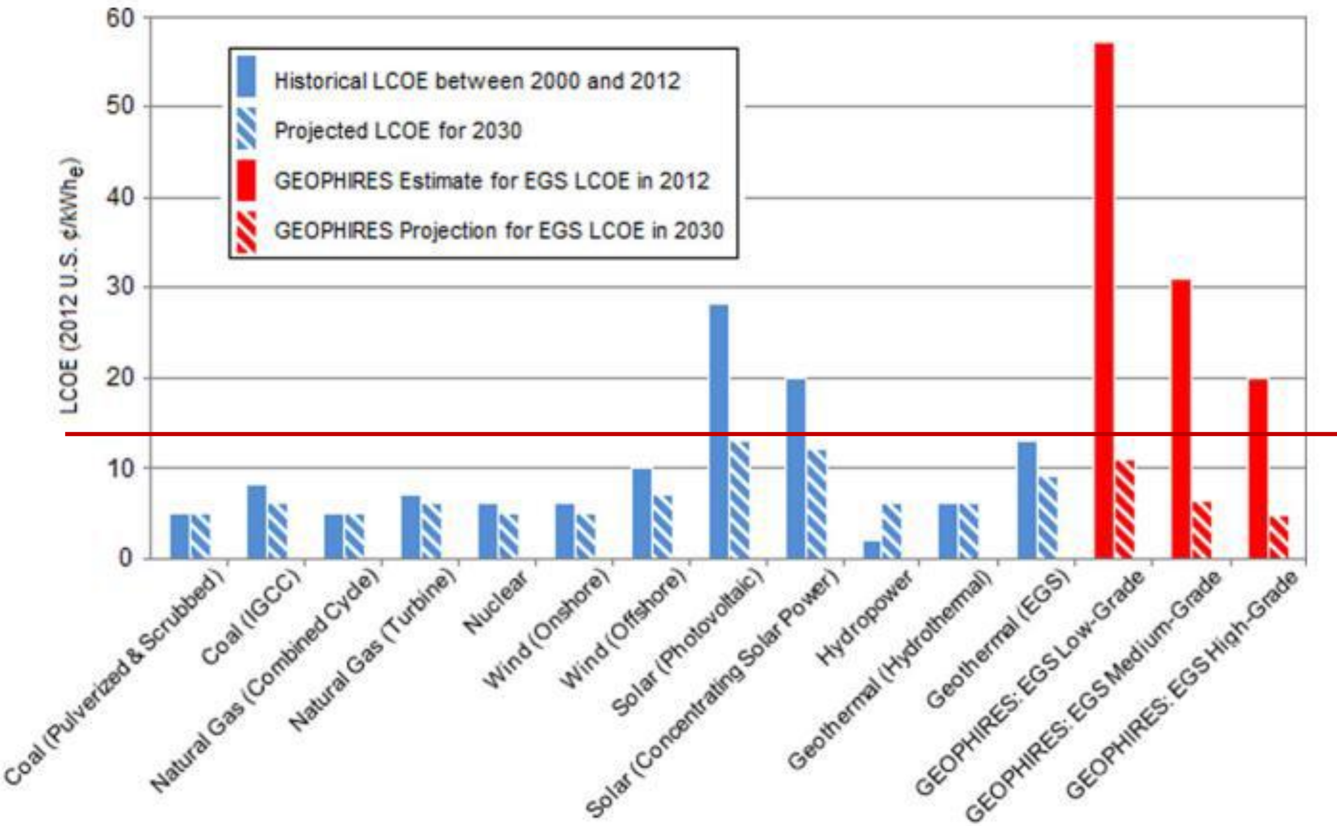
The Energy Level – comparison of EGS with different energy sources:

LCOE – Levelized Cost of Electricity – comparative analysis on a \$/MWh (¢/kWh or similar) basis. The projection of LCOE should include both capital expenditures (CapEx) as well as operational expenditures (OpEx).

Lack of historical data makes difficult to model LCOE for EGS.



OpenEI Transparent Cost Database (2018); Beckers et al. (2014);

—— electricity price level for non-houshold consumers in EU-28 (second half of 2018)

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The Energy Level – LCOE, CapEx, OpEx for different scenarios of EGS:

EGS Results	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Resource Temperature	100°C	150°C	175°C	250°C	325°C
Resource Depth	2 km	2.5 km	3 km	3.5 km	4 km
Plant type	Air-Cooled Binary	Air-Cooled Binary	Air-Cooled Binary	Flash Steam	Flash Steam
# of Production Wells	21.5	7.6	7.9	6.4	4.3
Ratio of Production to Injection Wells	2:1	2:1	2:1	2:1	2:1
Production Well Cost - each	$5,187K	$6,965K	$8,973K	$8,237K	$10,280K
Injection Well Cost - each	$5,187K	$6,965K	$8,973K	$11,210K	$13,678K
Total Geothermal Flow	860 kg/s	303 kg/s	316 kg/s	256 kg/s	171 kg/s
Power Sales	10 MW	15 MW	20 MW	25 MW	30 MW
Geothermal Pumping Power	3,499 kW	738 kW	383 kW	997 kW	679 kW
Plant Output	13.50 MW	15.74 MW	20.38 MW	26 MW	30.68 MW
Generator Output	17.07 MW	20.34 MW	24.4 MW	27.42 MW	31.72 MW
Power Plant Cost	$8,128/kW	$4,668/kW	$3,597/kW	$2,091/kW	$1,571/kW
Overnight Project Capital Cost (with contingency)	$343,960K	$187,291K	$217,994K	$176,620K	$152,299K
Present Value of Project Capital Cost	$396,252K	$235,706K	$276,042K	$229,634K	$211,177K
Exploration & Confirmation (₵/kW-hr)	9.44	7.27	6.56	4.83	4.88
Well Field Completion - Including Stimulation (₵/kW-	32.46	7.47	7.24	4.56	2.53
Permitting (₵/kW-hr)	0.37	0.23	0.17	0.13	0.11
Power Plant (₵/kW-hr)	16.98	7.13	5.30	3.09	2.33
O&M (₵/kW-hr)	17.22	5.65	4.74	4.78	3.53
Levelized Cost of Electricity - LCOE (₵/kW-hr)	76.47	27.75	24.01	17.4	13.39

Mines and Nathawani (2013)

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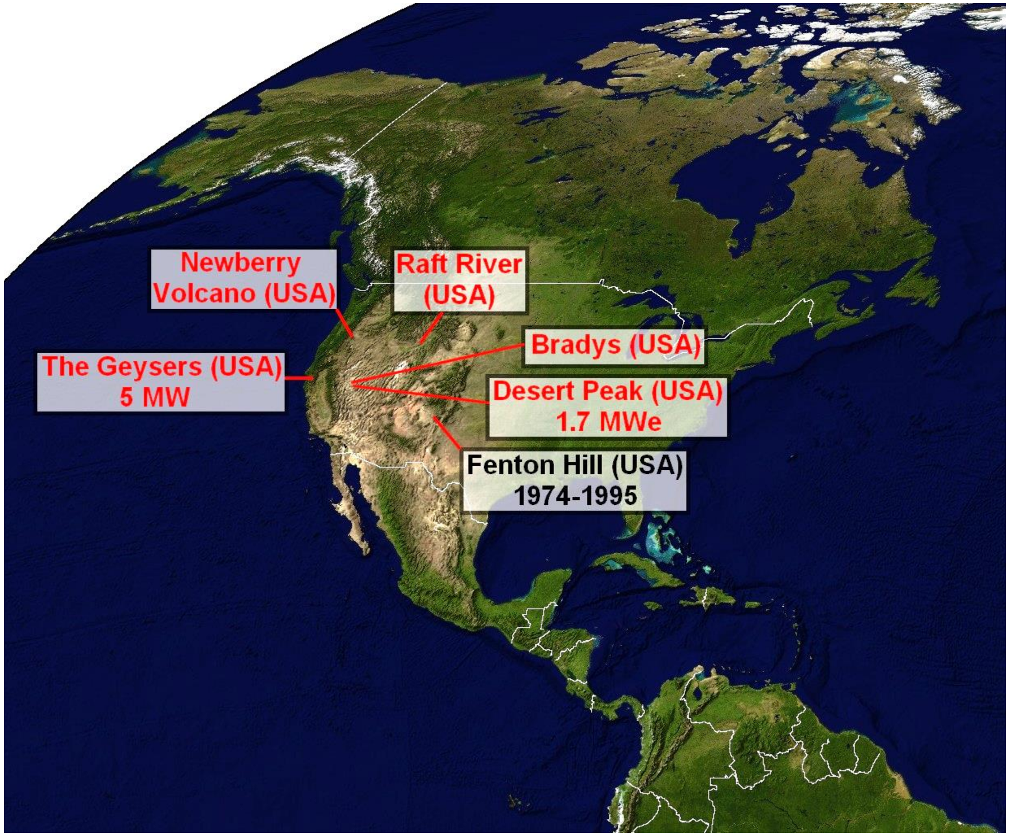
<u>The Energy Level – U.S. EGS Experience:</u>



	CapEx Requirments ($ million)	Note
Newberry Volcano	$ 44 M	Greenfield EGS, in development
The Geysers	$ 13 M	Near field EGS, **in operation, 2013**
Raft Rivers	$ 10 M	Near field EGS, in development
Desert Peak	$ 7.6 M	In field EGS**, in operation, 2013**
Bradys	$ 6.4 M	In field EGS, in development

70% of requirements subsidized by US DOE.

Strategic goal of US DOE (6 ¢/kWh by 2030)

Division of EGS on Greenfield, Near field and In field

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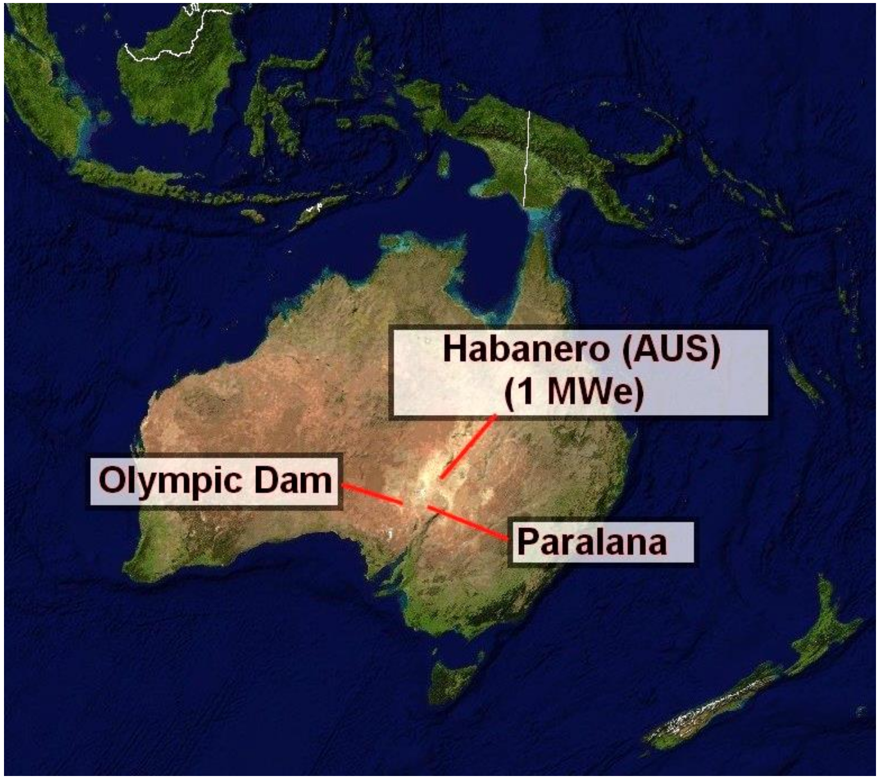
The Energy Level – Australian EGS Experience:



ASX shareholders were probably not willing to bear large risk of the insufficiently proven feasibility of EGS technology.

	CapEx Requirments ($ million)	Note
Habanero	$ 108 M	Greenfield EGS, terminated, high OpEx

Smaller portion of requirements is subsidized by state or governmental funds, which are conditioned by securing an additional money.

Australian EGS developing companies tried to raise money at Australian Stock Exchange (ASX).

3 main projects Habanero, Paralana, Olympic Dam (close to the mineral deposit).

Habanero was the most successful, they finished 1 MWe EGS, but terminated after successful test of electricity generation (OpEx higher than revenue).

Other two projects were abandoned due to failure in securing additional money (condition for state funds).

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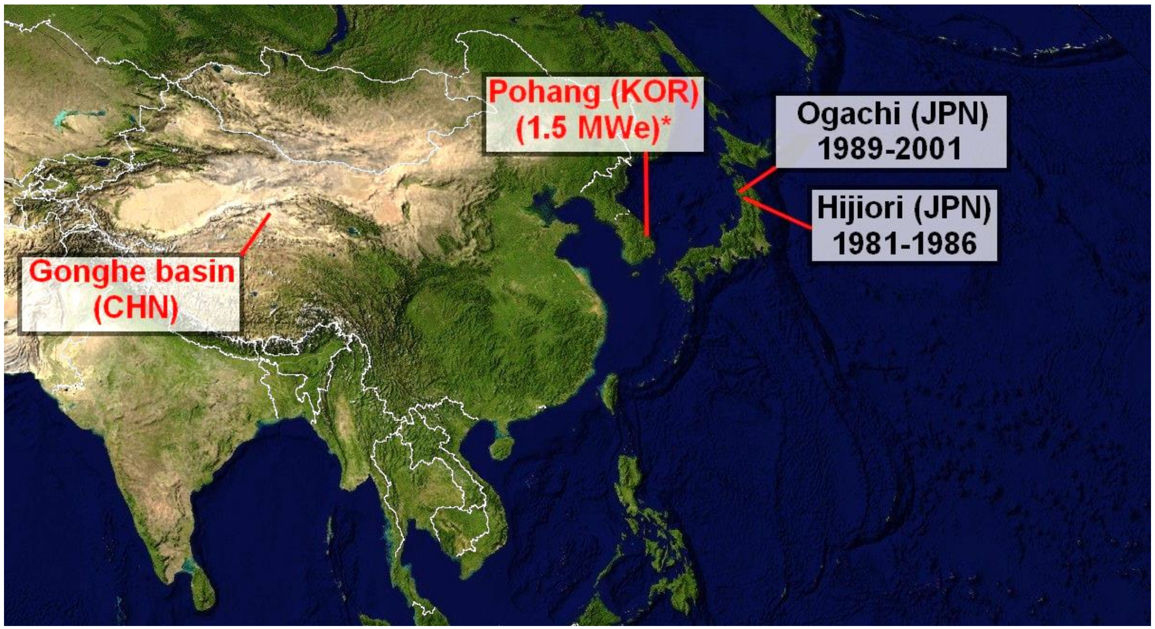
The Energy Level – Asian EGS Experience:



Pilot EGS project in South Korea – Pohang EGS – is recently suspended due to investigation of possible EGS triggered induced seismicity event of very strong intensity (magnitude-5.5).

The first exploration geothermal well drilled in Gonghe basin, China.

	CapEx Requirments ($ million)	Note
Pohang	$ 38 M / $ 16 M governmental subsidy	Greenfield EGS, suspended, induced earthquake?

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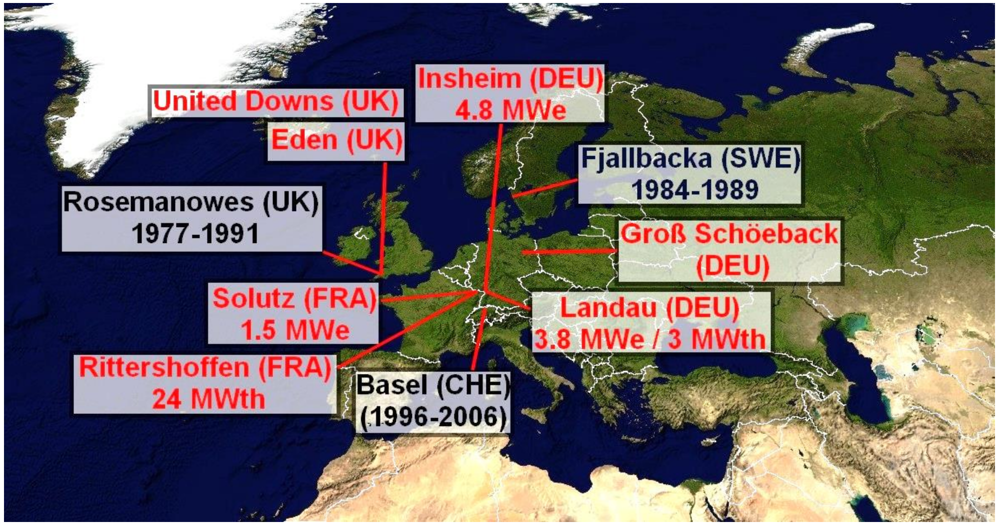
The Energy Level – European EGS Experience:



	CapEx Requirments ($ million)	Note
Soultz-sous-Forêts	$ 94 M	Greenfield EGS, **in operation, 2007**
Landau	$ 24 M	Greenfield EGS, **in operation, 2007**
Insheim	N/A	Greenfield EGS, **in operation, 2012**
Rittershoffen	$ 65 M	Greenfield EGS, **in operation, 2016**

All European EGS power plant can be considered as Greenfield (US DOE definition)

50-70% of requirements subsidized by governmental or EU funds.

Strategic goal to reduce cost of EGS related technologies by 2020, many EU funded technological projects.

There are new EGS projects in development: e.g. Vendenheim (Strasbourg, France) and United Down (Cornwall, UK).

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The Energy Level – Conclusion:

Present and modelled LCOE for EGS development and operation is higher than present EU electricity price.

All currently operated EGS power plants worldwide were developed thanks to large governmental subsidies.

Drilling and reservoir stimulation very often consume as much as 70% of total CapEx.

Technological projects in EU and U.S. are aiming to reduce cost of EGS development to achieve feasible and competitive LCOE by 2030, which is in accordance with time framework of CHPM.

The Australian case suggests that EGS developing companies have problematic issues to secure money at a Stock Exchange.

There are many state or governmental funding options supporting development of EGS worldwide.

Big differences in CapEx and time needed for EGS development is based of specific site/target (US DOE definition of Greenfield, Near field and In field EGS).

Development of 'cheaper EGS power plants' (or more precisely the EGS technology – near field, in field) in the EU, could help to increase knowledge and public acceptance of the EGS technology (also more expensive 'greenfield type '), which subsequently can lead to higher attractivity for investment.

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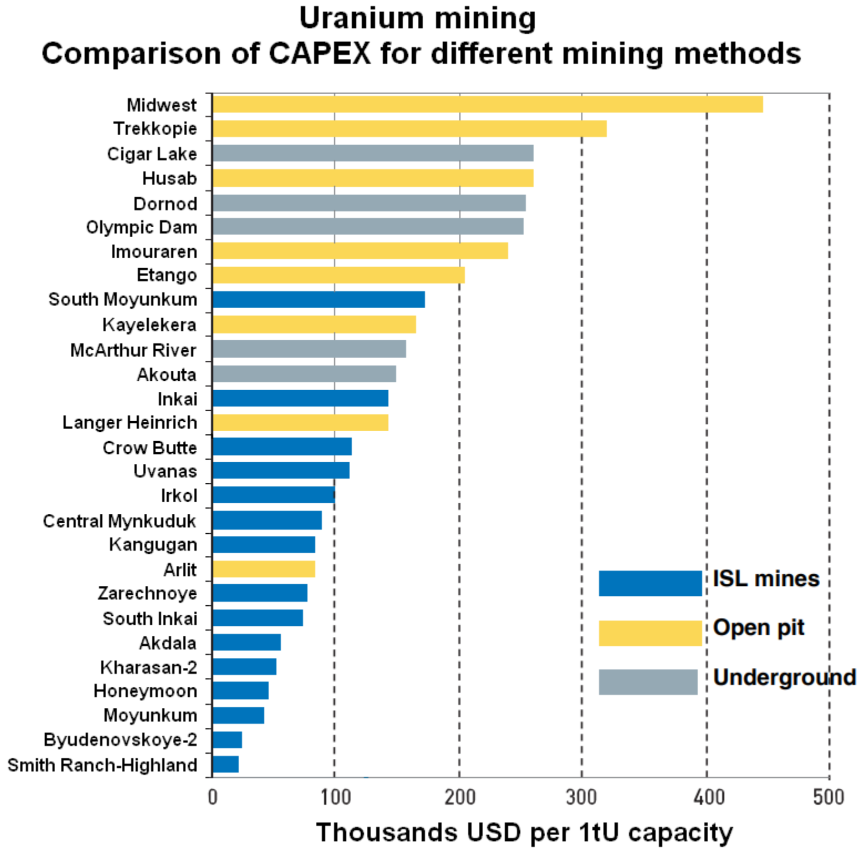
The Metal Extraction Level – cost comparison of different mining methods

Surface, underground and in-situ recovery / in-situ leaching (ISL/ISR). CHPM metal recovery is type of in-situ recovery.

Uranium mining industry is only mining industry sector which is often using all three mining methods. Deployment of ISR/ISL in other raw materials is very limited.

ISL/ISR is achieving the lowest CapEx and also OpEx.

However, ISL/ISR in uranium mining is using stronger leaching reagents, then milde ones considered for the CHPM technology.



(Edited after Boytsov 2014)

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The Metal Extraction Level – extraction from geothermal brines

Metal extraction from geothermal brines is currently on low Technology Readiness Level.

Several demonstration plants in development are limited only on lithium and silica recovery.

Removing of silica can have positive effect also on LCOE by reducing silica scaling issues, as suggested by calculations of Bourcier (et al. 2009). Reduction even up to 1 ¢/kWh.

Feasibility assessments are based mostly on calculations and derivation from the similar technologies with known CapEx and OpEx – Desalination water treatment facilities.

Feasible operation were calculated for lithium and silica recovery at several sites in U.S. (Salton Sea, Mammoth Lake) and New Zealand (Wairakei, Ohaaki).

Models for precious metals or REEs suggesting non-feasible operations.

Ohaaki silica extraction pilot plant had started commercial operation of colloidal silica production on August 2018 (Geo40 2019)

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The Metal Extraction Level – Conclusions

Calculation were done only for conventional geothermal sites, not EGS. Models done for conventional geothermal sites calculating with high total fluid flow from many geothermal wells, e.g. lithium extraction model for Wairakei lithium extraction plant (New Zealand) calculated with very high fluid flow of 2000 l/s and 11 mg/kg of Li in geothermal brine. With efficiency factor of 85% and very optimistic Lithium Carbonate price at $20K per ton would create revenue of **$64M**. Derivation of **CapEx** and annual **OpEx** from Desalination Water Treatment (DWT) Facility yield **$96M** and **$12M**, respectively. DWT is based on electrodialysis – electricity consumption takes 25% of OpEx (Waste 2 Wealth, Robinson 2015)

With use of the same data for Rittershoffen EGS power plant with natural Li concentration of 140 mg/kg and fluid flow of 73 l/s, it would create annual revenue of **$23M.**

Problem and future feasibility assessments lies in calculation the OpEx and CapEx of the metal extraction level for CHPM (EGS) plant, in current TRL it is difficult to assess a more precise cost calculations for metal extraction level.

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Task 5.3 Self Assessment Tool

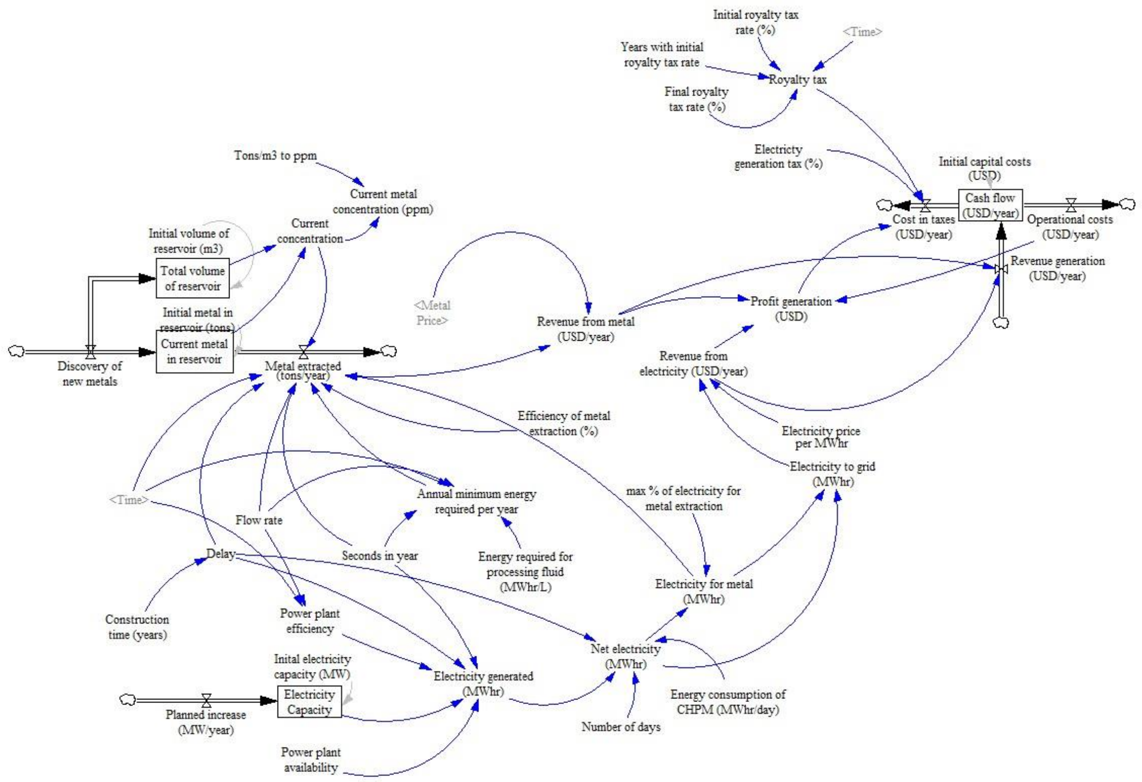
D5.3 – Self Assessment Tool (Task leader MinPol)

SAT is using Vensim software environment based on the System Dynamics.

System Dynamics Approach was choosen as it allows to put different variable (CHPM Energy and Metal Extraction Levels, commodity prices, time, etc.) to one model.

The SAT allow users to set and evaluate their own data.

The SAT user guide is available on CHPM (https://www.chpm2030.eu/outreach/) webpages and the Tool itself on MINPOL websites (http://www.minpol.com/references.html).



CHMP electricity and metal production module

WP5 - Integrated sustainability assessment
Task 5.5 Environmental Impact Assessment

WP5 - Task 5.5 Environmental Impact Assessment

Task leader: University of Szeged

(a) development of an environmental impact assessment methodology framework, in which the environmental impacts of the proposed CHPM technology can be evaluated in an objective manner

(b) monitor and evaluate the actual environmental impacts as they arise during the, implementation of WP1-WP4; and

(c) develop a methodology framework with recommendations as to how an EIA should be carried out for a CHPM facility.

This task will closely follow up the laboratory experiments carried out in WP2 and WP3, using output data and results for the subsequent modelling of environmental impacts.

Report is publicly available at the CHPM webpages (https://www.chpm2030.eu/outreach/)

Model environmental assessment process

Main environmental criteria that need to be considered in EIA before moving forward with a commercial EGS/CHPM project:

- Electricity and/or heat demand in the region
- Proximity to transmission and distribution infrastructure
- Volume and surface expression of a high quality EGS reservoir
- Reservoir life and replacement wells
- Circulating fluid chemistry, radioactivity
- Flash vs. binary technology
- Cost/installed MWe and cost/MWh delivered to a local or regional market
- Load-following vs. baseload capability
- Plant reliability and safety

Model environmental assessment process

Additional environmental criteria that need to be considered in EIA before moving forward with a commercial EGS/CHPM project:

- Geologic formations that are not prone to large seismic events, devastating landslides, or excessive subsidence
- Drinking water and aquatic life protection
- Air quality standards, GHG and other emissions
- Noise standards
- Chemical composition of fluids, radioactivity
- Solid waste disposal standards
- Reuse of spent fluid and waste heat
- Acceptable local effects of heat rejection
- Compatible land use planning
- Compliance with all applicable federal, state, and local laws

Actvity	Type of Impact	Magnitude	Frequency / Duration	Likelyhood	Consequence (+/-)
EXPLORATION PHASE					
Drilling deep (3+ km) geothermal wells	On-site storage of specialised materials and equipment	Medium	Temporary	Definite	Negative
	Contamination of surface/ground water due to spills and propagation of chemical elements	Medium / Significant	Temporary / Long-term	Medium / High	Negative
	Noise pollution	Significant	Temporary	High	Negative
	Unsustainable water use	Minimal / Medium	Temporary	Low/ Medium	Negative
Hydraulic stimulation of the reservoir	Surface felt seismic events, tremors, low magnitude earthquakes	Minimal / Medium / Significant	SIngle event occurences	Low/ Medium / High	Negative
CONSTRUCTION PHASE					
Site preparation	Earthworks may have an impact on the native topography	Minimal / Medium	Permanent	Medium	Negative
	Dust emissions generated from earthworks due to loading and unloading materials on site	Minimal	Only during construction	Medium	Negative

The EIA framework is describing a various impacts (type, magintude, duration, etc.) related to varisous stage of the CHPM develpment.

Environmental and social impacts	Activity stage								
	Expl.	Construction			Operations				Decommissioning
	Well drilling	Land preparation / Mobilisation	Well Drilling / Plant Facilities	Transmission / Pipeline / Road	Well drilling	Power Generation	Transmission / Pipeline / Road	In-situ leaching	
Physical-Chemical									
H2S Emissions	NEG		NEG		NEG	NEG			
GHG						NEG			
Heavy metal emissions	NEG		NEG		NEG			NEG	
Dust		NEG	NEG	NEG			NEG		NEG
Noise		NEG	NEG		NEG	NEG			NEG
Erosion and sedimentation/ water quality, increased run-off rate	NEG	NEG	NEG	NEG	NEG				NEG
Ground- and surface water usage		NEG	NEG		NEG	NEG		NEG	
Induced seismicity	NEG		NEG						
Solid and liquid ...		NEG	NEG	NEG	NEG	NEG		NEG	NEG

More detailed division of CHPM develpment stages.

Impacts are also divided to several categories:

Physical-Chemical

Biodiversity

Social-Cultural

Workforce

General

Plus the statement in which stage is a risk a **negative** or possibility of **positive** impact

Thank you for your attention