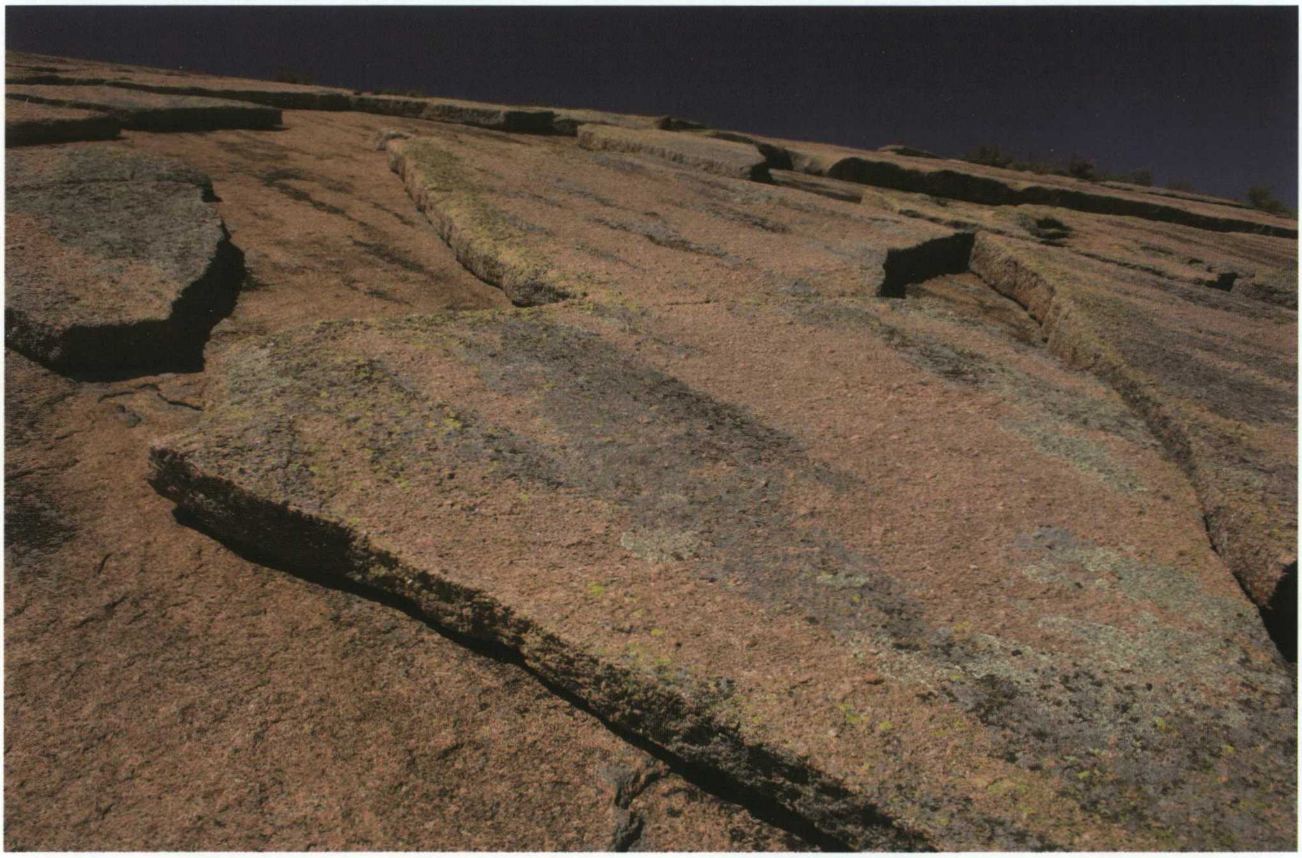
Heat From Deep Within



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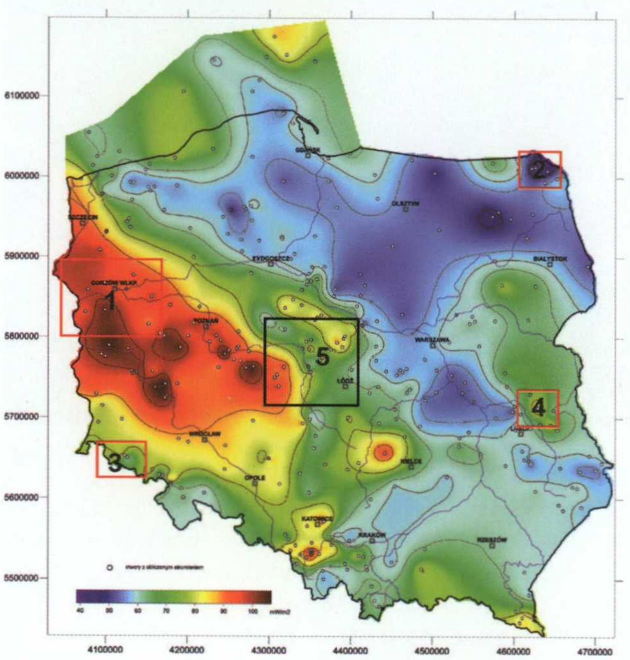
Dr. Adam Wójcicki is a geophysicist specializing in geothermal energy. This includes problems of geological storage of CO_2, estimating the potential of enhanced geothermal systems (EGS) and hot dry rocks (HDR), and estimating hydrocarbon resources.

Hot dry rocks have been used in experimental and non-commercial installations for decades. These resources, locked deep within Earth's crust, have a greater potential than the currently popular hydrogeothermal systems. Preliminary results of studies into hot rocks in Poland are promising: generating thermal and electrical energy at relatively low costs should become a reality in the coming years

Hot dry rock (HDR) technology harnesses heat from deep crystalline rocks that are essentially dry and impermeable to water. Enhanced geothermal systems (EGS), in turn, are a method of generating energy from similar sources, albeit with a limited supply of water. In both technologies (HDR and EGS are sometimes used interchangeably), energy is obtained from hot rocks by sealing the rock mass hydraulically and pumping water into the system; the water travels through fractures in the rock, capturing the heat until forced out of a second borehole as very hot water. The water's heat is then converted into electricity or simply used as thermal energy. The process relies on two key elements. The first is a sufficiently high temperature - over 160°C for generating electricity directly, or over 100°C for producing electricity and heat in "binary" power plant systems (using another "working" fluid with a lower boiling point). The second challenge is identifying rocks that can be fractured easily and that exhibit good heat conductivity to ensure stable energy production during the installation's lifetime.

The first attempt at extracting energy from HDR was the Fenton Hill project in the US between 1974 and 1992, operating near an extinct volcano. Further attempts were made at the Rosemanowes Quarry in Cornwall in the UK (1977-1991) and in Hijori in Japan (1981-1986). An experimental HDR installation has been in operation in Soultz in France since 1990. The first pre-commercial HDR/EGS plants - running on a self-sufficient basis, or at least not requiring subsidies - have been opened in the last decade in Cooper Basin, Australia, and Landau, Germany.

It is generally believed that the best locations for HDR/EGS installations are deep igneous rocks such as granite (used by most existing systems). However, there are exceptions: the experimental station at Gross Schoenebeck in Germany uses volcanic and sedimentary rocks, while the pre-commercial installation at Landau uses granite plus sedimentary rocks.



Regions under investigation for potential geothermal systems in Poland (presented against Szewczyk & Gientek's thermal map, 2009; temperature distribution in the rock mass, at a depth of e.g. 3km, is qualitatively similar). The research project commissioned by the Ministry of the Environment (financed by the National Fund for Environmental Protection and Water Management) and conducted by the Polish National Geological Institute (a National Research Institute) as the project leader and the AGH University of Science and Technology, the PAS Mineral and Energy Economy Research Institute, and PBG S.A. has so far identified a few preliminary locations with parameters supporting the development of potentially profitable closed HDR/EGS geothermal systems for generating heat and electricity (Wójcicki A., Sowiżdżał A., Bujakowski W., 2013). Ranked in order of potential, they are the Karkonosze region (granite - region 3), Gorzów Wielkopolski region (igneous rocks - region 1) and Krośniewice region (home to deep sedimentary rocks with a low water content - region 5)

A single geothermic system including a pair of drilling wells, generally three to five kilometers deep, can generate around 1-3 MWe net electrical energy (or thermal energy an order of magnitude greater); this is equivalent to a single wind turbine, which of course is only able to generate energy at certain wind speeds. Coal-fired power plants, by comparison, usually generate power in the range of hundreds or even thousands of MW.

Potential for HDR technology in Poland

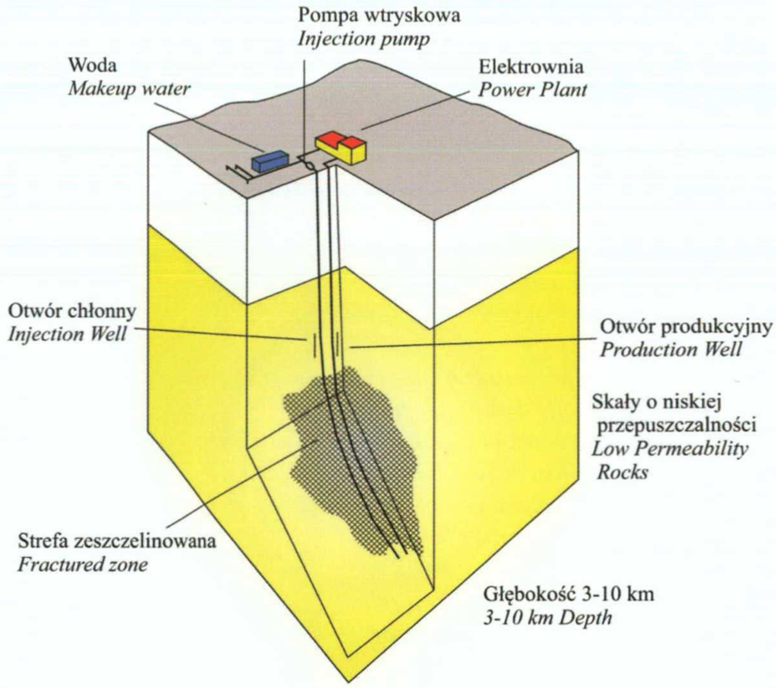
In European terms, our country offers average geothermal conditions. This means that at depths of around 3km, temperatures are lower than in Germany, France and southern Europe in particular, although they are higher than in Scandinavia and Russia. The highest rock mass temperatures can be found in western and north-western regions of Poland. The presence of rocks that are most susceptible to hydraulic fracturing does not fully overlap with areas with the highest temperatures. Recent research has identified three regions and specific locations within them that may be suitable for siting geothermic installations for generating heat and electricity (see the map and legend on this page). They were selected using results of geophysical and geological field studies, laboratory analysis of rock samples, and reviews of archive data such as petrographical, thermal and geomechanical parameters of rocks. The locations were then subjected to multivariate modeling of their geothermal systems, including their potential for generating electrical and thermal energy; as a result, several scenarios for the exploitation of geothermal installations have been generated.

The systems are located at depths between 4.5 and 5.5km below the surface, and they are characterized by relatively high temperatures, falling between 150 and 180°C. They are also likely to fracture relatively easily, enabling the geothermal system to function in a stable manner. It is important to ensure a sufficiently high permeability and volume of the hydraulic fracturing zone, and to use an optimized water flow that would minimize cooling of the rock mass and the resulting inevitable reduction of energy of the system.

The most likely and optimal scenarios for the exploitation of geothermal installations at the selected locations include the construction of systems with a net electrical output of around 1-2 MWe, able to function for up to 50 years (the maximum period allowed by the technical specifications), or heat-only generating systems with a power output in the order of 8-16 MWt.

Is cheap HDR energy possible?

Preliminary research results have been used as the basis for designing pilot geothermal installations. Given our insufficient understanding of the behavior of rock-



Schematic representation of harnessing energy from hot dry rocks in closed geothermal systems (Wójcicki A., Sowiżdżał A., Bujakowski W., 2013; based on Tester et al., 2006). In this instance, water is injected through the injection well using a pump; it reaches rocks in the production zone, which had previously been hydraulically fractured (like in shale gas mining, this process is repeated when system efficiency drops below a certain level, although hydraulic fracturing for HDR does not require the addition of as many chemicals to the water as used for shale gas extraction). There the water becomes heated to the temperature of its surroundings. Next it is extracted through the production well to the surface, where it is used in a special installation (including an exchanger and/or turbine) to generate electrical energy or heat

masses at the locations under consideration in terms of fracturing and transport of injected fluids, the designated sites need to be studied further before making any decisions to go ahead with the projects. This should include detailed geophysical research of the surface, creating test wells (or adapting and deepening existing ones), and analyzing rock samples collected from the depths of the geothermal systems. It is also important to conduct simulations of the processes of fracturing and the transport of injected water into the fractures, in parallel with computer simulations of these processes, and running tests in the wells to verify the assumptions made during the modeling stage in order to confirm the efficiency estimates.

Only after the successful completion of this stage (lasting a minimum of three to five years, depending on the location) can the construction of actual geothermal installations begin.

As is the case with classic geothermal energy (hydrogeothermal installations), one major problem is the high cost of drilling deep boreholes, although HDR also entails additional high fracturing costs. Drilling and fracturing are the most significant part of the investment and exploitation expenditure; additional costs involved with geothermal installations under Poland's geological and deposit conditions can be estimated using global literature and local experiments and experience. Assuming the most likely and optimal scenarios of exploitation of the likely geothermal installations, and supposing electrical and thermal energy prices remain steady, the results are rather promising. It certainly seems that HDR installations would perform no worse than existing geothermal plants (hydrogeothermal installations), most of which had been developed with the aid of significant public subsidies. A particularly promising aspect of HDR technology appears to be that the systems can be used to generate heat; assuming stable levels of energy generated by the geothermal system, and the potential of using existing wells, each installation should break even financially within 25-30 years (the total operational lifetime of an installation with a power output of 6-16 MWt is estimated at up to 50 years). An installation used purely to generate electricity (with a power output of 1-2 MWt) would bring a return after 40-50 years, making it a borderline case. However, reliable estimates of the costs of energy and heat generated by sources such as these in Poland will only be possible after the completion of a few pilot projects. Theoretically, the potential electricity output of HDR/EGS systems operating in Poland is in the order of 2-4 GWe (equivalent to the power output of a large coal-fired power plant, or a single planned nuclear power plant), while the heat energy potential is eight times greater (greater than all existing coal-fired combined heat and power plants in Poland). ■

Further reading:

Huenges E. (Ed.) (2010). *Geothermal Energy Systems: Exploration, Development, and Utilization.* Wiley-VCH Verlag GmbH. ISBN: 978-3-527-40831-3.

Szewczyk J., Gientka D. (2009). *Mapa gęstości ziemskiego strumienia cieplnego Polski* [Map of Poland's Terrestrial Heat Flow Density]. PIG Warszawa. www.pig.gov.pl.

Tester J.W., Anderson B.J., Batchelor A.S., Blackwell D.D., DiPippo R., Drake E.M., Garnish J., Livesay B., Moore M.C., Nichols K., Petty S., Toksöz M.N., Shrock R.R., Veatch R.W. Jr., Baria R., Augustine C., Murphy E., Negraru P., Richards M. (2006). *The Future of Geothermal Energy - Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century.* ©Massachusetts Institute of Technology. Idaho Falls: Idaho National Laboratory.

Wójcicki A., Sowiżdżał A., Bujakowski W. (2013) (eds.). *Ocena potencjału, bilansu cieplnego i perspektywicznych struktur geologicznych dla potrzeb zamkniętych systemów geotermicznych (Hot Dry Rocks) w Polsce* [Evaluation of the Potential, Thermal Balance, and Promising Geological Structures for Closed Geothermal Systems (HDR) in Poland]. PIG-PIB. ISBN 978-83-7863-263-4.