Norway grants

Project EnerGizerS

CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply

Anna Sowiżdżał AGH University of Science and Technology

GeoModel conference
5 September 2023

CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply | EnerGizerS

- **Project Promoter:** AGH University of Science and Technology, **Poland**
- **Partner 1:** Mineral and Energy Economy Research Institute, Polish Academy of Sciences, **Poland**
- **Partner 2:** SINTEF Energi, **Norway**
- **Partner 3:** Norwegian University of Science and Technology, **Norway**
- **Partner 4:** EXERGON Sp. z o.o, **Poland**

The project EnerGizerS has received funding as part of the POLNOR 2019 Polish-Norwegian research projects financed under Norway Grants via the National Centre for Research and Development.

Norway grants

The National Centre for Research and Development

Project: *CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply*, acronym **EnerGizerS**, registration number NOR/POLNOR/EnerGizerS/0036/2019, obtained funding as part of the POLNOR 2019 Polish-Norwegian research projects financed under Norway Grants

ENERGIZERS

CO_2 - Enhanced Geothermal Systems for Climate Neutral Energy Supply

Duration: 2020 – 2023

Total budget: 5 932 700 PLN
Grant funding: 5 793 975 PLN

Project Manager:
Anna Sowiżdżał, Professor AGH
Contact: ansow@agh.edu.pl

Project Partners

AGH · IGSMiE PAN · SINTEF · NTNU · EXERGON

Working together for a green, competitive and inclusive Europe

Main objective of the EnerGizerS project

- ✓The main objective of the project is to progress the technology of **Enhanced Geothermal Systems (EGS) using CO_2** as a working fluid closer to industrial deployment

- ✓This is done by analyzing test fields, located in **Poland and in Norway**, respectively, and by closing knowledge gaps needed to bring the technology forward in these cases

- ✓An important objective of the project is also to enhance the cooperation between the Polish and Norwegian partners involved in projects with the aim for building cooperation for future activities

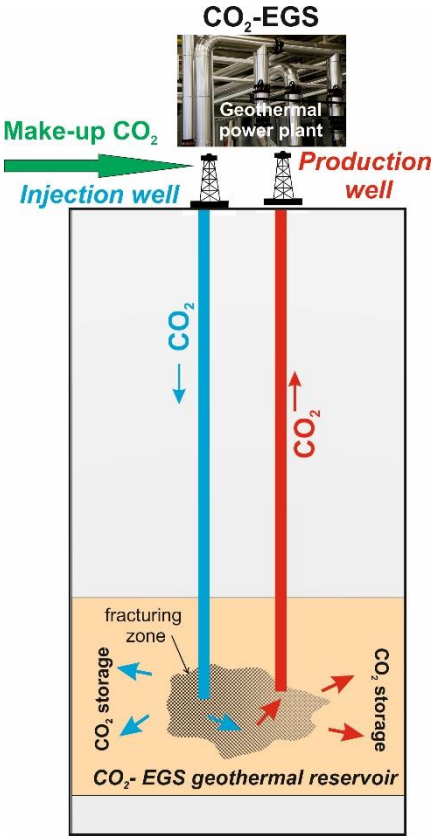
The energy of hot dry rocks is used in the world by means of **EGS - Enhanced Geothermal System**

This is done by artificially increasing the hydraulic capacity of a geothermal reservoir, and then introducing a working fluid into it, which is an energy carrier, and bringing it to a power plant or combined heat and power plant

The EGS technology was developed in the 1970s in the United States, when a group of scientists from Los Almos National Laboratories created the world's first installation in Fenton Hill

The most common working fluid in EGS is water, however, due to numerous reasons, including the excellent thermodynamic properties of carbon dioxide and the need to reduce greenhouse gas emissions into the atmosphere, CO_2 as a working fluid instead of water is a very interesting alternative (CO_2-EGS)

CO_2-EGS system scheme



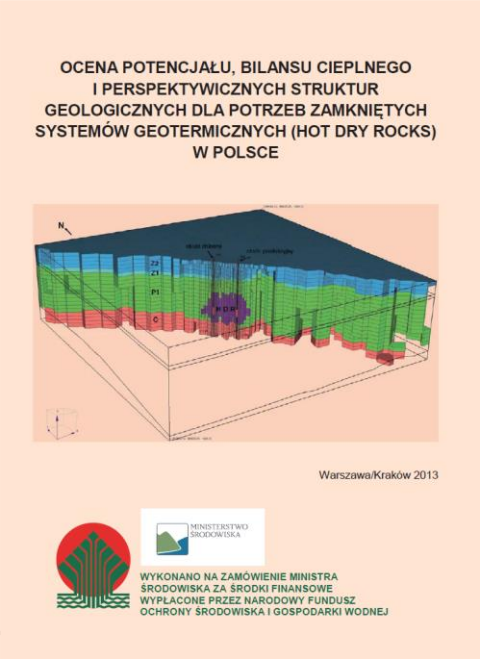
Norway grants

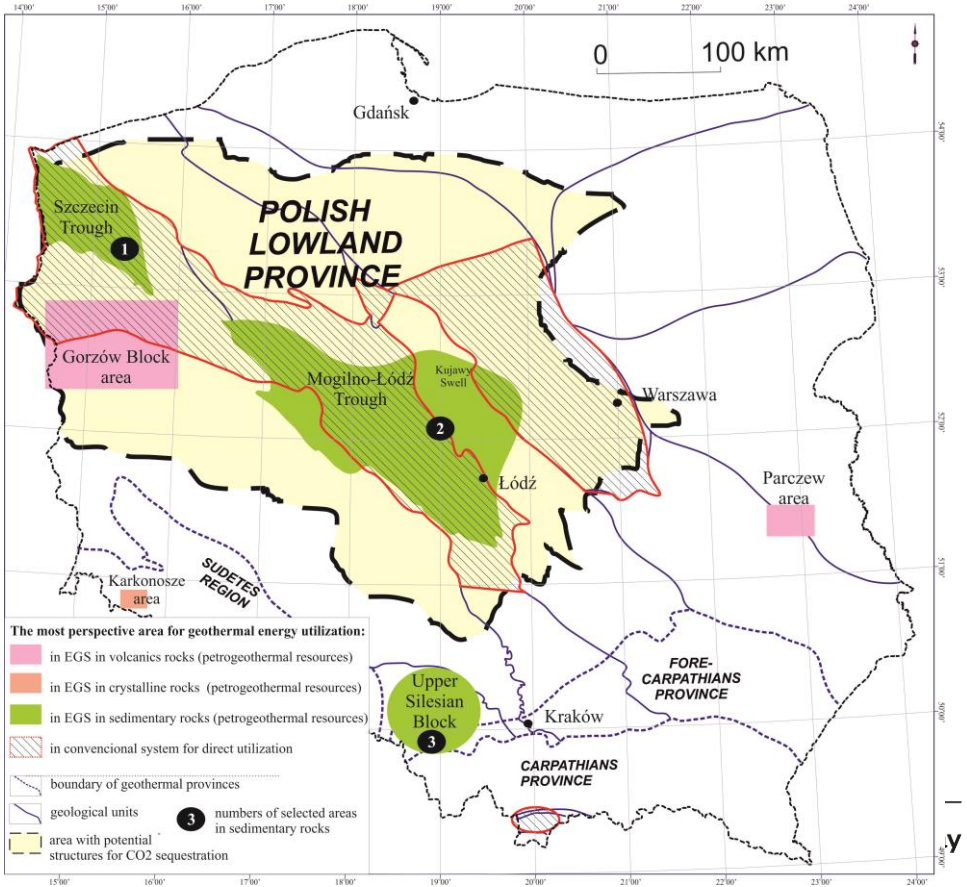
The most prospective area for petrogeothermal energy utilization in Poland

Based on : Wójcicki, Sowiżdżał, Bujakowski (red) i in., 2014 & Sowiżdżał, 2018;

2010-2013

Evaluation of Potential, Thermal Balance and Prospective Geological Structures for Needs of Unconventional Geothermal Systems (Hot Dry Rocks) in Poland

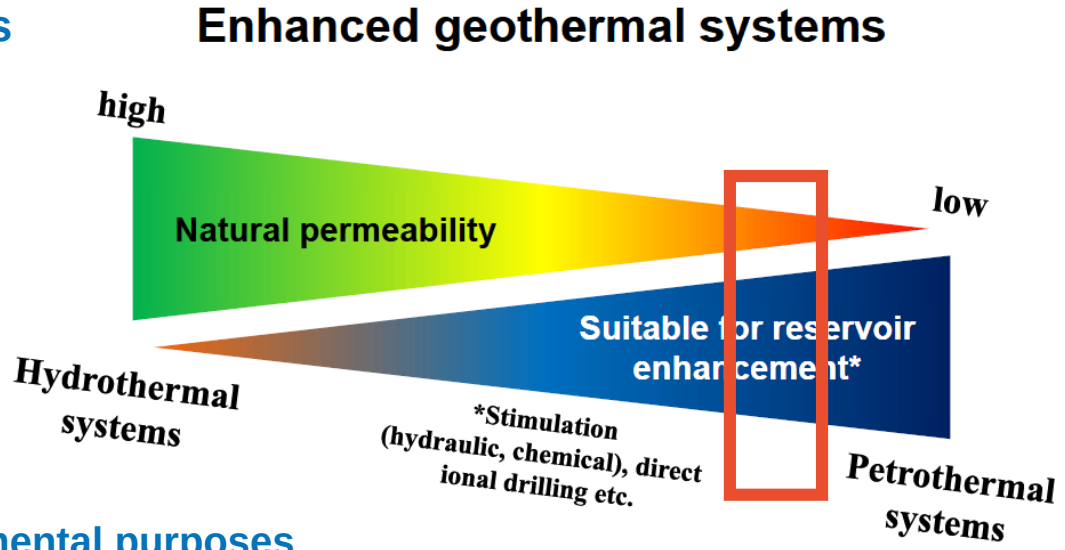




EnerGizerS project objectives

1. EGS – for energetic purposes

The concept of utilization of heat from hot dry rocks assumes drilling wells in areas characterized by **high temperature anomalies and intense heat transfer**

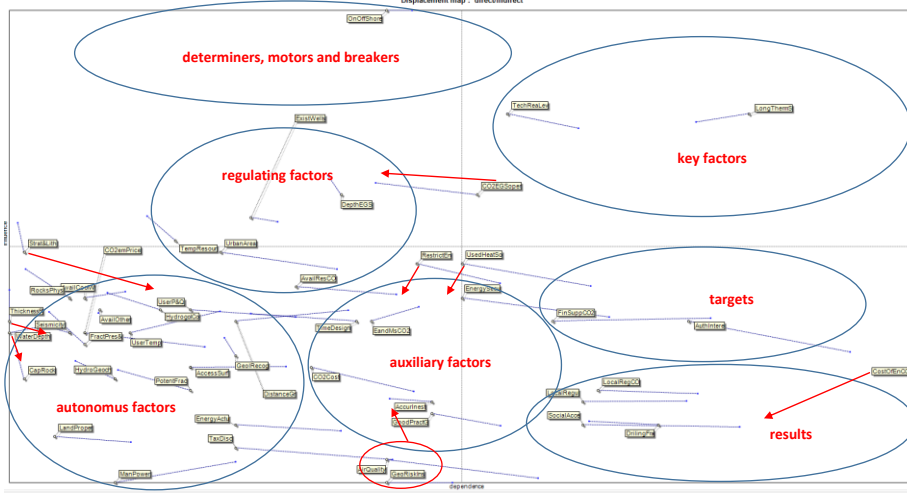


2. CO_2 sequestration – for environmental purposes

Based on Zimmermman i in., 2011

CO_2-EGS site selection criteria

Based on the research the most essential variables for the development of CO2-EGS systems technology can be selected, in particular:



Red arrows indicates the factors moved by expert and joined to a certain group of parameters

Matrix of Influences (MOI)

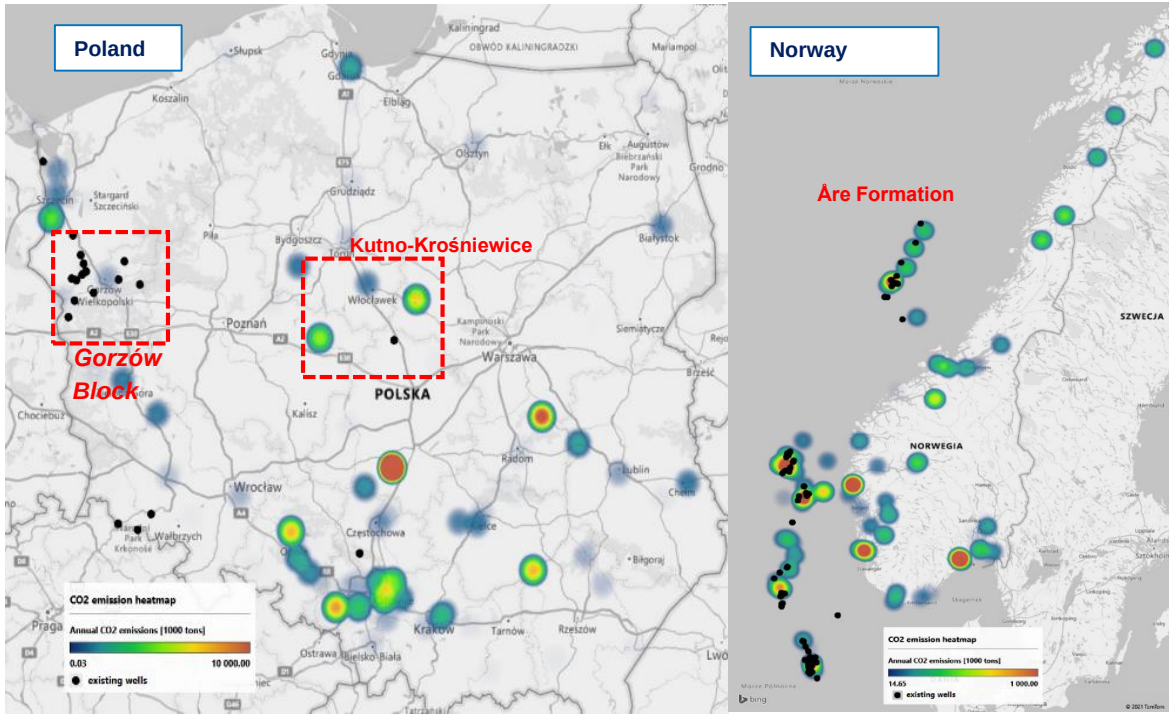
- ❑ Formal constraints related to the local nature protection areas - this variable is essential in the case of an onshore system,
- ❑ Availability of CO_2 sources,
- ❑ Level of geological recognition,
- ❑ The distance of the CO_2-EGS from a thermal energy user and electricity grid,
- ❑ Existing wells and other infrastructure,
- ❑ Depth of the EGS system,
- ❑ Water depth if offshore, this variable is only important when offshore systems are involved,
- ❑ Physical parameters of reservoir rocks,
- ❑ Reservoir temperature

Identification of key parameters for the effective use of the EGS-CO_2 systems and selection of appropriate locations (WP1)

After a number of analyzes, the following locations were selected:

- **in Poland**: **the Gorzów Block** area and the Mogilno-Łódź Trough (**Krośniewice-Kutno area**)
- in Norway: **Åre Formation** in the Norwegian Sea, Skagerrak Formation and Ula Formation (North Sea).

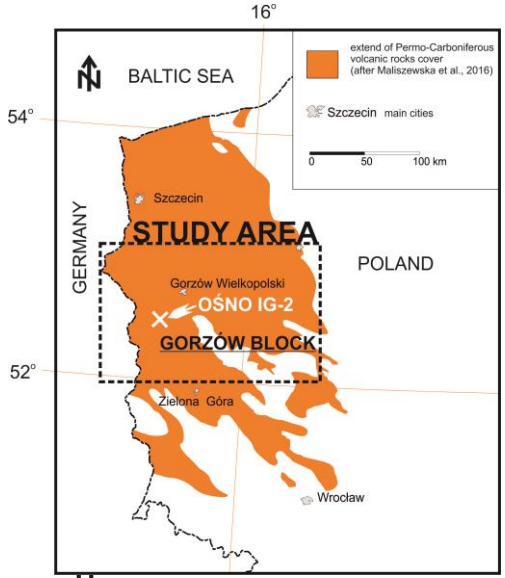
Matrix of Influences (MOI)



Three main potential location for CO_2-EGS

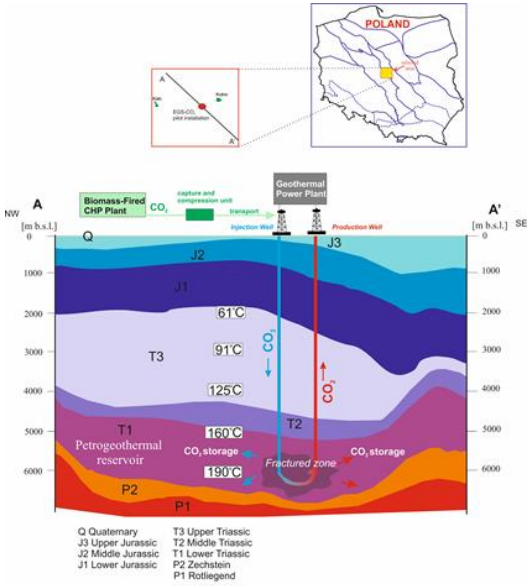
Gorzów Block – Poland

- Reservoir depth [m] 4200-4300
- Reservoir temperature [°C] 145-150
- Reservoir rock: sedimentary&effusive



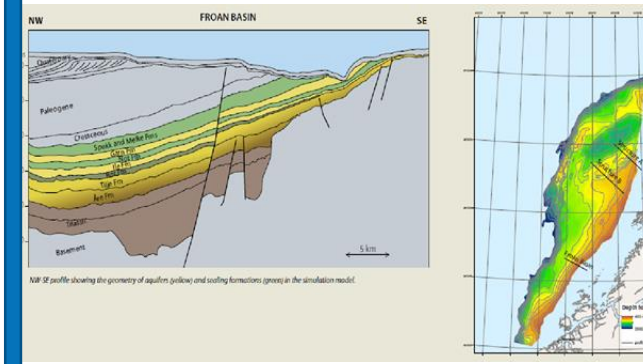
Krośniewice-Kutno- Poland

- Reservoir depth [m] 5000-6500
- Reservoir temperature [°C] 165-195
- Reservoir rock: sedimentary



Åre Formation - Norway

- Reservoir depth [m] 4700
- Reservoir temperature [°C] 160
- Reservoir rock: sedimentary

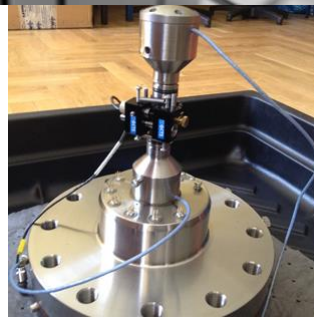


Characteristics of the geothermal reservoir based on the results of comprehensive laboratory tests of rocks

- ❑ **DATABASE CONTAINING ARCHIVAL PETROPHYSICAL AND MECHANICAL DATA**
- ❑ **CORE SAMPLE**

Laboratory tests:

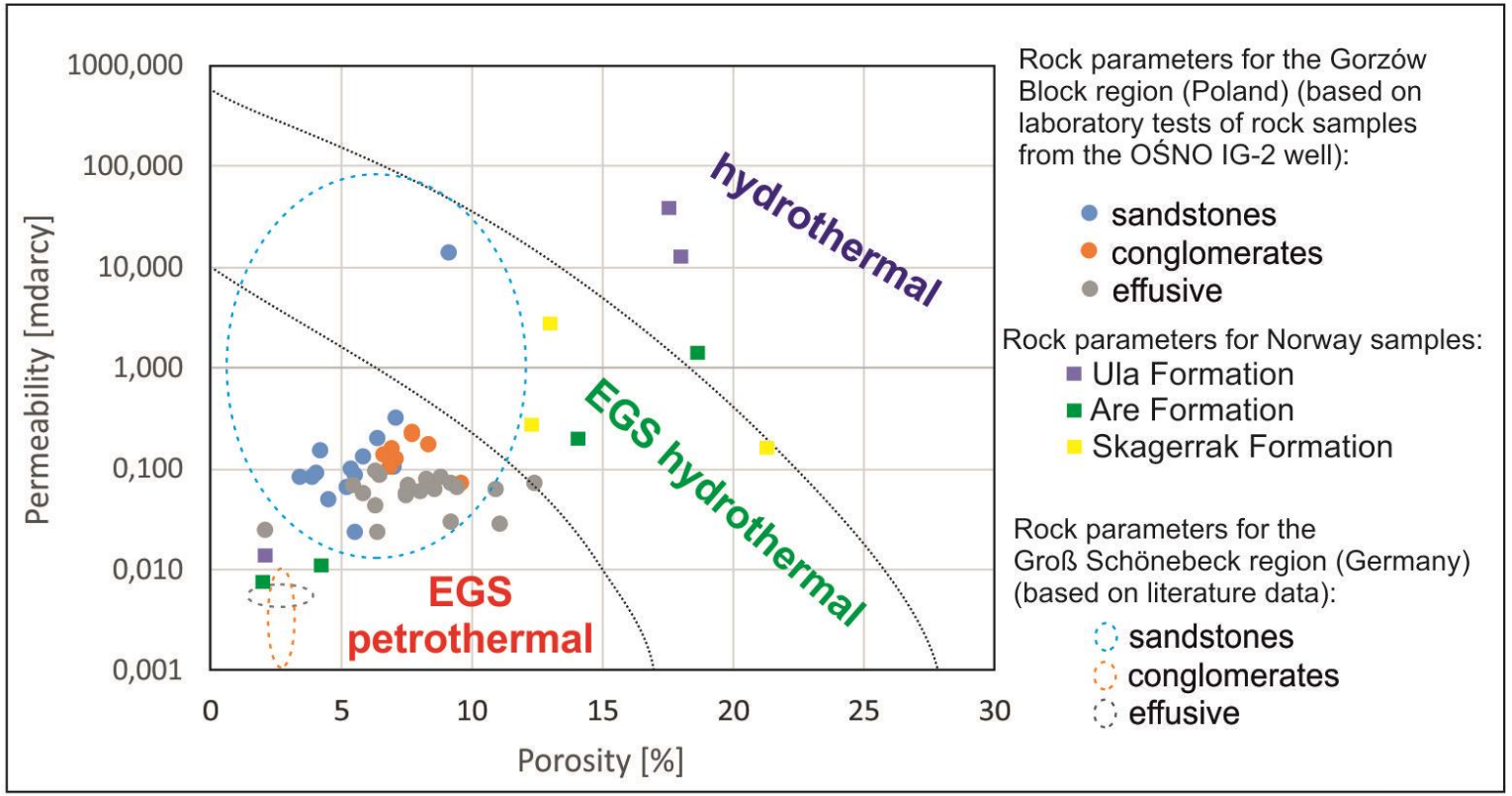
- ✓ **Petrophysical** - pore space saturation measurements by Nuclear Magnetic Resonance (NMR) method, pore space investigations using the mercury porosimetry (MICP) method
- ✓ **Mechanical** - Elastic moduli: Young, bulk and shear modulus were calculated taking into consideration P-, S-wave velocity and density for each geomechanical test stage
- ✓ **Thermal** - thermal conductivity measurements using the FOX50 set
- ✓ **Mineralogical** composition using the XRD method



Poland: **42 core samples** were collected from the Ośno IG-2 well from the depth interval 3212 – 3659 m bgl for laboratory tests; analysis of three different types of potential reservoir rocks: sandstones, conglomerates and effusive, in terms of the CO_2 – EGS.

Norway: **10 core samples** from the depth range of 2804 – 5231 m and represent three formation: Are, Skagerrak and Ula.

AGH TEAM:
Anna Sowiżdżał
Grzegorz Machowski
Artur Krzyżak
Edyta Puskarczyk
Paulina Krakowska-Madejska



Porosity and permeability relation of different geothermal reservoir rocks

Application as EGS petrothermal, EGS hydrothermal or pure hydrothermal are presented based on (Moeck, 2014)

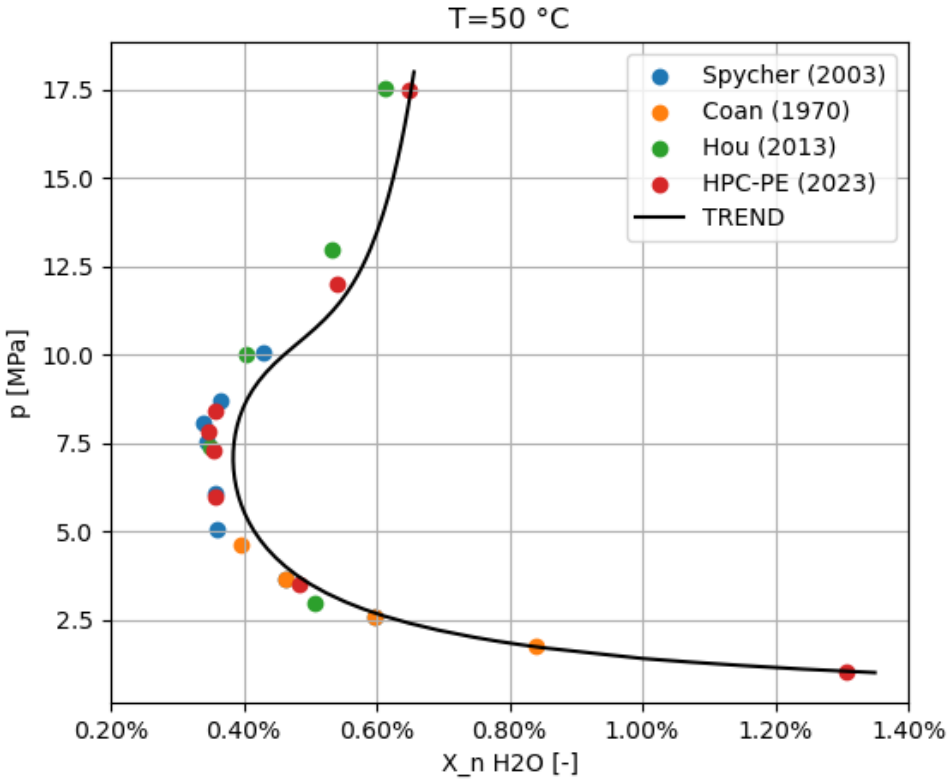
EXPERIMENTAL DETERMINATION OF PROPERTIES AND BEHAVIOUR OF CO_2-EGS WORKING FLUIDS

The experimental campaign was carried out using the laboratory infrastructure located at SINTEF with the participation of a PhD student from AGH who participates in laboratory experimental measurements during a 6-month internship.

The setup that was used for the phase equilibrium measurements, the ECCSEL High Pressure and Complex Phase Equilibrium facility (HPC-PE) is highly instrumented

Result: A new setup for accurate measurements of phase behaviour of CO_2 mixtures relevant for Enhanced Geothermal Systems working fluid, covering a range from -60 to 200°C in temperature and up to 100 MPa in pressure.

Experimental data compared with literature data and TREND



Digital structural models for selected EGS fields

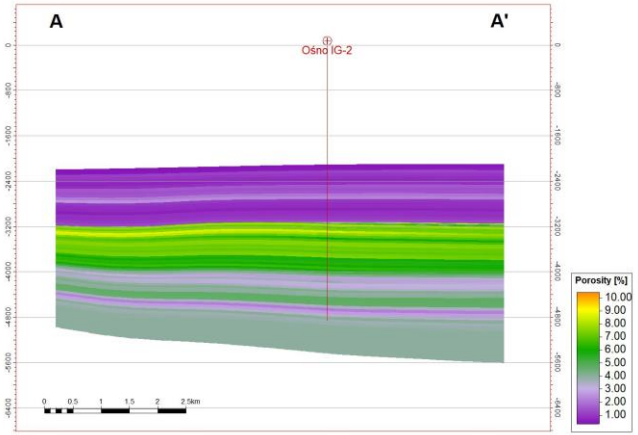
AGH TEAM:
Bartosz Papiernik
Gabriel Ząbek

Structural model:
- ❑ Zechstein
- ❑ Sedimentary Upper Rotliegend
- ❑ Upper Autunian
- ❑ Volcanic Autunian
- ❑ Lower Autunian

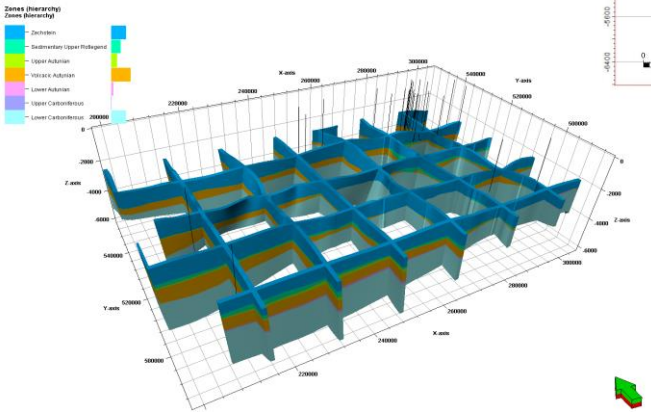
(except for the OŚNO local model)
- ❑ Upper Carboniferous

(except for the OŚNO local model)
- ❑ Lower Carboniferous

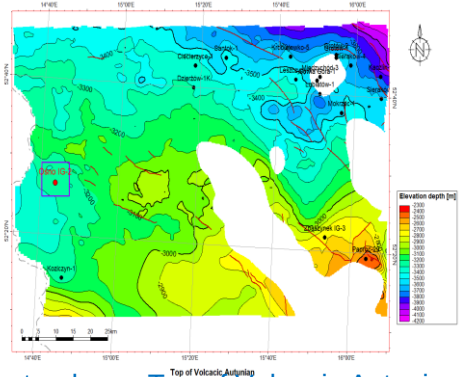
3D models for Gorzów Block area



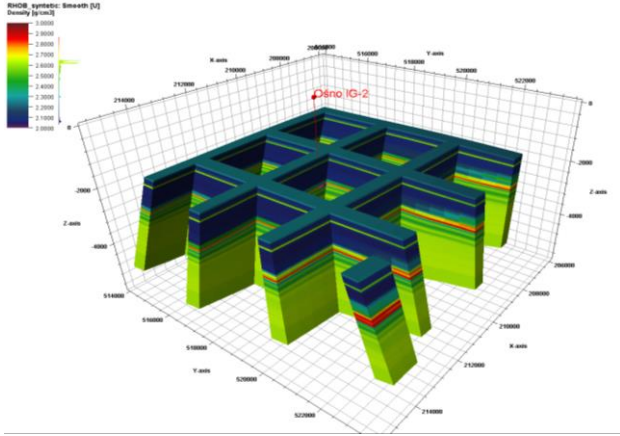
Parametric model:
- ❑ Porosity (PHI)
- ❑ Shale volume (VSH)
- ❑ RHOB model



Plot diagram of 3D structural model (zone division) in Gorzów Block Area



Structural map Top of Volcanic Autunian horizon



Plot diagram of 3D density local model in Gorzów Block area

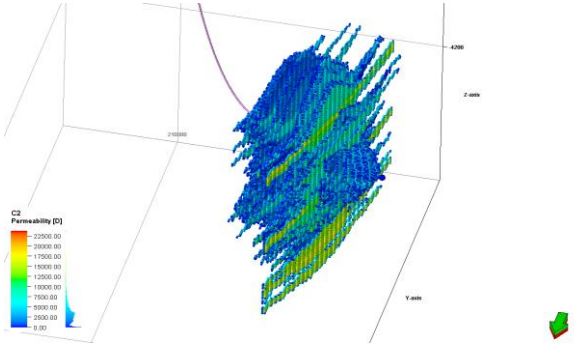
Simulation of hydraulic fracturing

Results: directional well and water as fracturing fluid, drilling a well with a production section length of more than about 600 meters is inefficient

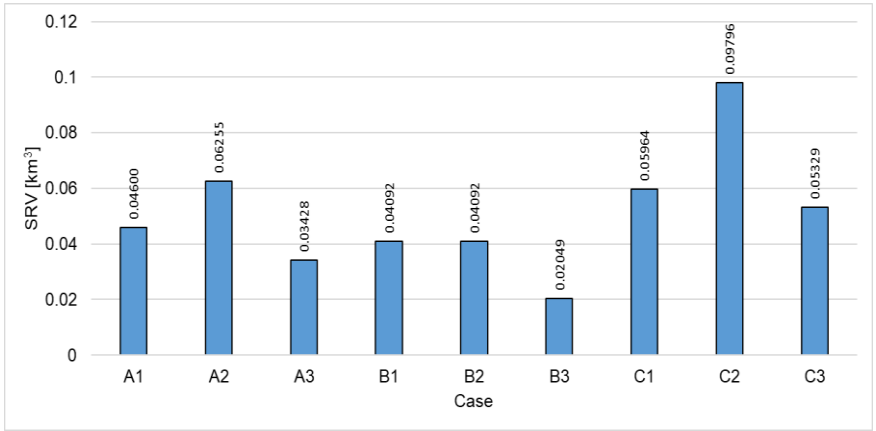
- **Base Case (horizontal well 1000 m)** well **injected 5000 m³** of **water** as treatment fluid
- **Cases A (horizontal well 600 m):**
  - A1 – Horizontal well **injected 5000 m³** of **water** as treatment fluid
  - A2 – Horizontal well **injected 7000 m³** of **water** as treatment fluid
  - A3 – Horizontal well **injected 5000 m³** of **CO_2** as treatment fluid
- **Cases B (deviated well case 1):**
  - B1 – Deviated well (case 1) **injected 5000 m³** of **water** as treatment fluid
  - B2 – Deviated well (case 1) **injected 7000 m³** of **water** as treatment fluid
  - B3 – Deviated well (case 1) well **injected 5000 m³** of **CO_2** as treatment fluid
- **Cases C (deviated well case 2):**
  - C1 – Deviated well (case 2) **injected 5000 m³** of **water** as treatment fluid
  - **C2 – Deviated well (case 2) injected 7000 m³ of water as treatment fluid**
  - C3 – Deviated well (case 2) well **injected 5000 m³** of **CO_2** as treatment fluid

GOHFER simulation software

AGH TEAM:
Paweł Wojnarowski
Damian Janiga



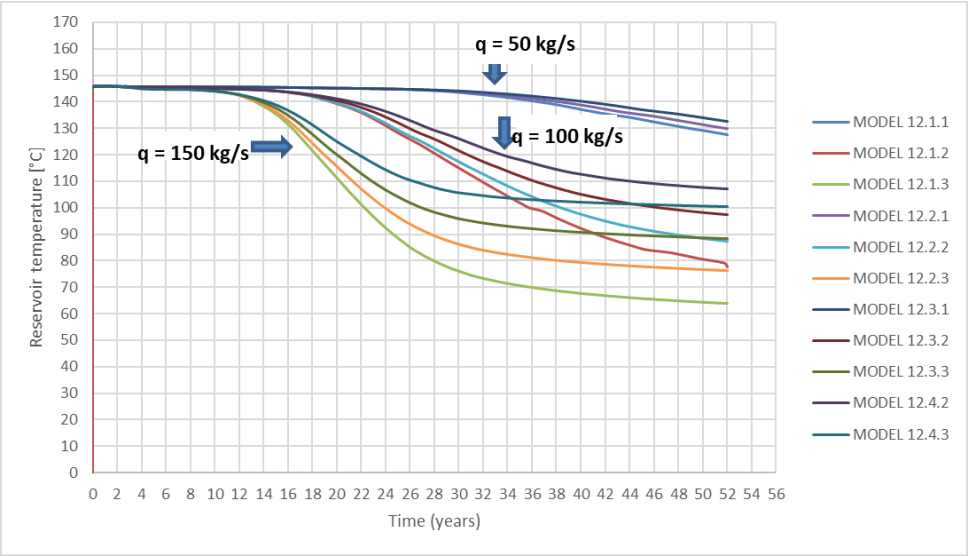
Fracture permeability distribution



Estimated stimulated reservoir volume results

CONSTRUCTION OF THE 3D NUMERICAL MODEL FOR MULTI-VARIANT SIMULATIONS OF CO2 INJECTION AND EXPLOITATION WITH FORECAST OF RESERVOIR BEHAVIOUR OVER TIME

The production modeling includes simulation of possible scenarios of CO2 injection and exploitation depending on the adopted parameters of the fractured reservoir and designed capacity of the surface installation.



Temperature evolution in the production zone, Gorzów Block model

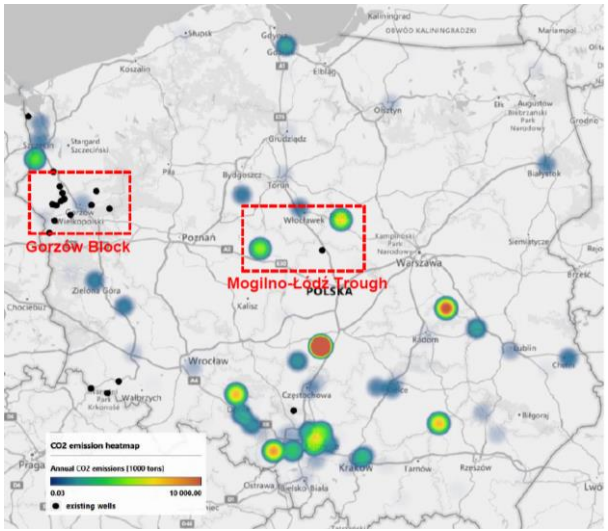
MEERI PAS TEAM

All production models were run using the TOUGH3 reservoir simulator

Polish and Norwegian scenarios

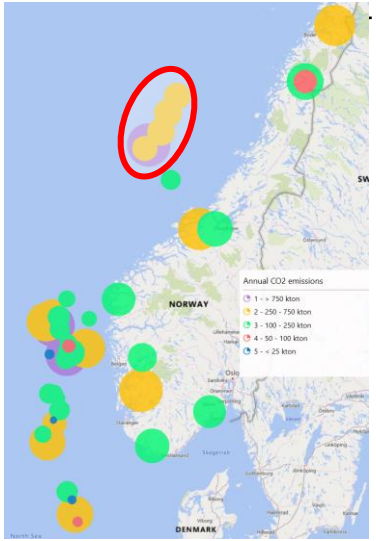
Polish scenario:

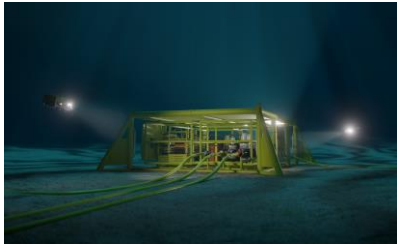
- Location: Onshore, near populated area
- Target output: Power and heat or power only



Norwegian scenario:

- Location: Offshore, subsea installation
- o





Polish and Norwegian scenarios

No.	General location type	Specific location	Heat demand type	Type of energy generation	Type of energy cycle
1	Onshore (Poland)	Gorzów Block	District heating system	Combined heat and power	Direct (sCO_2 cycle)
2	Offshore (Norway)	Åre Formation	Lack of heat demand	Power generation only	Hybrid (sCO_2 cycle with ORC)
3	Onshore (Poland)	Mogilno-Łódź Trough	District heating system	Combined heat and power	Indirect (ORC)
4	Offshore (Norway)	Åre Formation	Lack of heat demand	Power generation only	Direct (sCO_2 cycle)

Mathematical modelling of CO_2-based topside systems for heat and power production

- **Goal**: Evaluate topside system designs and performance for selected case studies in Poland and Norway.
- SINTEF focus on Norwegian scenario, AGH and Exergon mainly on Polish scenarios.
- Compare merits **of different modelling tools**, exchange experience.

SINTEF

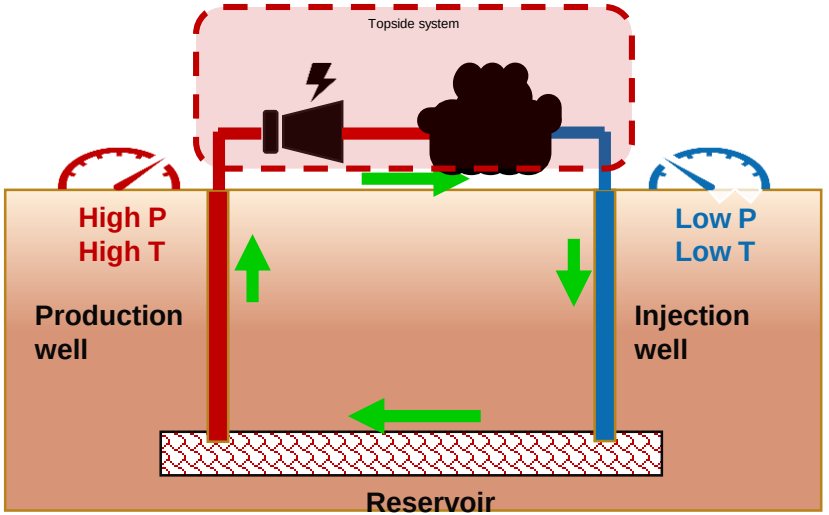
EXERGON

AGH

RESEARCH UNIVERSITY EXCELLENCE INITIATIVE

Ministry of Science and Higher Education

- **TOPSIDE CONCEPT DESIGN**
- **SYSTEM AND COMPONENT MODELING FRAMEWORK**
- **SYSTEM PERFORMANCE SIMULATION AND OPTIMIZATION**

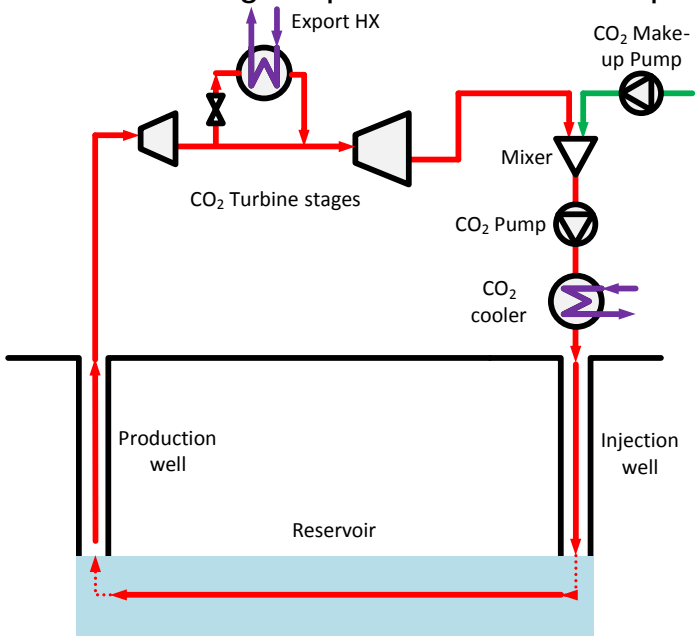


Topside systems – example configurations

Many alternative configurations are possible

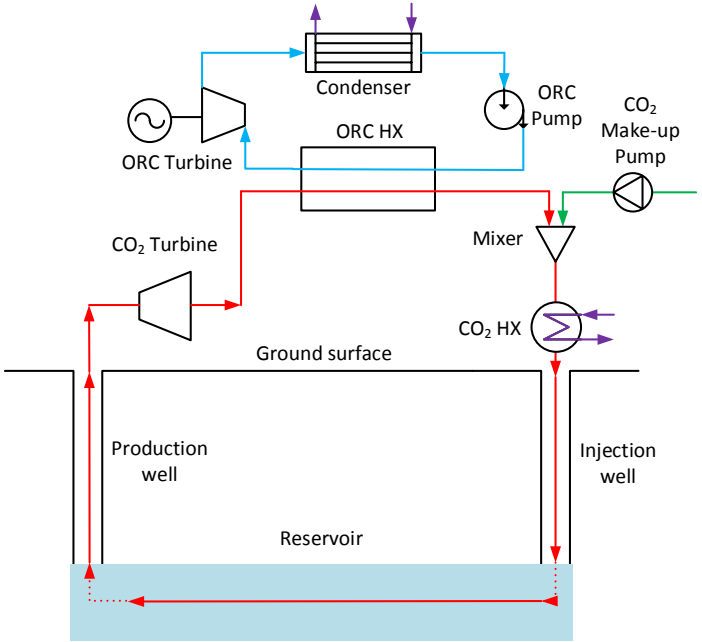
Power + heat export:

Two-stage expansion and heat export



Power only:

"Hybrid" - direct expansion + ORC



Techno-economic and environmental assessment

- TECHNO-ECONOMIC AND ENVIRONMENTAL ASSESSMENT FRAMEWORK FOR CO2-EGS
- TECHNO-ECONOMIC PRE-FEASIBILITY STUDIES (4 CASES: 2 PL, 2 NOR)
- ENVIRONMENTAL IMPACT ASSESSEMENT, INCLUDING CO2 STORAGE SAFETY
- REGULATORY AND POLICY FRAMEWORK ANALYSIS

Life Cycle Assessment – SimaPro software

Journal of Cleaner Production
Volume 379, Part 2, 15 December 2022, 134768

www.energizers.agh.edu.pl

Petrophysical evaluation of the Lower Permian formation as a potential reservoir for CO_2 - EGS – Case study from NW Poland

Anna Sowiżdżał, Grzegorz Machowski, Artur Krzyżak, Edyta Puskarczyk, Paulina Krakowska-Madejska, Anna Chmielowska

Publications & conference proceedings

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Article

Multi-Criteria Studies and Assessment Supporting the Selection of Locations and Technologies Used in CO_2-EGS Systems

Leszek Pająk [1,*], Anna Sowiżdżał [1], Paweł Gładysz [2], Barbara Tomaszewska [1], Maciej Miecznik [3], Trond Andresen [4], Bjørn S. Frengstad [5] and Anna Chmielowska [1]

Norway grants

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Thank you!

Acknowledgements

The research leading to these results has received funding from the Norway Grants 2014-2021 via the National Centre for Research and Development. The results are part of the Polish-Norwegian project: *CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply*, acronym *EnerGizerS*, registration number NOR/POLNOR/EnerGizerS/0036/2019.

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