Cornell University
David R. Atkinson Center
for a Sustainable Future

The Energy Underneath Our Feet

Cornell University
Cornell Energy Institute

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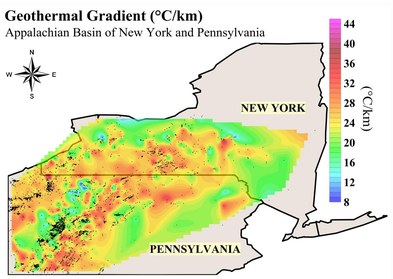
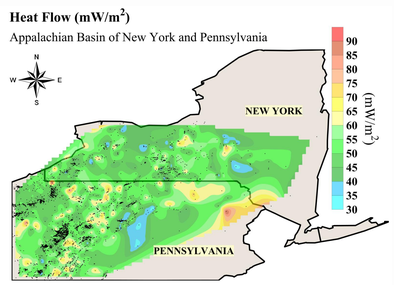
Geothermal Resource Assessment of New York and Pennsylvania

This study draws a more complete picture of geothermal resources in the Northeastern United States—with a particular focus on New York and Pennsylvania—by incorporating thousands of new temperature-depth data collected as a result of continuing drilling for unconventional natural gas in the region. Using these new data, a series of maps covering the Appalachian Basin of New York and Pennsylvania were produced that show variations in subsurface thermal gradient and surface heat flow. The increased spatial accuracy and resolution compared to earlier geothermal maps of the Northeast U.S. illuminate better spatial variations in the resource quality, and have a much smaller degree of uncertainty in both extent and magnitude. The maps indicate that the temperatures required for direct-use applications are available at economically viable drilling depths over a majority of the region.



The thermal gradient of geothermal resources within the Appalachian Basin of New York and Pennsylvania. The black points are locations of the individual well whose bottom hole temperature and depth measurements are included (data sources: SMU; PA Geological Survey; NYS Museum; NYSDEC, 2011).



Surface heat flow in the Appalachian Basin of New York and Pennsylvania, calculated as the product of thermal gradient and average thermal conductivity for a specified location. The black points are locations of the individual well whose thermal gradients were derived (data sources: SMU; PA Geological Survey; NYS Museum; NYSDEC, 2011)

Researchers: Elaina Shope, Tim Reber, George Stutz, Andrea Aguirre

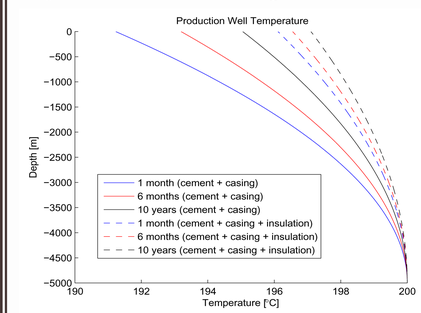
Geothermal energy has the potential to provide reliable, environmentally friendly, and affordable electricity and heat. Enhanced/Engineered Geothermal Systems (EGS) are a type of geothermal energy that is implemented in areas with any of the following combinations: low permeability, dry rock, and/or great depths. A site is engineered or enhanced by stimulating a reservoir, inducing fractures where water may be pumped through the reservoir to "farm" or extract out the thermal energy contained in the formation. Our research group investigates the complete integration of the low-temperature EGS and shallow geothermal systems including geothermal resource assessment, hydrothermal drilling, heat farming and thermal mapping, geothermal reservoir utilization, and ground-source heat pumps.

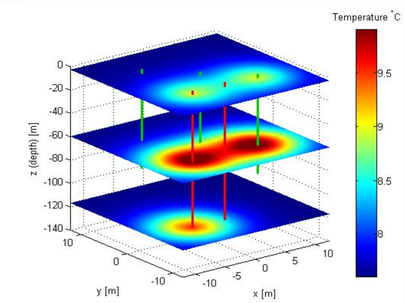
In order to facilitate EGS project placement and design, the resource assessment study draws a more complete picture of geothermal resources by incorporating new temperature-depth data into a set of maps showing the inherent subsurface thermal gradient and surface heat flow. Once exploration sites are determined, hydrothermal drilling has the potential to provide access to deeper EGS reservoirs by penetrating crystalline bedrock at a much faster rate than conventional rotary drilling techniques. To determine the sustainability of EGS reservoirs, heat farming strategies, specifically conduction dominated models, are being studied. These models estimate heat transfer during subsequent periods of extraction and recovery. Low-temperature geothermal energy utilization can greatly increase the range of options for EGS development. The proposed solutions include electricity generation using subcritical and supercritical Organic Rankine Cycle, electricity and heat co-generation using geothermal energy and biomass, and use of district heating systems for community redevelopment projects. For shallow geothermal projects, ground-source heat pumps offer an environmentally-friendly and cost-effective way of heating and cooling.

Heat Transfer Modeling of Geothermal Wells and Ground Heat Exchangers

Heat losses through geothermal production wells can lead to temperature drops of up to tens of degrees Celsius and correspondingly to significant decreases in overall system efficiency. My research is to quantify and economically minimize this temperate drop as a function of time-dependent mass flow rate and fluid input temperatures, different wellbore geometries and insulation thicknesses, and varying rock properties. The figure below on the left shows the temperature drop after 1 month, 6 months and 10 years, for a production well with casing and cement (solid line) and for a production well with casing, cement and insulation (dashed line). Both cases represent a 5 km geothermal production well with internal diameter of 30cm, reservoir temperature of 200ºC and water mass flow rate of 70kg/s (50MW$_{th}$).

Ground-source heat pumps offer an environmentally-friendly and cost-effective way of heating and cooling. My research is to develop an accurate and computationally-efficient model to simulate and optimize vertical borehole heat exchangers taking into account groundwater flow, variable surface temperature, multiple boreholes and variable heating and cooling loads. The figure below on the right shows the temperature distribution at different depths after 1 year of operation with 2 heat exchangers activated and an average heat injection of 6.6kW.





Researcher: Koenraad Beckers

Hydrothermal Drilling

Hydrothermal flame drilling can penetrate hard, crystalline rocks encountered in EGS at a faster rate than conventional rotary drilling techniques. Hydrothermal drilling is non-contact, and thus has the potential to lower drilling costs by eliminating the need to replace worn drill bits and avoiding the associated trip time. In order to realize the full potential of a hydrothermal drilling system, ignition of the hydrothermal flame downhole is vital. However, electrical spark ignition systems cannot be expected to perform reliably after extended exposure in a high temperature geothermal environment. Therefore, experimental studies are being conducted to determine the auto-ignition temperatures of various compounds in conditions that would be present in a geothermal reservoir. The viability of the fuels will be assessed according to performance, safety, availability, and price. This research is being performed in conjunction with an industry partner, so the findings may be applied in field studies in the near future.

Similar studies are being conducted whereby chemicals are added to a hydrothermal flame to enhance rock disintegration and drilling rates. Trials are being conducted in an experimental apparatus at supercritical conditions to evaluate solubility and dissolution (drilling) rates of various rock-types into hydrothermal jets. Models have been constructed from literature solubility data to predict dissolution rates as a function of temperature, salt concentrations and pH. From solubility data alone, drilling could be up to 10 times faster than conventional methods under optimal conditions.

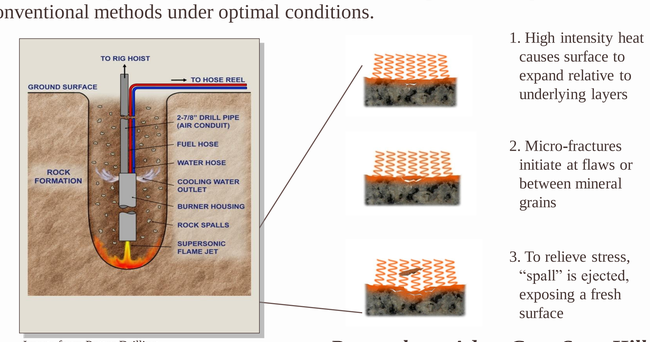


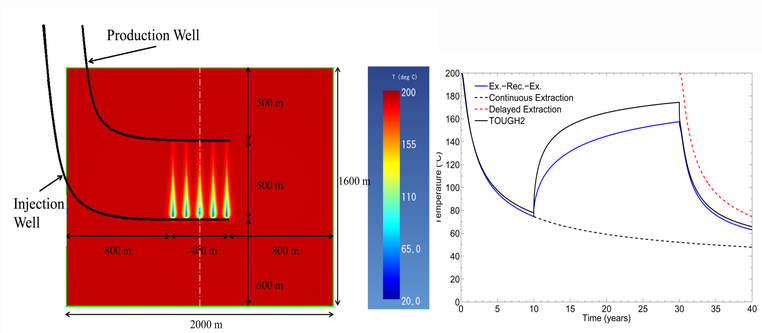
Image from Potter Drilling

Researchers: Adam Carr, Sean Hillson

Sustainable Heat Farming and Thermal Mapping of EGS Reservoirs

A way to increase the sustainability and renewability of Enhanced Geothermal Systems is to implement a heat farming strategy. Under this strategy, several reservoirs are used in a rotating manner. When the first reservoir is deemed depleted and is no longer able to satisfy the thermal needs of the surface installation, production is shifted to a new reservoir. The process continues until the first reservoir has recovered significantly and can be used once again. To determine how renewable EGS reservoirs are, a conduction dominated ideal rectangular fractured EGS reservoir was constructed to estimate heat transfer during alternating periods of extraction, recovery, and subsequent extraction. Simulation results show that multifracture EGS reservoirs have a greater capacity to sustain high outlet temperatures, suggesting that conductively dominated EGS can be regarded as renewable over times scales of societal systems (three to five times the extraction time).

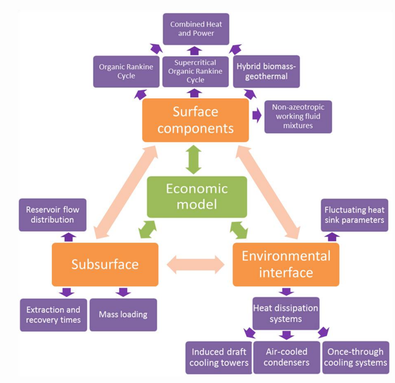
Reactive tracers can be used to elucidate the subsurface environment by providing data of the thermal evolution of the reservoir. By knowing the thermal map of a reservoir, one would be able to make conclusions on the progress of thermal breakthrough and the anticipated level of temperature decline in the reservoir, information important for the surface installation.

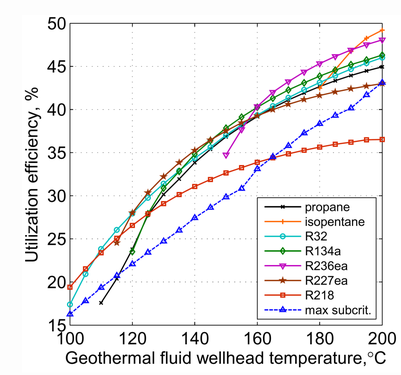


Researcher: Don Fox

Optimization of Geothermal Reservoir Utilization and Design of Innovative Energy Conversion Cycles

Our study investigates the integration potential of the low-temperature EGS geothermal energy in the U.S. We aim to identify the strategy for energy- and cost-effective exploitation of EGS resources. To reach this goal and demonstrate that geothermal energy truly has the potential to be a national energy source, we are optimizing the management strategies of EGS reservoirs, designing and examining innovative uses of low-temperature geothermal resources and optimizing the energy conversion systems. The proposed solutions include electricity generation using subcritical and supercritical organic Rankine cycle, electricity and heat co-generation using geothermal energy and biomass, and use of district heating systems for community redevelopment projects. Numerical models of heat and mass transfer in EGS reservoirs are connected to energy conversion and utilization models by using an overall integrated approach to modeling. This method allows us to capture the interactions between subsystems and impose realistic constraints on each of the system elements.





Researcher: Maciej Lukawski