Professional Development Workshop on

Critical Raw Materials Content in Thermal Waters: Analysis and Assessment

30th March 2023
University of Miskolc, Hungary

Co-production of clean energy and metals from a single interlinked process - the CHPM concept

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Content

CHPM2030 - Combined heat, power and metal extraction from ultra deep ore bodies

1. CHPM2030 project facts
2. Research concept
3. Main research results

CHPM2030

Project facts

- Call: H2020-LCE-2014-2015 two-stage, Research and Innovation action
- Topic: Developing the next generation technologies of renewable electricity and heating/cooling
- Project ID: 654100
- Implementation: 01.01.2016-30.06.2019
- Budget: 4.2 million EUR
- TRL: 4-5

Members of the consortium

Partner organisation	Country
University of Miskolc (UNIM), coordinator	Hungary
University of Szeged (USZ)	Hungary
European Federation of Geologists (EFG)	France
Iceland Geosurvey (ISOR)	Iceland
British Geological Survey (BGS)	UK
Laboratório Nacional de Energia e Geologia (LNEG)	Portugal
Vlaamse Instelling voor Technologisch Onderzoek (VITO)	Belgium
La Palma Research S.L. (LPRC)	Spain
Agency for International Minerals Policy (MinPol)	Austria
Geological Survey of Romania (IGR)	Romania
Katholieke Universiteit Leuven (KLeuv)	Belgium
Geological Survey of Sweden (SGU)	Sweden

Challenge and rationale

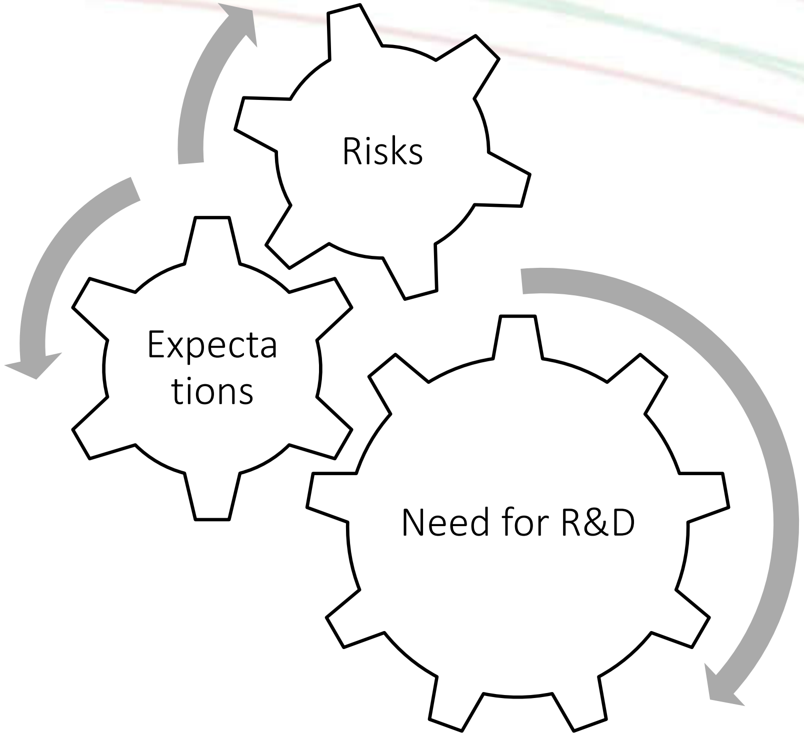
1) Increasing demand for green energy in the EU and worldwide – EGS is expensive

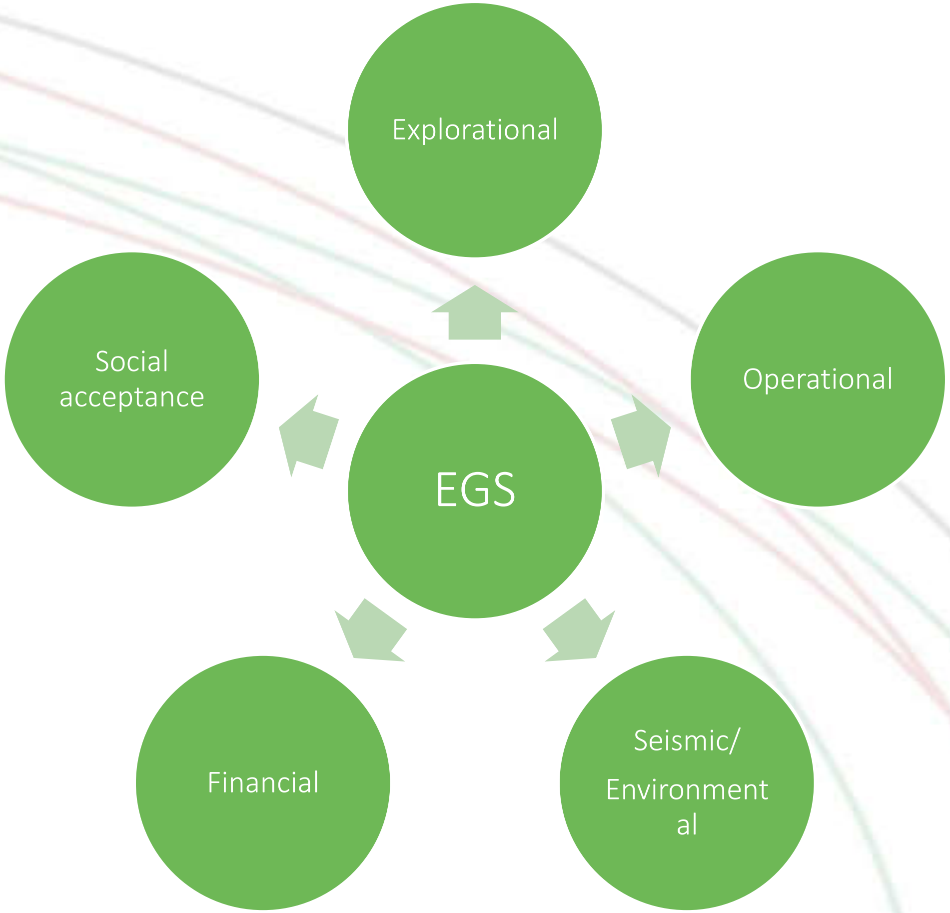
2) EU needs critical raw materials – limited mining

Developing a new technology for combining geothermal energy production and metal mining

Create a proof of concept of the technical and economic feasibility at laboratory scale

EGS (Enhanced Geothermal Systems) - a risky business



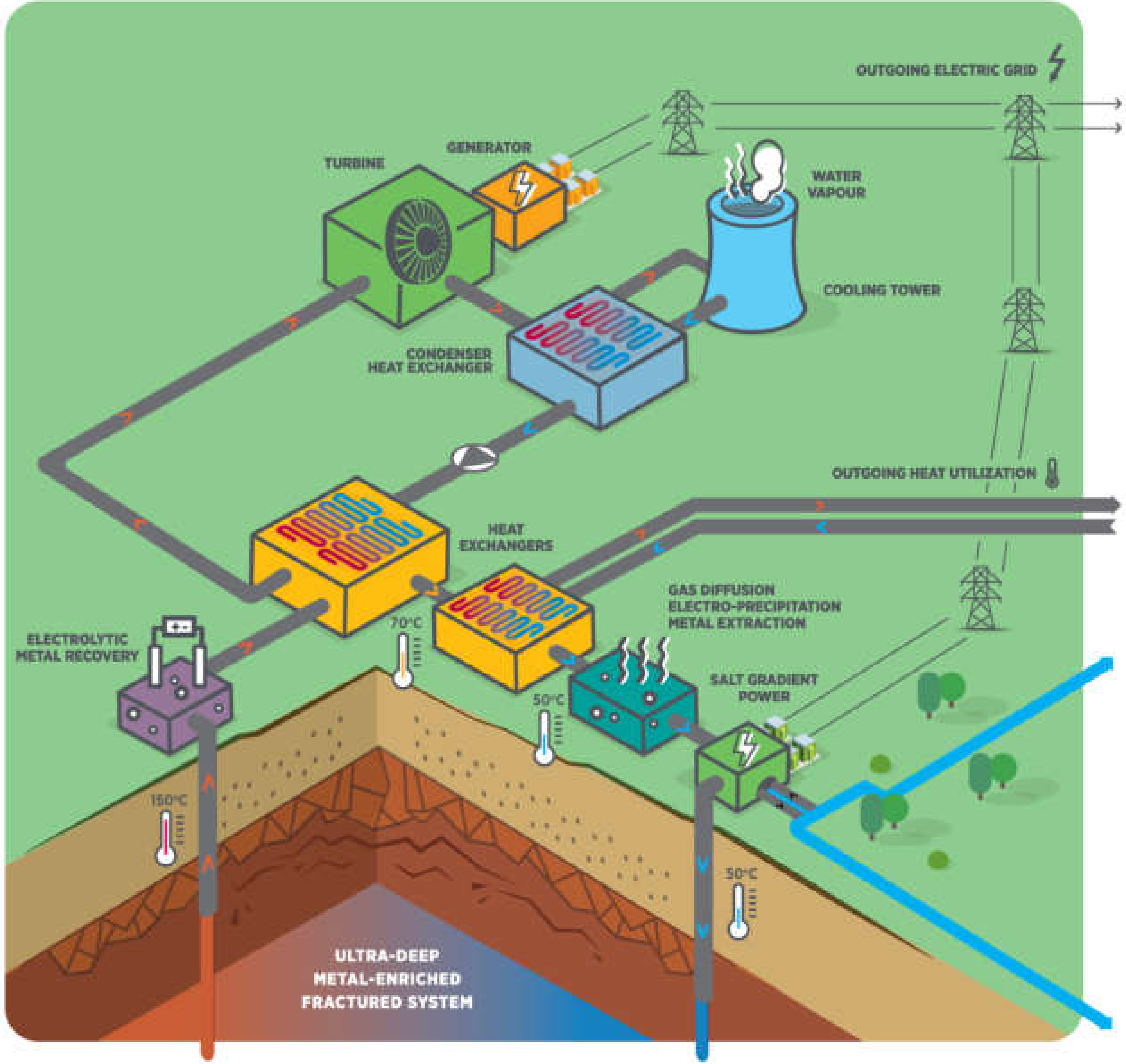


One potential means of cost reduction for geothermal resources is also the co-production of metal and non-metallic material contained in the geothermal fluids in addition to thermal and electrical energy.
(Strategic Research and Innovation Agenda, ETIP Geothermal - 2019)

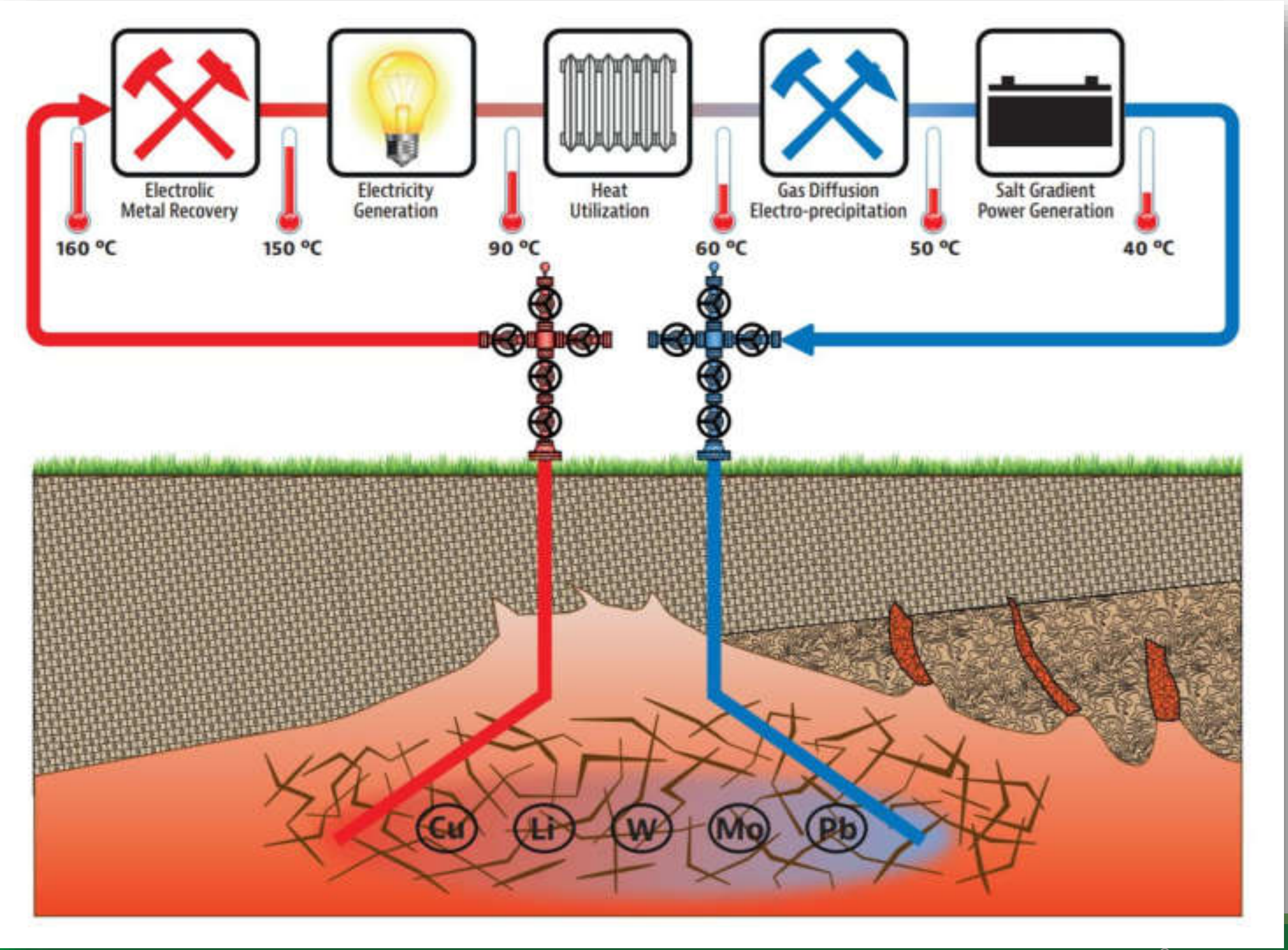
The research concept

- Identifying ultra deep metalliferous formations
- Establishment of EGS
- Enhancing the interconnected fracture systems within the orebody
- Leaching metals from the orebody
- Extracting metal from the geothermal brine
- Production of heat and electricity
- Financially more feasible operation/earlier return of investment

The CHPM research concept

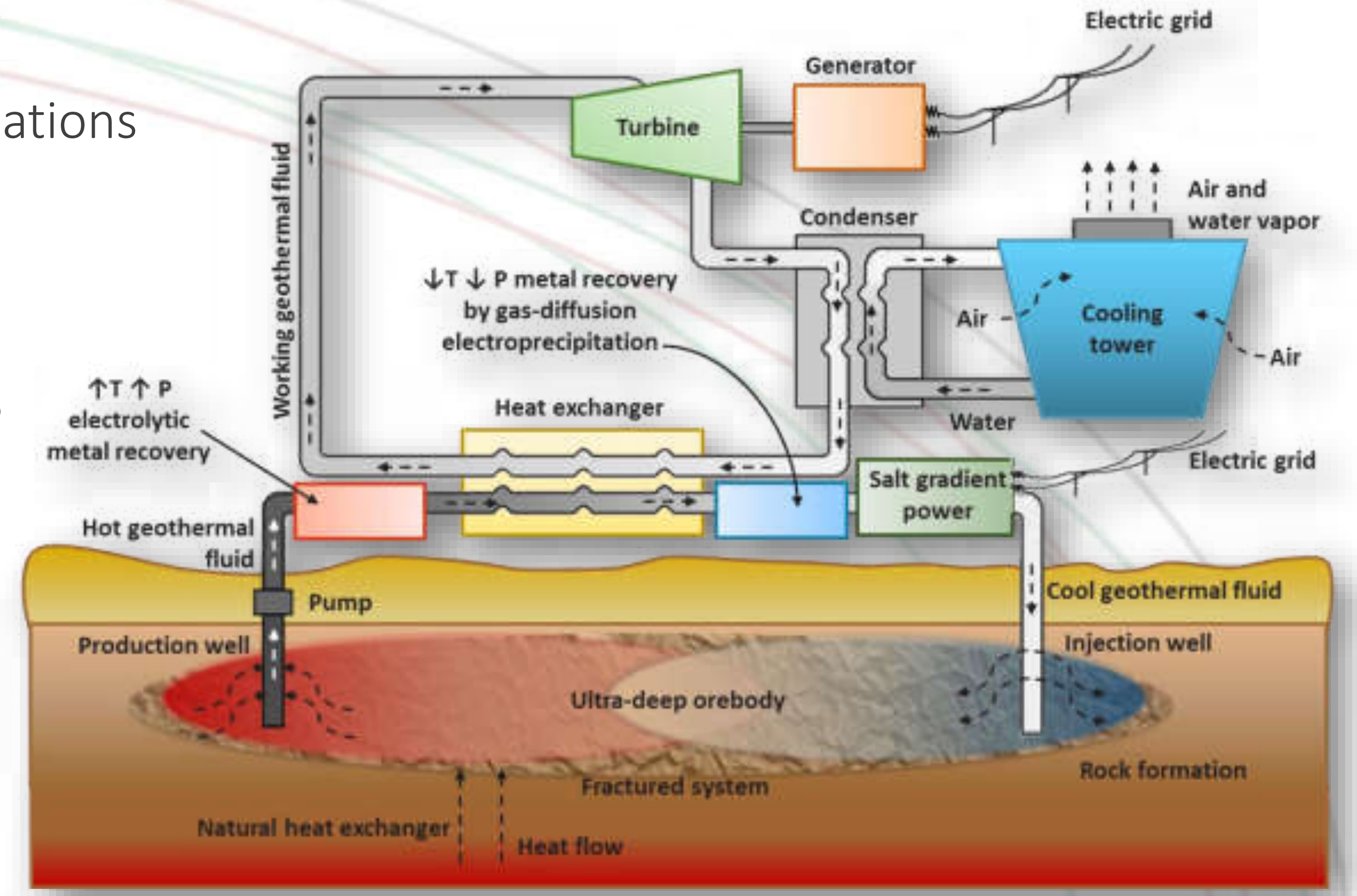


Conceptualisation



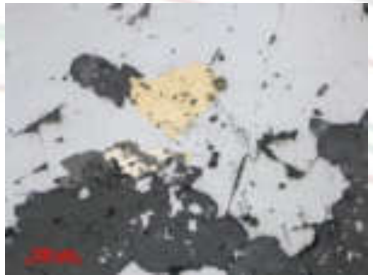
Main research results

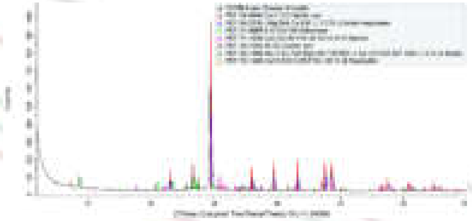
- EGS relevant review of ore mineralisations
- Identification of potential test sites
- Laboratory tests on metal leaching
- Metal recovery in two steps
- Additional power generation by SGP
- System integration
- Complex assessment
- Research Roadmap

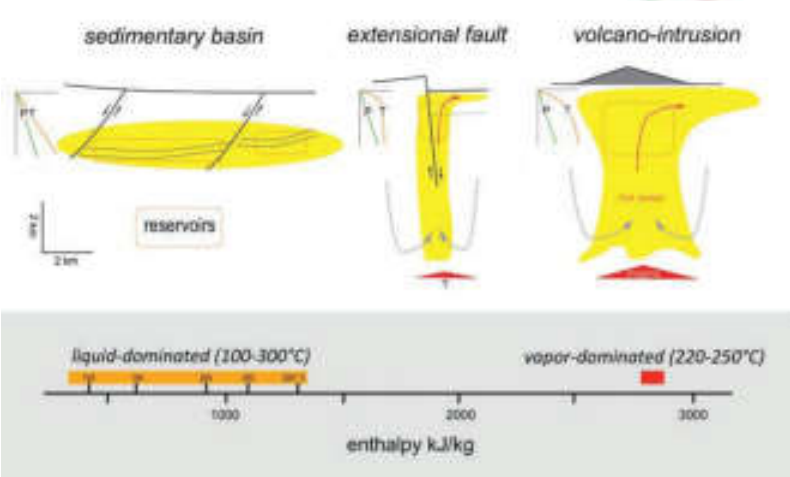


Schematic overview of the envisioned CHPM Installation

EGS relevant review of ore mineralisations







Most appropriate geological settings

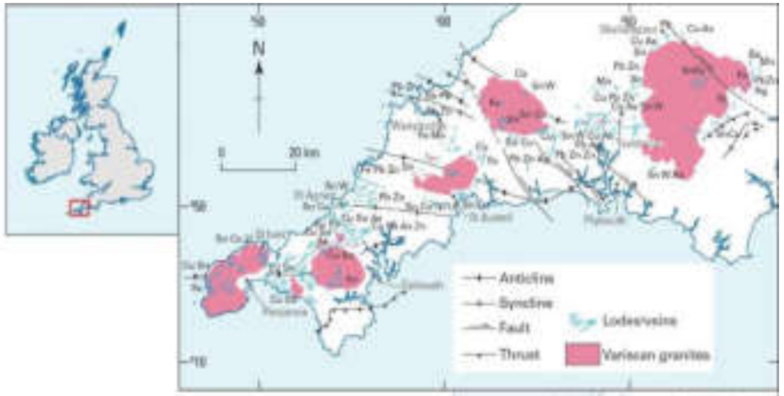
1) Magmatic-hydrothermal mineralisations associated with intrusive bodies (appropriate mechanical properties of host rocks)
2) Basins in rift or subduction zones (relatively thin mineralised horizons, but with large lateral extension)
3) Deep-rooted fault zones, with larger extension and elevated heat flow (deep-seated fertile rock body, which can have a potential for further leaching)

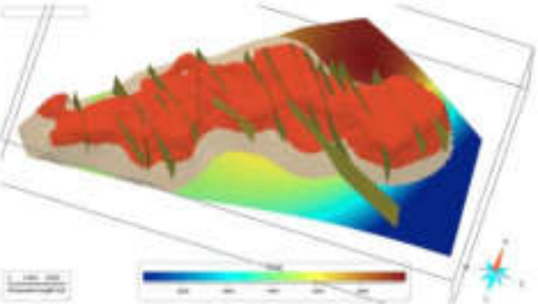
Potential test sites

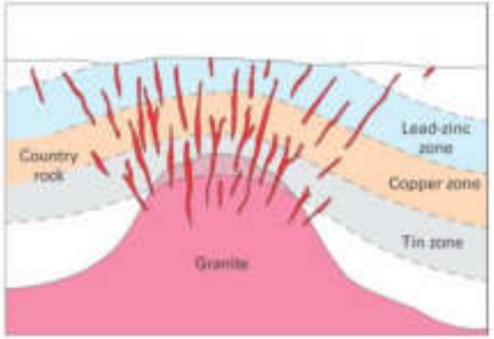
Cornwall, SW England, BGS

Paul A. J. Lusty, plusty@bgs.ac.uk,

- SW England, Cornwall, major magmatic province, high heat production, extensive polymetallic mineralisation (Cornubian Orefield), UK HDR project, United Downs Deep Geothermal Power project, 5 km 200 Celsius.
- Geological environment, geothermal characteristics, potential for deep metal enrichment, technical, environmental, social and regulatory factors.
- 3 models: Cornubian Batholith (geothermal energy development, fracture mapping), site scale 1: HDR project site, fracture data, hydrogeological properties, district fracture network models, potential flow paths; site scale 2: NW Carnmenellis granite, UDDGP site,







Sinclair (1995)

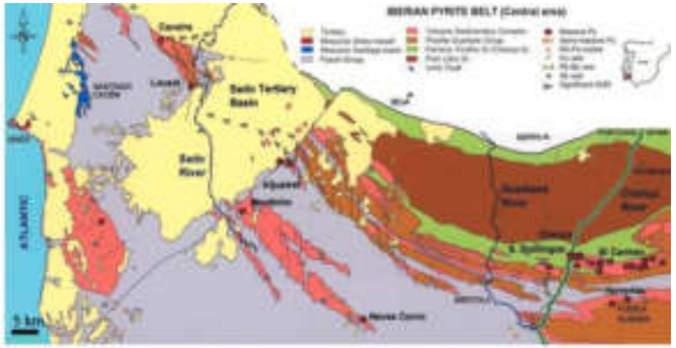
Cornwall report

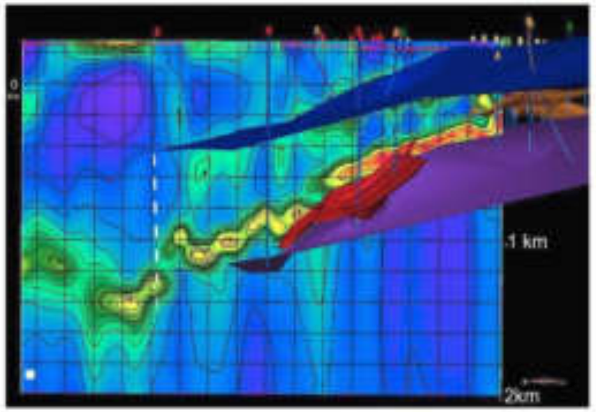
Potential test sites

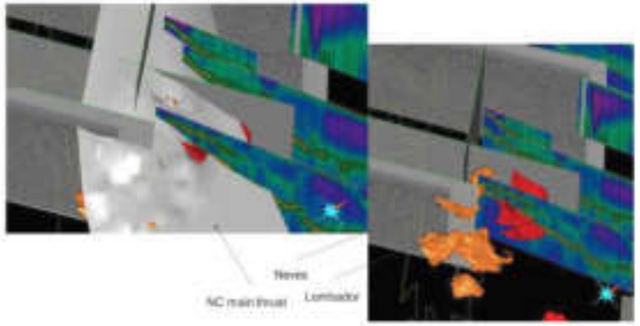
Portuguese Iberian Pyrite Belt, LNEG

Elsa Cristina Ramalho, elsa.ramalho@lneg.pt

- SW IPB, Variscan metallogenic province, massive sulphides deposits, active mining region, prospect for deep mineralization, energy transition in PT, Neves-Corvo Mine (extend lifetime with CHPM?)
- Update on geoscientific data and information on SW IPB, 3D modeling, geophysical data
- Ivestigate the deeper ore deposits, 3D modeling, new upcoming deep seismics, 3D electromagnetic forward modeling, 3D inversion, → mineralization at depth. Lombador orebody at 2-3 km: extend lifetime with CHPM? cooperation with the mining company and government.





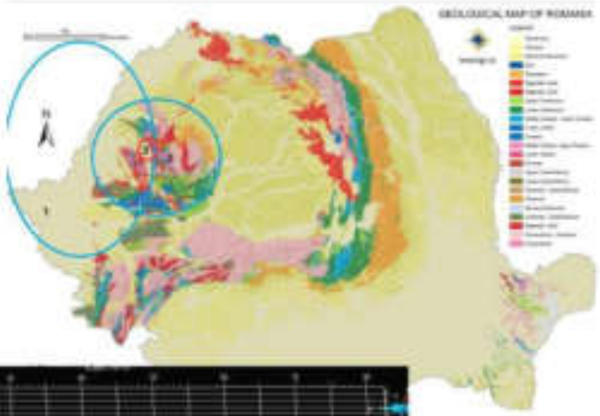


IPB report

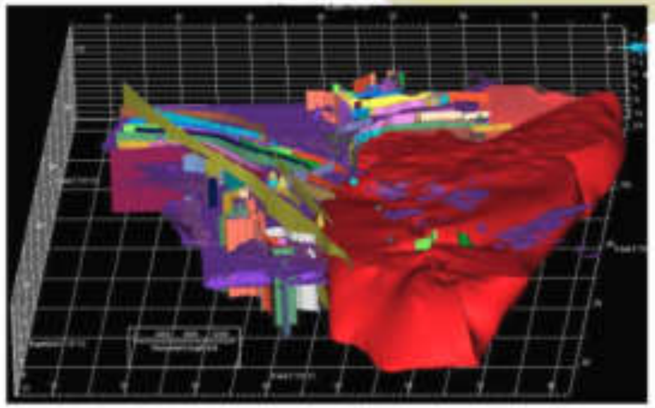
Potential test sites

Beius Basin-Bihor Mountains, Romania, IGR

Diana Persa, persa.diana@yahoo.ro



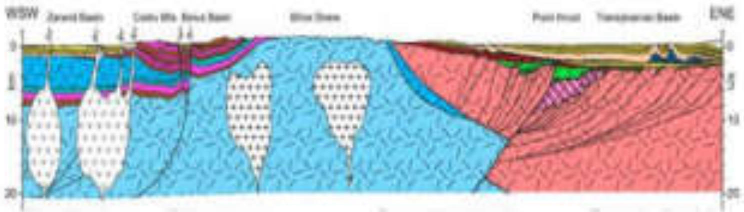
- Beius basin and Bihor Mountains, favourable geothermal (~Pannonian basin, thin crust, high heat flow/gradient) and mineral (intrusive magmatic bodies, Banatitic Magmatic and Metallogenic Belt) potential.



- Beius Basin geothermal potential (DHS up and running Mg, geothermal potential), Bihor Mountains (granodiorite-granite plutonic body related, skarn (Fe, Boron, Bismuth, Moly), vein (Cu, Zn, led-Pb, sulphides), brucite deposit, borate deposit, metal skarn (W).

- 1) Geothermal models (150 Celsius), 2) refraction seismic for the plutonic body and mineral indications, 3) fracture network modeling for understanding reservoir characteristics.

Beius-Bihor report

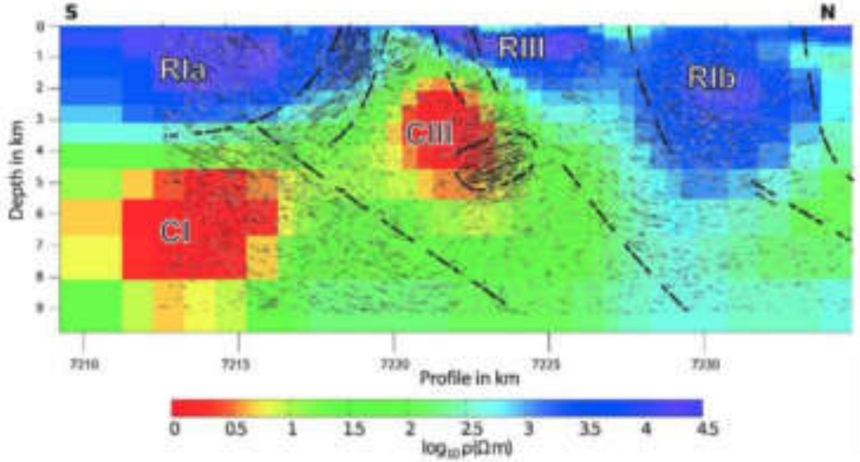


Potential test sites

Kristineberg, Nautanen areas, Sweden, SGU

Gerhard Schwarz, Gerhard.Schwarz@sgu.se

- 2 ore provinces: Kristineberg area (Skellefte district, volcanogenic massive sulphide deposits, Zn, Cu, Au), Nautanen area (Northern Norrbotten district, IOCG, Cu, Fe, Au).
- low geothermal gradient, limited info 5-7 km, permeability, deep-seated fluids in the crystalline bedrock is rudimentary, hydraulic conductivity,
- Geophysical studies, deep seismic, magnetotelluric measurements, cooperation with the mining industry?



Sweden report

Potential sites (European overview)

European Outlook, EFG

Domenico Marchese, projects@eurogeologists.eu
Anita Demény

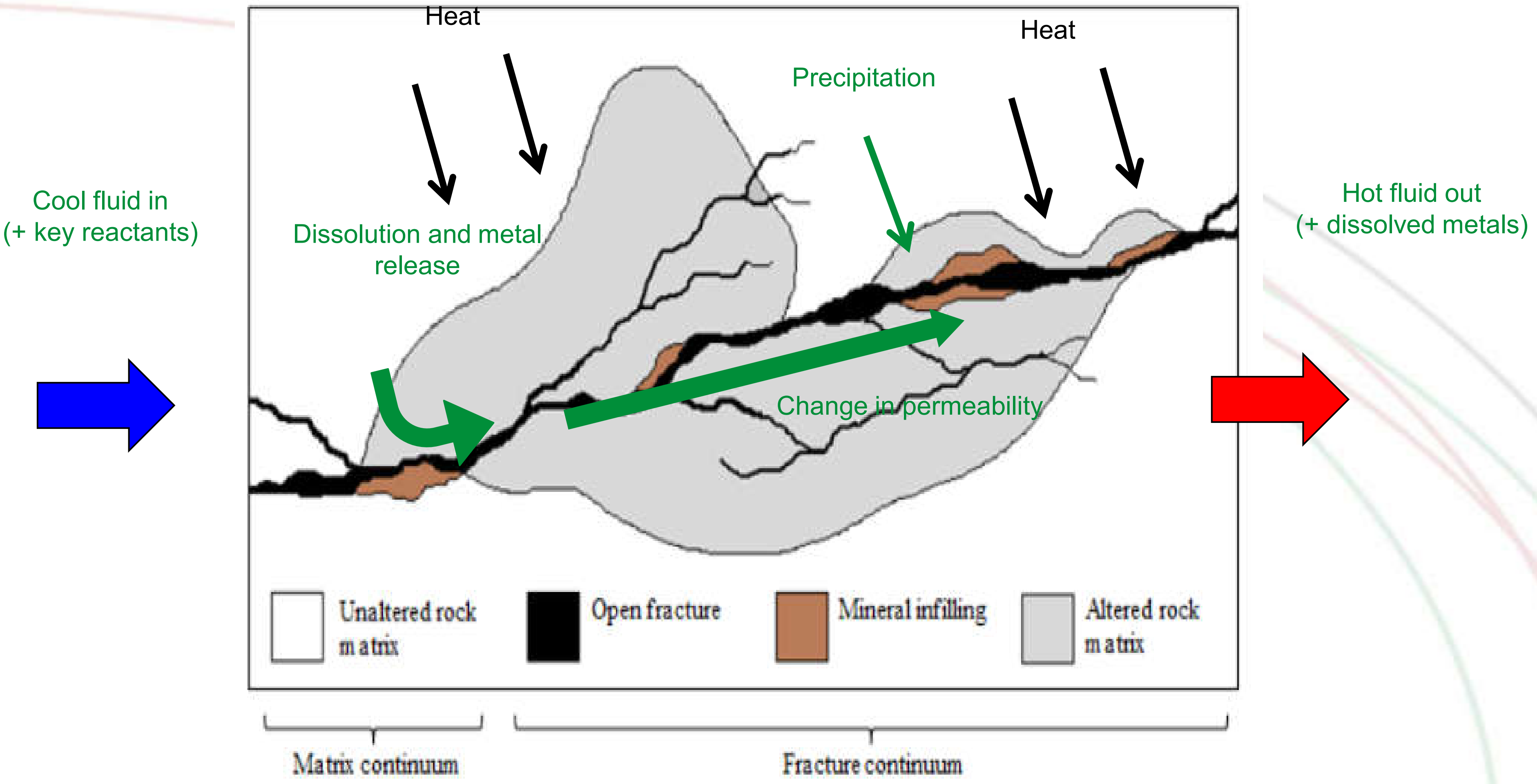
1. Area selection
2. Basic area evaluation
3. CHPM characteristics

EFG's National Geological Associations
CHPM information platform on prospective locations:
http://bit.ly/CHPMinfoplatform

EFG LTPs involved in CHPM2030 (16+1)			Data collected by RBINS (7)
• Belgium • Czech Republic • Finland • France (by EFG) • Germany • Greece	• Hungary • Ireland • Italy • The Netherlands • Poland • Portugal	• Serbia • Slovenia • Spain • Switzerland • Ukraine	• Austria • Croatia • Cyprus • Luxembourg • Slovakia • Sweden • United Kingdom

EU outlook report

Lab experiments on metal leaching



The concept of enhanced metal leaching in geothermal systems

Selected samples

Sample ID	Sample locality	Geological setting	Summary of bulk mineralogy as determined via X-ray diffraction
HTLMix	Herodsfoot, SW England	Baked sediments with partial quartz vein	87% quartz, 5% muscovite, 2% dolomite, 5% galena, minor albite, chlorite, pyrite and sphalerite
HTL315	South Caradon, SW England	Mainstage mineralisation, associated with granite bodies	70% quartz, 7% schorl, 5% chlorite, 2% calcite, 10% pyrite, 5 % arseonpyrite, minor greigite and biotite
HTL319	Cligga Head, SW England	Tin–tungsten mineralisation, associated with granite bodies	88% quartz, 2% muscovite, 3% cassiterite, 3% columbite and 4% ferberite
HTL321	Masca-Cocovaleni, Romania	Mineralised skarn country rock	22% dolomite, 49% pyrite, 27% magnetite, minor quartz, calcite and barite
HTL322	Rudabánya, NE Hungary	Carbonate hosted lead-zinc mineralisation	8% quartz, 2% calcite, 68% magnesite, 6% cerrusite, 1% sphalerite, 1% columbite, 11% barite, 2% magnetite and minor dolomite
HTL324	Recsk, NE Hungary	Porphyry sulphide polymetallic ore	74% quartz, 5% calcite, 9% pyrite, 11% magnetite, minor albite, dolomite and sphalerite

HPHT batch and flow through experiments

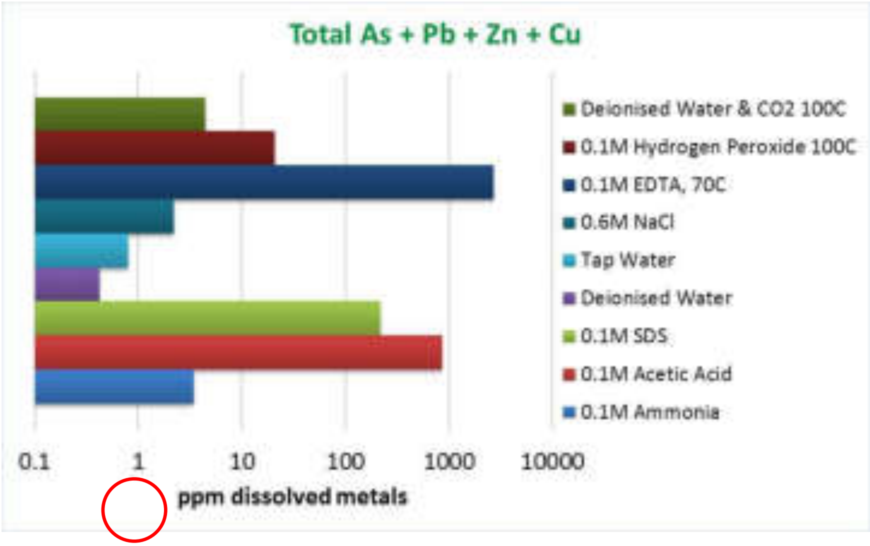
BGS
- 5 g solid sample
- 40:1 fluid:rock ratio
- 70°C, 100°C, 150°C, 200°C
- 1 bar, 200 bar
- 600-1000 hours
- Leaching agents: deionized water, 0.1 M acetic acid, 0.013 M „aqua regia”

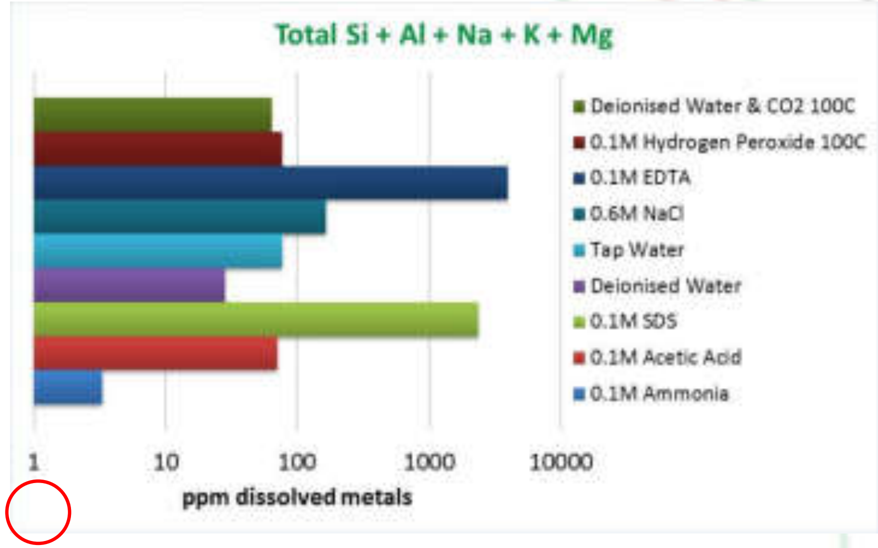
University of Szeged

– HTHP (40 MPa) system: HPLC pump, external heating and insulation;
– Flow through tests on grinded rock (250 µm) under 300 bar pressure at 300°C temperature
– Pressure, temperature and flow rate can be controlled any time during experiments
– Output analysis: XRF, ICP-MS

Leachate performance at HTHP batch experiments

- Tap-water & deionised water: poorest performing fluids (addition of CO_2 improved leaching, but generally restricted to base metals)
- Best performing fluids: dilute EDTA, SDS and acetic acid (organics): leached 100-1000s ppm base metals & liberate some minor or 'critical ' metals
- Most fluids dissolved high loads (10s-1000s ppm) of elements derived from silicate minerals → implications for permeability of the EGS reservoir

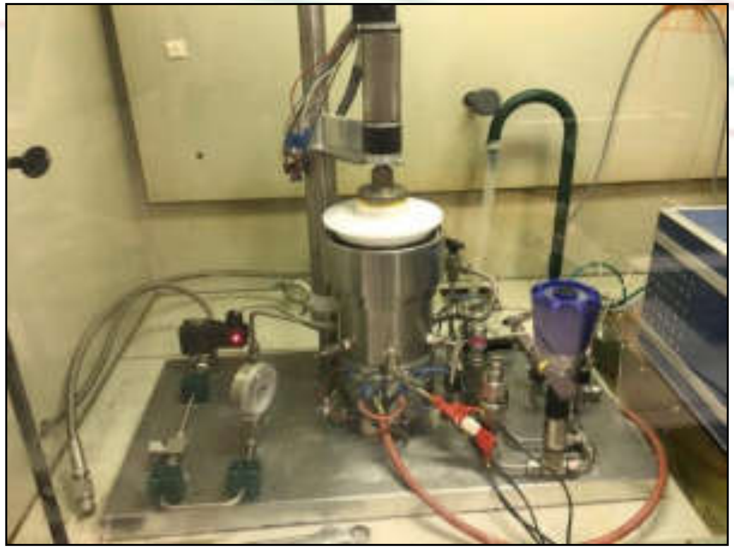


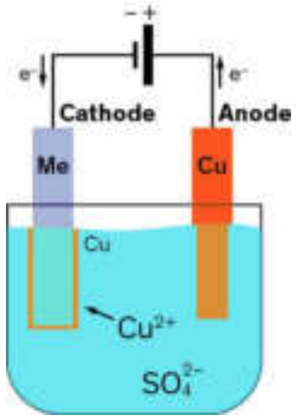


Report on metal leaching

- 62 pages of main report.
- Plus 305 pages of appendixes.
- Contains details of the experiments, all analytical data, plus conceptual or numerical modelling.

HTHP metal recovery (KU Leuven)

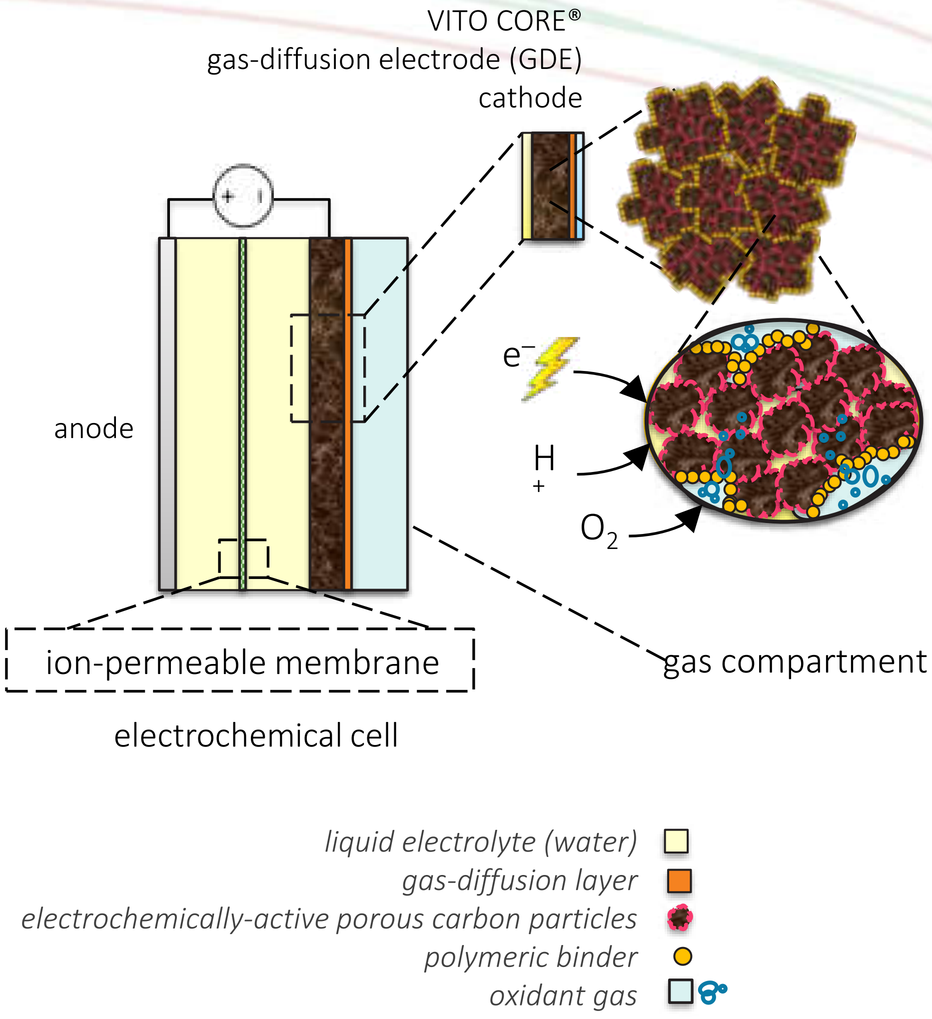




Electrolitic metal recovery

- Ox/red of metal ions in solution by an electricity-driven conversion, such that they "deposit" onto an electrode: **electrodeposition**
- ↑T ↑P electrodeposition from geothermal brines (100°C, 5MPa):
  - Increases kinetics and mass transport
  - Avoids issues like precipitation of silica
  - More energetically favorable vs. ambient conditions
  - Completely unexplored (no thermodynamic data)
- It only works for a limited number of metals (Cu, Ag, Ni, Pb, Sn, Fe, PGM)

Metal recovery with GDEx (LTLP)

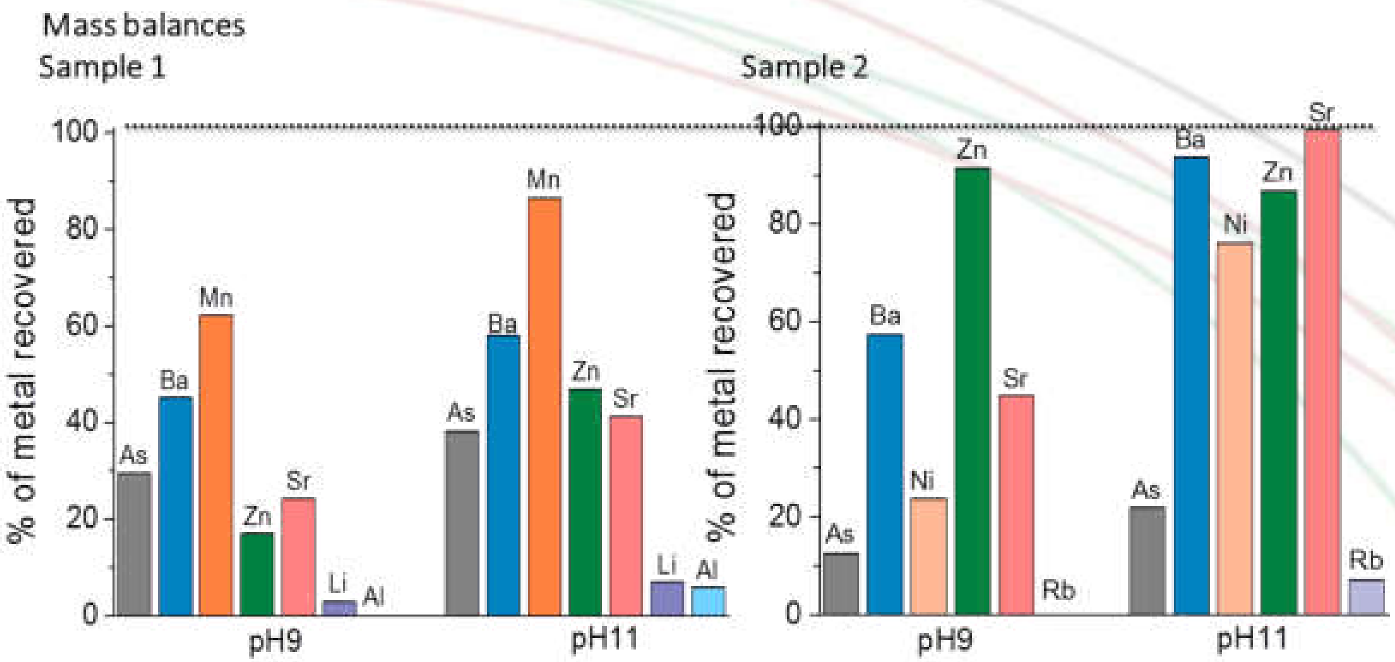


Test setup

- 250 ml batch vessels
- 10 cm^2 GDE anode

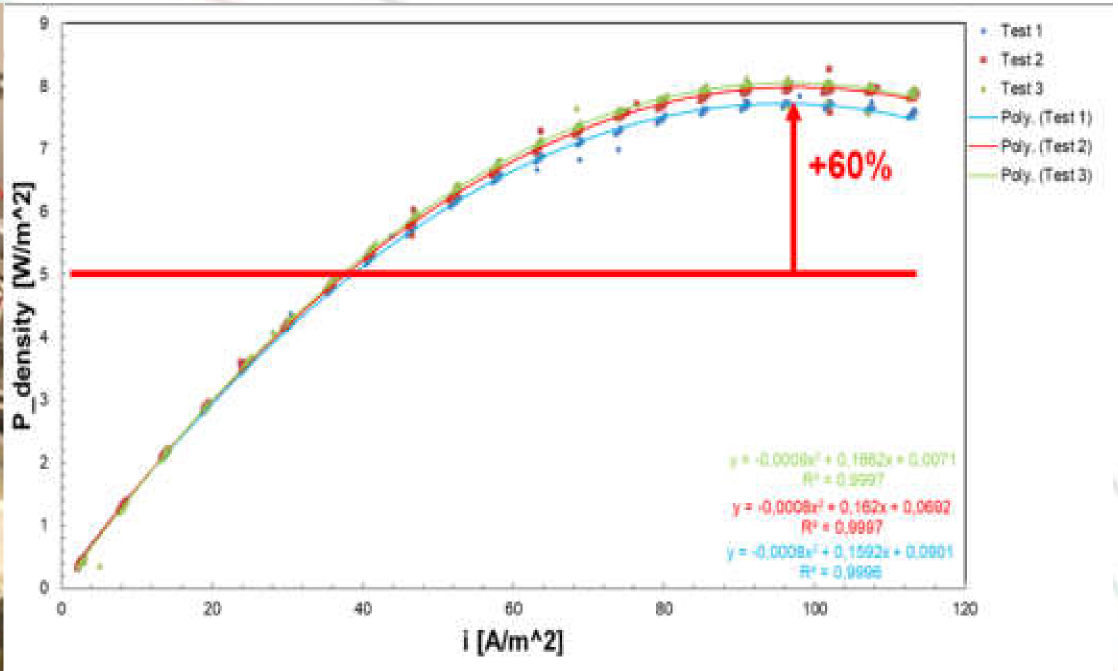
Metal recovery with GDEx (LTLP)

Geothermal brines from Romania



Real brine	Main precipitated products
Sample 1	**Magnesium hydroxide** **Strontium manganese oxide** **Zinc sulfate hydrate**
Sample 2	**Strontium manganese oxide** **Calcium iron oxide**

Additional electricity production by salinity gradient power generation



- Reverse electrodialysis
- Effect of T on power generation in the stack: higher T increases power generation

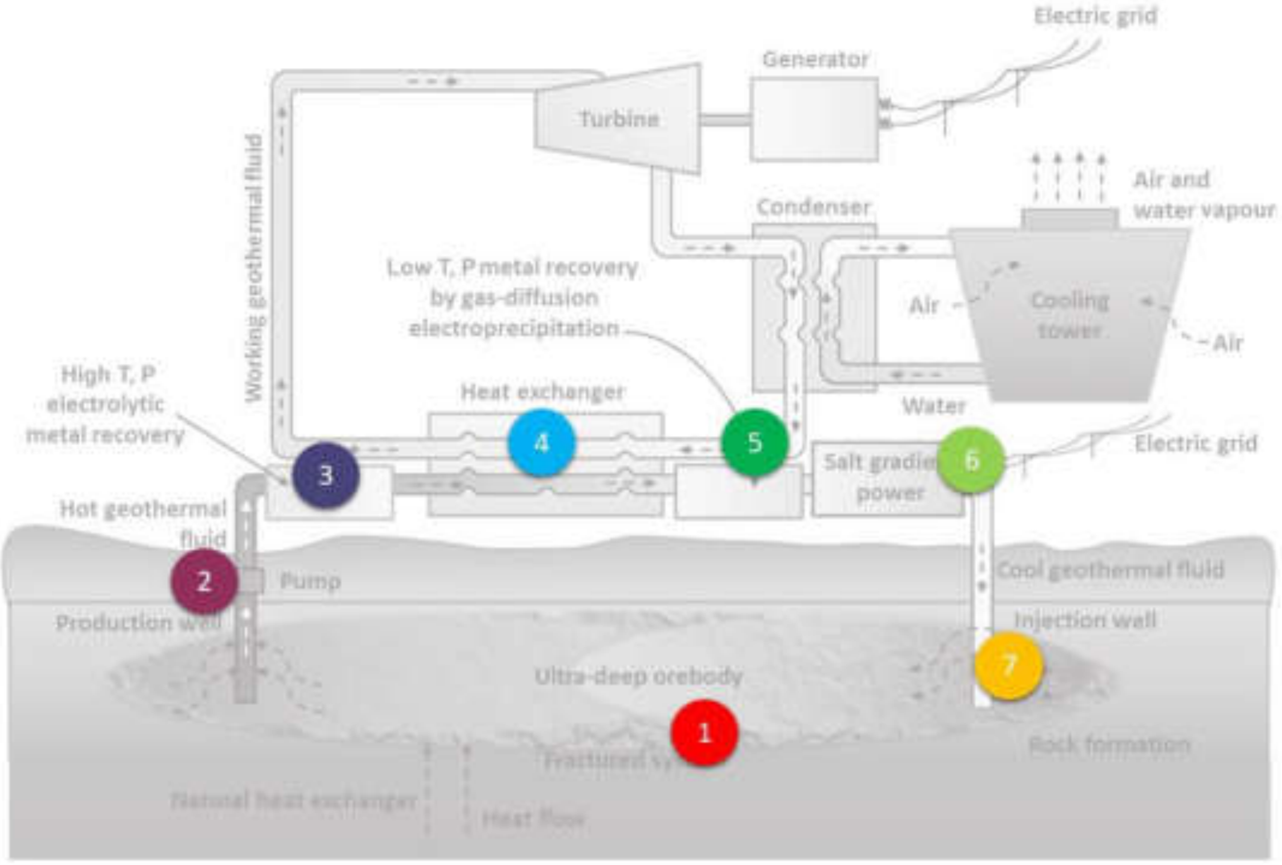

Report on performance and design criteria for high-temperature, high-pressure electrolysis
CHPM2030 Deliverable D3.1
CHPM2030
Report on performance, mass and energy balances and design criteria for gas-diffusion electroprecipitation and electrocrystallization
CHPM2030 Deliverable D3.2
CHPM2030
Report on performance, energy balances and design criteria for salt gradient power reverse electrodialysis
CHPM2030 Deliverable D3.3
CHPM2030

System integration: technological components – design parameters

Design parameters:

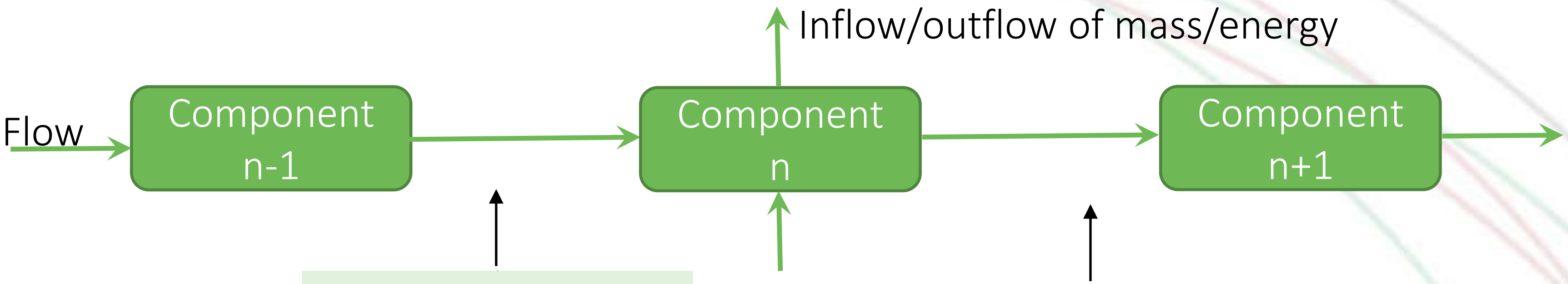
- Temperature
- Pressure
- Acidity/basidity
- Redox condition
- Oxygen fugacity
- Carbon dioxide
- Conductivity
- Flow rate
- Salinity
- Oxidizing compounds
- Concentrated suspended solids

Main technological components



Model framework based on component level models

The different system components were integrated into a single system by a mathematical model. This model is used to develop optimisation strategies for heat, energy and metal production.



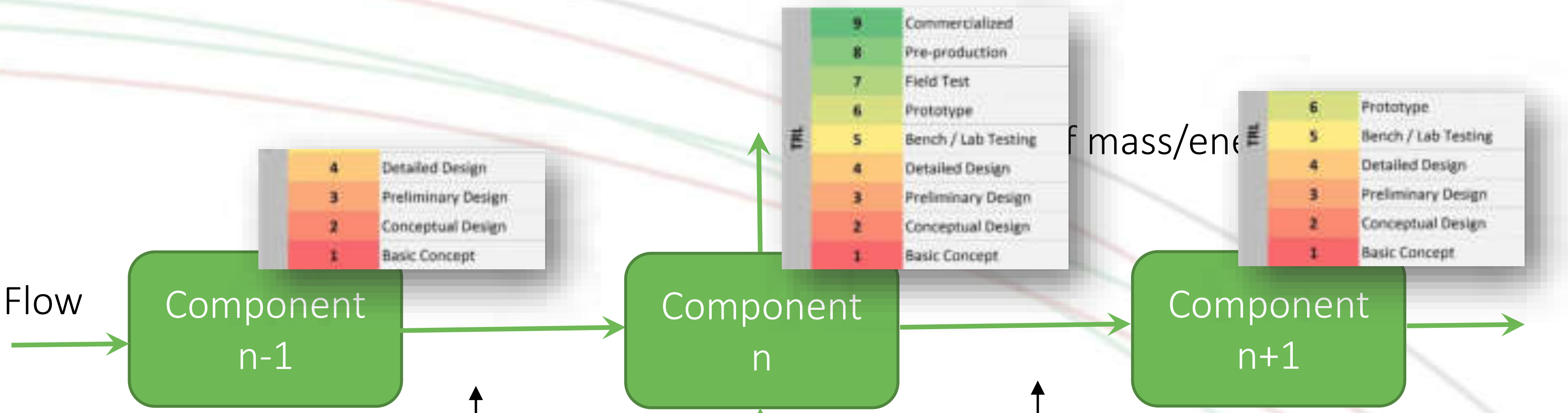
Set of relevant input parameters (A_n):

T: temperature
P: pressure
m: flow rate
M: concentration
S: salinity
etc.

Set of output parameters $A_{n+1} = f(A_n)$

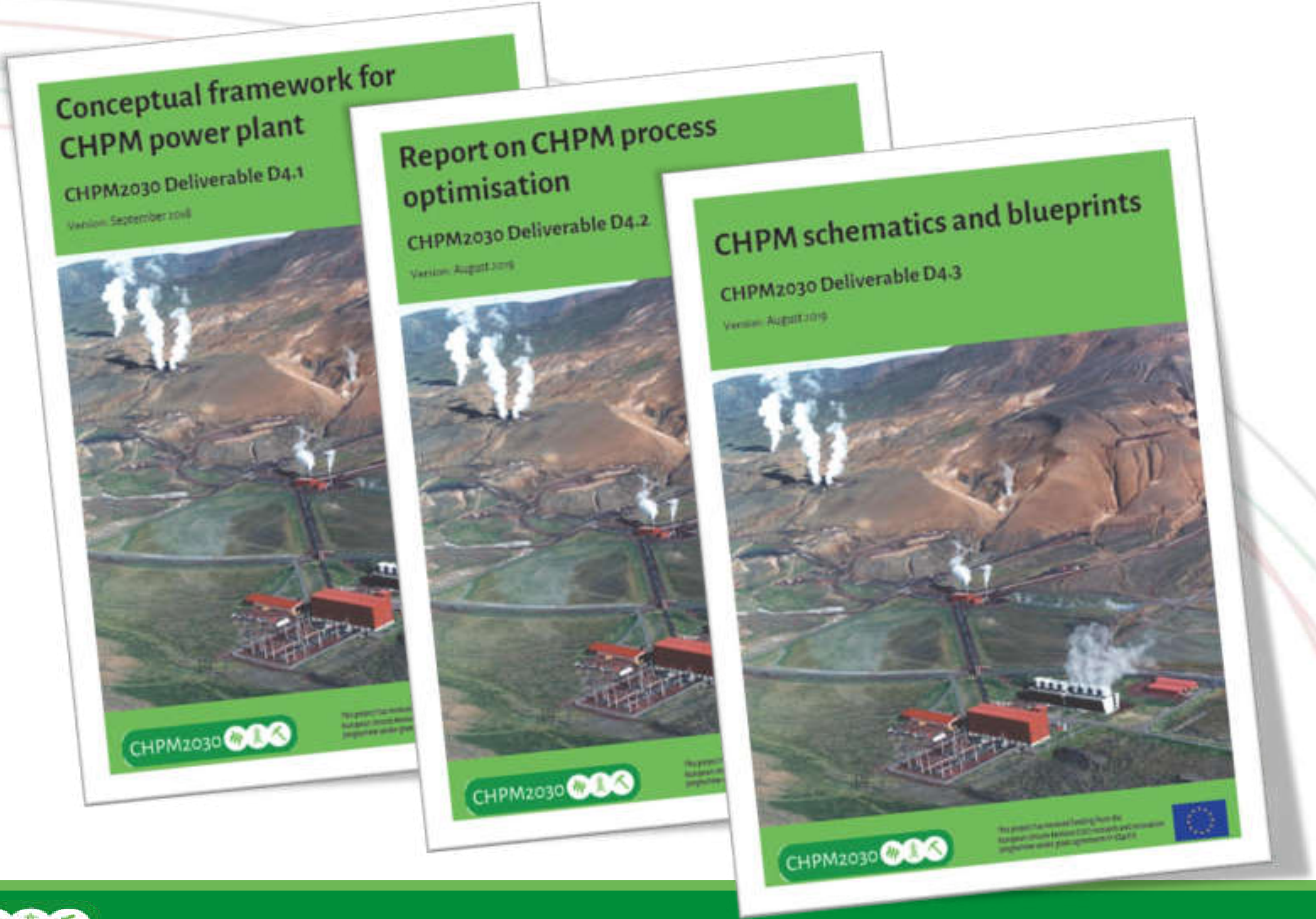
f is a function that describes the relationship between the input and output parameters of component n

From component model to systems dynamic



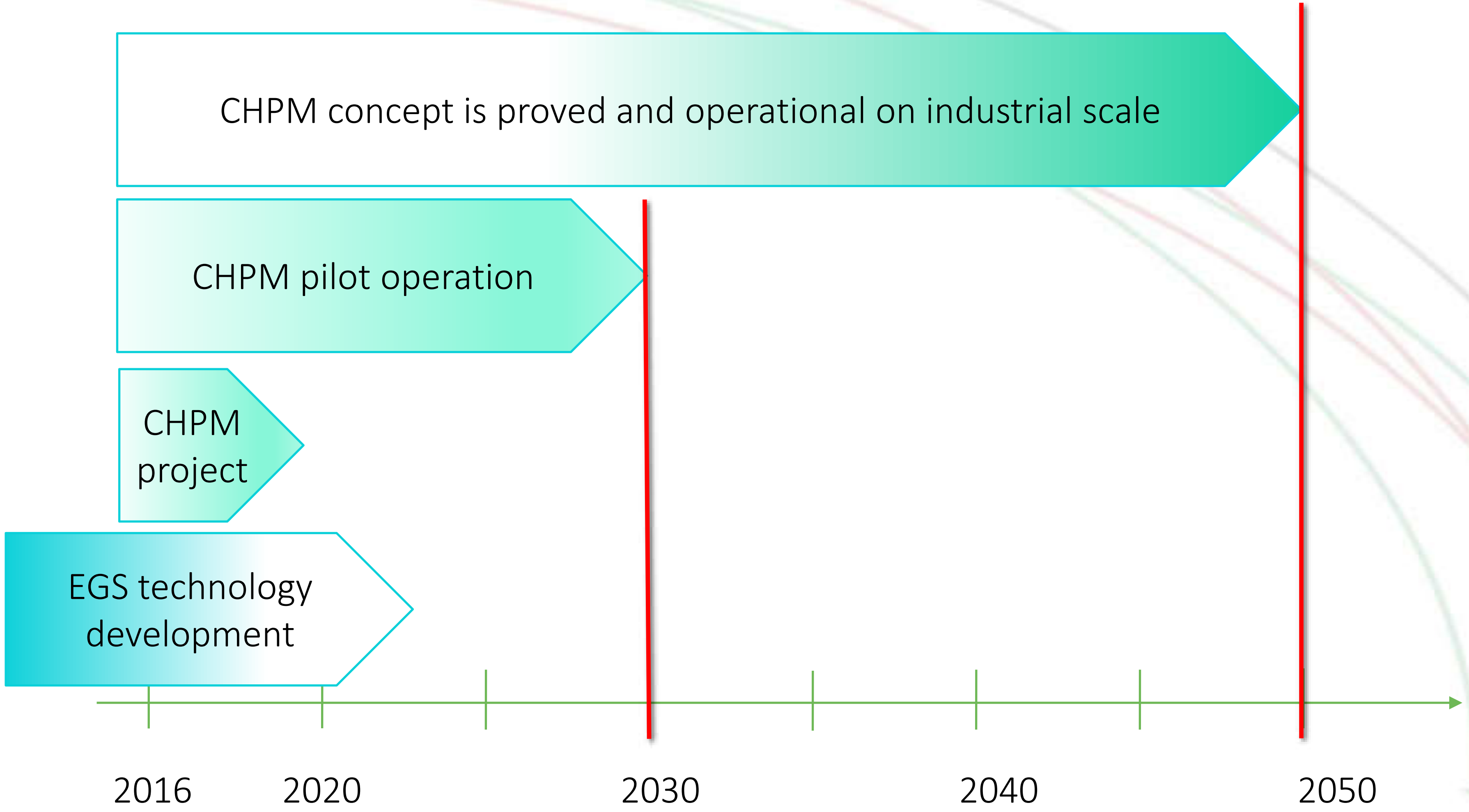
Technology harmonisation issues within the CHPM loop:

- Technology components are at different TRL
- Component models represent different levels of complexity
- The system dynamics model must handle various levels of data reliability
- Agreement on the minimum dataset of design parameters
- Move from very simple to complex
- Move from site specific scenarios toward a general CHPM plant

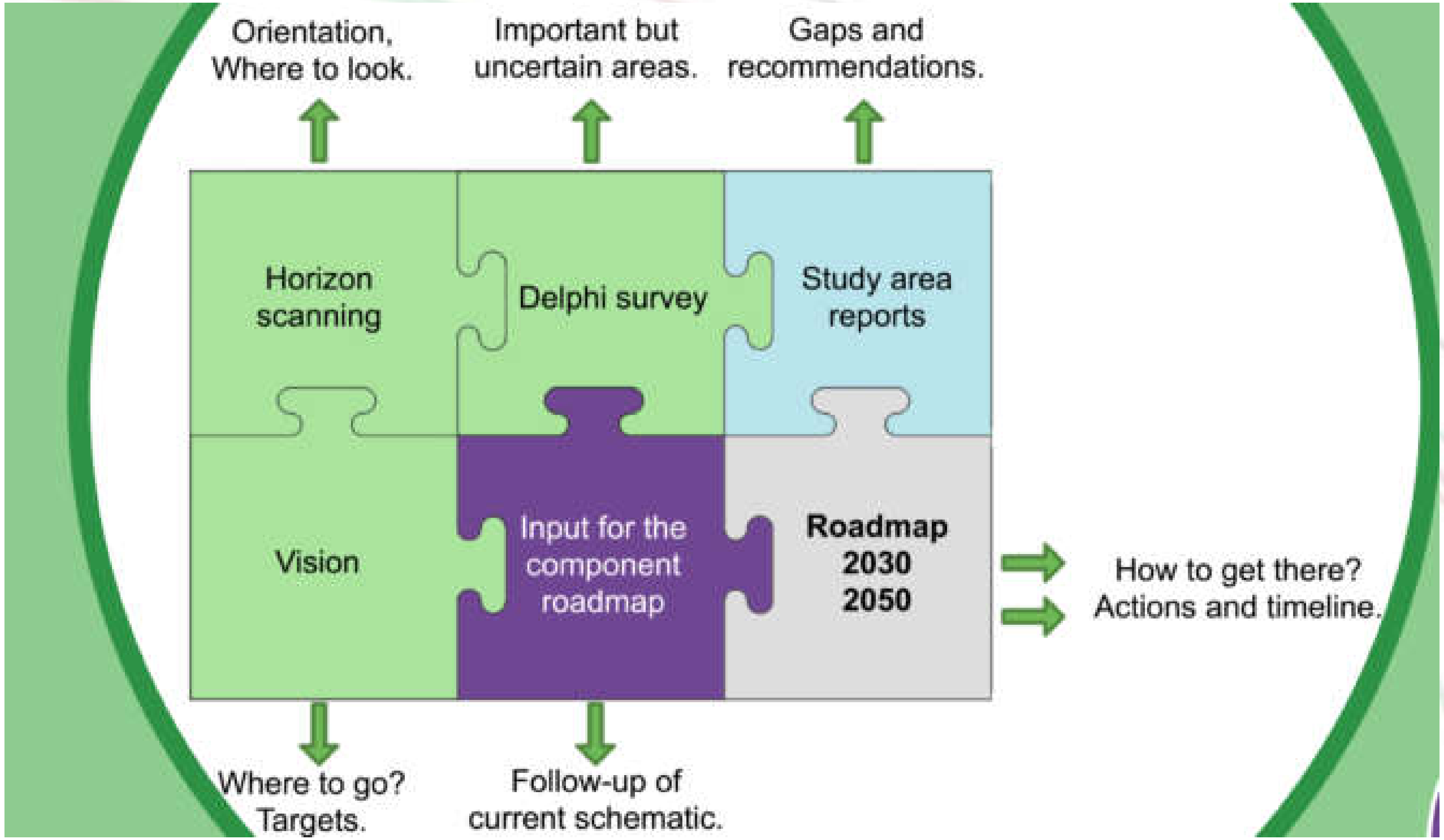

Conceptual framework for CHPM power plant
CHPM2030 Deliverable D4.1
CHPM2030
Report on CHPM process optimisation
CHPM2030 Deliverable D4.2
CHPM2030
CHPM schematics and blueprints
CHPM2030 Deliverable D4.3
CHPM2030

Integrated sustainibility assessment

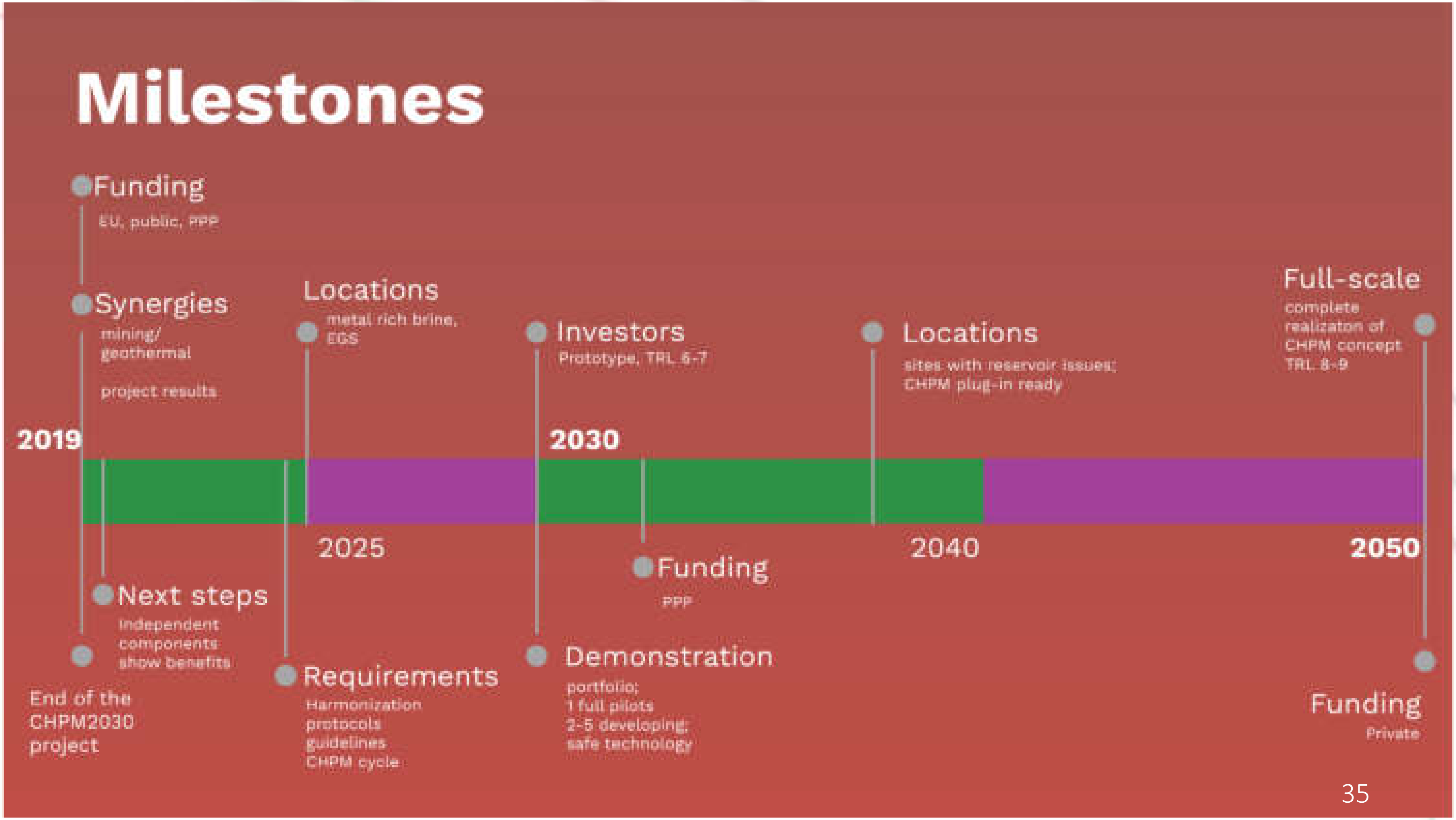
The time horizon



Research roadmap



Research roadmap - timeline




Report on Emerging and Converging Technologies
CHPM2030 Deliverable D6.1
CHPM2030
Report on Pilots
CHPM2030 Deliverable D6.2
CHPM2030
Roadmap for 2030 and 2050
CHPM2030 Deliverable D6.3
CHPM2030

Conclusions

- CHPM2030 was a low TRL project, promising a proof of concept on lab scale.
- Some technology components were developed on lab scale, while other elements are readily available full scale.
- Parallel activities of technology development and a whole system dynamic modelling are special features of the project.
- Full loop concept was not achieved during the project implementation phase (was not even the purpose).

Thank you for your attention!

www.chpm2030.eu

CA questions: