EnerGizerS

Enhanced Geothermal Systems (EGS) using supercritical carbon dioxide as a working medium

Norway grants

The National Centre for Research and Development

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ABSTRACT

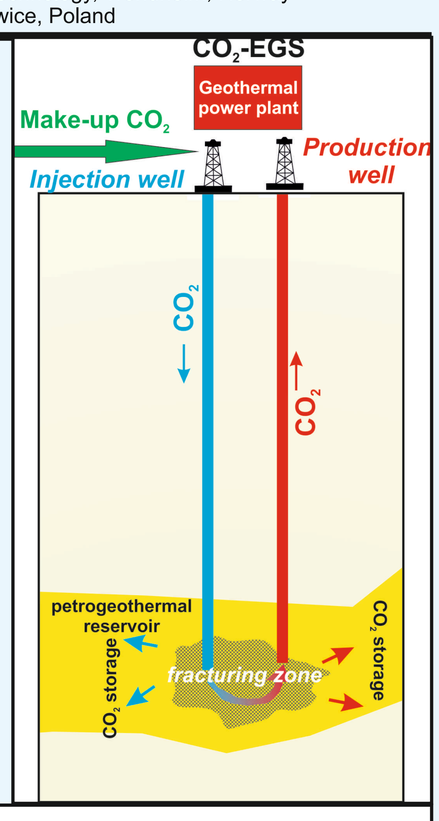
In the era of energy transformation and the search for effective and clean energy production technologies, activities aimed at the use of geothermal energy are of particular importance. An equally important issue is limiting the emission of harmful substances into the atmosphere, including anthropogenic carbon dioxide. Thus, the Polish-Norwegian consortium of scientists led by the AGH University of Science and Technology in Kraków has started the ***EnerGizerS project: CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply***. The main goal of the project is to analyse the effectiveness of the operation of enhanced geothermal systems (EGS) using supercritical carbon dioxide as a working medium.

These systems (**CO_2-EGS**) combine obtaining clean energy from the Earth's interior along with the mitigation of carbon dioxide emissions coming from the combustion of fossil fuels. The research carried out within the **EnerGizerS** project aims to identify and characterise potential geological structures for the location of CO_2-EGS systems **in Poland and Norway**, combining the requirements for both EGS and CCS (Carbon Capture and Storage) technologies. The project results will help to determine the validity of combining two technologies, EGS and CCS, to use and store captured carbon dioxide and produce energy simultaneously. Another important aspect is the exchange of experience and the deepening cooperation between Polish and Norwegian partners to define the best framework for CO_2-EGS technology and reduce the risk of future geothermal investments. At the current stage of the project, it has been possible to select two geological areas in Poland and one in Norway, which will be subject to detailed analysis in the further course of the project.

The final results of the EnerGizerS project will be known in the second half of 2023 and released on the project's website: **www.energizers.agh.edu.pl** and in other publications.

Enhanced Geothermal System (EGS) involves extracting energy from rock by artificially increasing the hydraulic capacity of a geothermal reservoir, then introducing an energy-carrying working fluid into the reservoir and feeding it to a power plant to generate electricity. These systems make it possible to harness geothermal energy when the hydrogeothermal conditions of a particular location prevent a sufficiently high well yield, making the potential locations for EGS much more numerous than for classical hydrogeothermal systems.

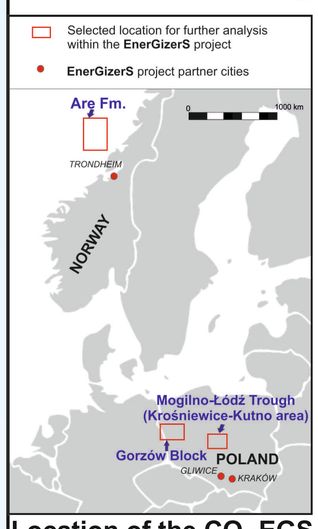
There are two working fluids used in EGS (Moeck, I.S., 2014): the first and most frequently used is **water**, while the second is **carbon dioxide** (CO_2). Although the first solution is definitely more common, EGS using CO_2 instead of water as working fluid is very interesting (CO_2 - EGS) due to the excellent thermodynamic properties of carbon dioxide and the need to reduce greenhouse gas emissions into the atmosphere. Such a reduction can be achieved through geologic storage of CO_2 during the power generation process since part of the carbon dioxide injected into the reservoir remains permanently stored. Therefore, apart from the energy aspect, this is an additional environmental aspect of this type of investment. There is no EGS installation in Poland or Norway, although some research work has been done in this area.



CO_2-EGS system scheme

The main objective of EnerGizerS project will be achieved through the implementation of specific work packages

WP1. IDENTIFICATION OF KEY PARAMETERS FOR THE EFFECTIVE USE OF THE EGS-CO_2 SYSTEMS AND SELECTION OF APPROPRIATE LOCATIONS



Location of the CO_2-EGS potential sites in Poland and Norway

To identify key parameters for the effective use of CO_2-EGS systems, the cross-impact method was used to select a list of factors that are key for the indication of optimal locations suitable for CO_2-EGS systems. Based on the research conducted, the most essential variables for the development of CO_2-EGS system technology can be selected, in particular the variables that are important when selecting locations for this type of system.

These variables include:

- Formal constraints related to the local nature protection areas
- Availability of CO_2 sources,
- Level of geological recognition,
- Distance of CO_2-EGS from a thermal energy user and the electricity grid,
- Existing wells and other infrastructure,
- Depth of the EGS system,
- The depth of the water offshore is important only when offshore systems are involved,
- Physical parameters of reservoir rocks,
- Reservoir temperature.

Table 1: Defined scenarios for the EnerGizerS project

Scenario number	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	Combined direct and indirect cycle
3	Onshore (Poland)	Mogilno-Łódź Trough	District heating system	Combined heat and power	Indirect cycle with ORC
4	Offshore (Norway)	Åre Formation	Site-specific heat demand	Combined heat and power	Indirect cycle with ORC
5	Onshore (Poland)	Gorzów Block	District heating system	Combined heat and power	Combined direct and indirect cycle
6	Onshore (Poland)	Mogilno-Łódź Trough	Lack of heat demand	Power generation only	Combined direct and indirect cycle

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 Formation (North Sea).

An analysis of potential carbon dioxide sources and the energy system suitable for CO_2-EGS technology was also performed. As a result, six scenarios (different combinations of energy systems) of the operation of an enhanced geothermal system for the Polish and Norwegian conditions were defined, which are currently the subject of activities carried out within the EnerGizerS project (Table 1).

WP2. CHARACTERISTICS OF THE GEOTHERMAL RESERVOIR BASED ON THE RESULTS OF EXTENSIVE LABORATORY TESTS OF ROCKS

Laboratory tests were carried out on collected drill cores from selected locations to perform characterization of the petrogeothermal reservoir in Poland and Norway. Based on the comprehensive geological analysis, the Lower Permian profile in the Ośno IG-2 well was selected for testing, including sedimentary and effusive rocks. The Ośno IG-2 well is located in the northwest part of Poland (Gorzów block), close to the border with Germany. A total of 42 core samples were collected from the Ośno-IG2 well from the depth interval 3212 - 3659 m for comprehensive petrophysical, thermal and mechanical tests. In addition, 10 core samples from Mesozoic reservoir formations from Norway (Skagerrak, Ula, Are Fms).

An example of a rock sample prepared for testing from the Polish (A) and Norwegian (B) research area

The set of laboratory tests performed in AGH laboratories included:

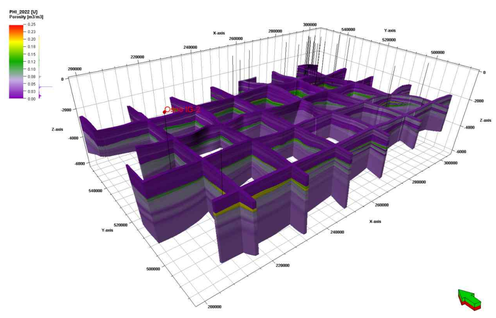
- analysis of the mineral composition of rocks and the pore space investigations using the mercury porosimetry (MICP) method and by Natural Magnetic Resonance (NMR),
- mineral composition of rock using the XRD method of rock samples,
- analysis of thermal properties of rocks - thermal conductivity measurements using the FOX50 set,
- testing of the mechanical properties of rocks - research on the elastic and mechanical parameters of rocks.

WP3. EXPERIMENTAL DETERMINATION OF PROPERTIES AND BEHAVIOUR OF CO_2-EGS WORKING FLUIDS

The goal of this work package is to provide high quality experimental data on phase behavior and viscosity and density properties of CO_2-EGS to cover the most critical knowledge gaps identified so far, thus allowing to improve existing fluid models of CO_2-EGS relevant working fluids based on generated fluid property data. The experimental campaign is 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 experimental data obtained will be used to direct verification of the operation states of CO_2-EGS, but will also be fitted and used to validate the existing fluid models used.

WP4. MATHEMATICAL MODELLING OF THE GEOLOGICAL RESERVOIR FOR CO_2-EGS EXPLOITATION

Structural models with a numerical distribution of reservoir parameters were constructed for two previously selected locations as prospective for CO_2-EGS in Poland, namely the Gorzów Block and the Mogilno-Łódź Basin (Krośniewice - Kutno area). Regarding the Are Formation in the Norwegian Sea, the data collected by NTNU are used to build a simplified 3D reservoir model. On the basis of the 3D structural model and the results of laboratory measurements, the numerical model of the fractured zone is developed. The model contains the distribution of the mechanical and physical properties of the rock. The analysis will allow to determine the fracturing zone range, fractures permeability distribution, and the best injection schedule schemes. Work is in progress on the construction of the 3D numerical model for multivariant simulations of CO_2 injection and exploitation with forecast of reservoir behaviour over time.

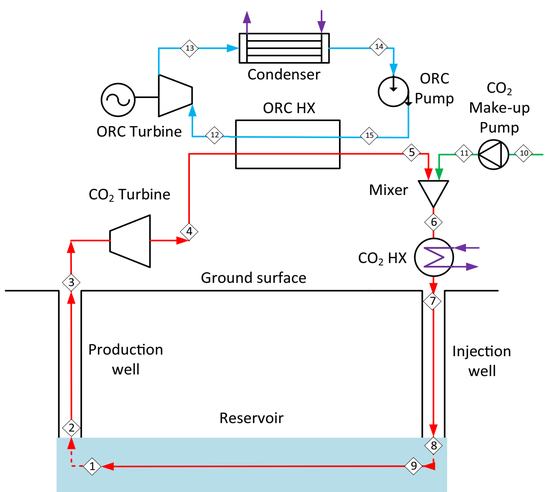


Plot diagram of 3D porosity semiregional model in Gorzów Block Area (Model authors: B. Papiernik, G. Ząbek)

WP5. MATHEMATICAL MODELING OF CO_2-BASED TOPSIDE SYSTEMS FOR HEAT AND POWER PRODUCTION

The concepts of high-performance topside systems for producing heat and/or electric power from geothermal energy, using CO_2 circulating in the EGS reservoir as the direct working fluid, will be developed.

One proposed CO_2-EGS configuration is illustrated in figure beside (Deng et al., 2022). CO_2 is injected into the seabed and flows downward in the injection well. Then, it flows through the reservoir and is heated to the reservoir temperature, as the injection and production wells are far enough to prevent thermal breakthrough. The fluid rises through the production well and reaches the surface at a higher temperature and pressure than at the injection point. A net pressure gain is possible between the extraction and injection points because of the density differences integrated over the length of the wells. On the top side, CO_2 expands through a turbine for power generation. After that, the CO_2 passes through a heat exchanger (ORC HX) to supply heat for an optional secondary Organic Rankine cycle, as indicated by the blue lines. At this point, some additional (make-up) CO_2 is mixed in to compensate for sequestrated CO_2 in the reservoir and, therefore, maintain a constant flow rate at extraction. The mixed flow is then cooled by a dumping heat exchanger (CO_2 HX) before re-injection. In this work, the system without ORC will be called the direct system, while the one with both ORC and direct expansion is called the hybrid system. In addition to the ORC evaporator, the ORC sub-system consists of a turbine, a condenser, and a pump. Seawater is used to cool the condenser and CO_2 HX.



"All-in-one" model. Red lines: sCO_2 stream; green lines: CO_2 make-up stream; blue lines: ORC working fluid stream; purple lines: cooling water and heat export

WP6. TECHNO-ECONOMIC AND ENVIRONMENTAL ASSESSMENT

The techno-economic framework and guidelines will be developed, following some of the best practices used in research and industry. Based on the technical parameters from the mathematical modeling, the costs (both CAPEX and OPEX) and cost metrics (e.g. Net Present Value or Levelized Cost of Electricity or Heat) as well as ecological effects will be analysed.

SUMMARY

Enhanced Geothermal Systems (EGS) using supercritical carbon dioxide as a working medium are undoubtedly an innovative technology for obtaining energy in an environmentally friendly way. Currently, it is not used in the world and requires the implementation of research to better understand the behavior of reservoir fluids in the system. One of such scientific projects is the ***CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply project, the acronym EnerGizerS***, realized by a Polish-Norwegian team of scientists. The main goal of the project is the development of Enhanced Geothermal Systems (EGS) technology that uses supercritical carbon dioxide as the working fluid (CO_2-EGS); such a system has attracted much interest worldwide due to the additional benefit of CO_2 geological storage while obtaining geothermal energy. The proposed solution aims to protect the climate by producing clean geothermal energy and simultaneously eliminating carbon dioxide emissions from fossil fuel combustion.

ACKNOWLEDGEMENTS

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References and the full text are given in the European Geothermal Congress 2022 proceedings.

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