Deep Geothermal Energy

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Executive Summary

The main objective of this section is to examine the potential of enhanced geothermal systems (EGS) in serving the heating demand in Tompkins County, and the opportunities and challenges in implementing EGS. The U.S. Department of Energy has broadly defined EGS as engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources at depths of 2 km (or 6,500 feet) or more. Compared to hydrothermal geothermal systems, EGS can be adopted in areas with low-grade geothermal resources and not enough natural fluid or permeability.

It is important to distinguish EGS from Geothermal heat pumps (GHPs), sometimes referred to as ground-source heat pumps (GSHP), which also utilize low-grade thermal energy from the earth, but at much shallower depth, typically 2-200 m (or ~7 to 600 feet), than EGS. Soil temperature typically does not vary with seasons at depths beyond 2 m. GSHPs are treated as energy efficiency measures rather than as an energy supply in the Energy Roadmap, and discussion of their potential may be found in the Demand-side Management and Energy Efficiency chapter. While EGS are still in the demonstration stage, GSHPs are readily available commercially and for that reason, EGS potential is not factored into the scenario development, but GSHPs are included.

Tompkins County has modest temperature gradient around 25 ^{o}C/km +/- 1 ^{o}C/km. In other words, ground temperatures within the County reach around ~140 ^{o}C at 5 km (or 3.7 miles). Although it is possible to generate electricity using low-temperature power cycles, direct use of geothermal heat in district heating systems could be a viable option for meeting the heating demand in the County, which accounts for approximately 40% of the County's primary energy consumption. There are several benefits for this option. Geothermal heat is not intermittent, and does not require energy storage. Geothermal systems have a small footprint and virtually no emissions, including greenhouse gases. Other environmental impacts such as radioactive wastes and microseismic activities typically range from negligible to manageable.

Although EGS has the potential to meet the entire heating demand in the County, implementation is currently limited by the small number of existing district heating systems to facilitate EGS use, lack of governmental incentives, absence of demonstration projects in the Eastern U.S., and skeptical public perception. A proposed hybrid system that combines EGS and biomass gasification on Cornell University campus would provide a much needed demonstration project to help the community understand and utilize geothermal resources in the County. The proposed Cornell system would supply 98% of the heating demand on Cornell campus with 94,000 metric tons of avoided CO_2 emissions.

1. Introduction

Geothermal heat originates from two main mechanisms: 1) Upward convection and conduction of heat from the Earth's mantle and core, and 2) Heat generated by the decay of radioactive elements in the crust, particularly isotopes of uranium, thorium, and potassium[1]. Thermal energy in the earth is distributed between the constituent host rock and the natural fluid that is contained in its fractures and pores at temperatures above ambient levels. Thermal energy is extracted from the reservoir by convective heat transfer in porous and/or fractured regions of rock and conduction through the rock itself. Typically, hot water or steam is produced and its energy is converted into a marketable product (electricity, process heat, or space heat). Any waste products must be properly treated and safely disposed of to complete the process.

A naturally occurring geothermal system, known as a hydrothermal system, is defined by three key elements: heat, fluid, and permeability at depth[2]. People often associate geothermal energy only with regions of high grade, high gradient hydrothermal reservoirs such as Iceland, New Zealand, or Yellowstone National Park, and neglect to consider geothermal energy opportunities in other regions. As shown in Figure 1, geothermal resources are not evenly distributed in the U.S. An Enhanced Geothermal System (EGS) is a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. The U.S. Department of Energy has broadly defined EGS as engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources[1].

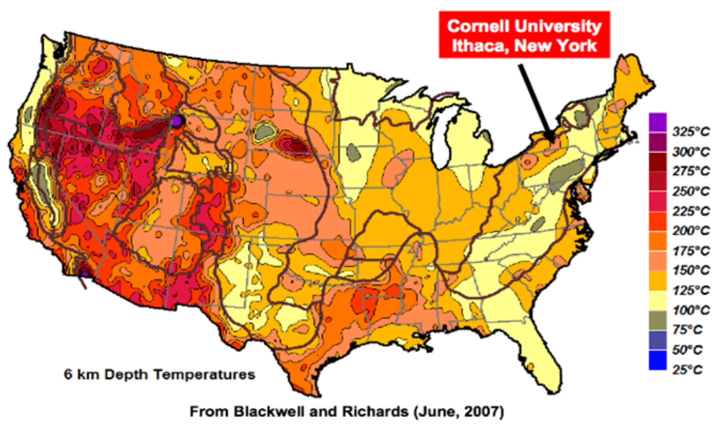

Figure 1: The geothermal resource of the continental United States[3]

In an EGS, fluid is injected into the subsurface under carefully controlled conditions, which cause pre-existing fractures to re-open, creating permeability. Increased permeability allows fluid to circulate throughout the now-fractured rock and to transport heat to the surface where electricity can be generated[4]. In other words, EGS can be implemented in areas with low-grade geothermal resources and not enough natural fluid or permeability. As depicted in Figure 2, fluid is pumped down into the rock and fractures it, creating permeability[4]. In principle, conduction-dominated EGS systems in low-permeability sediments and basement rock are available all across the United States.

[1] Tester, J. W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., et al. (2006). The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. Massachusetts Institute of Technology, 372
[2] https://www1.eere.energy.gov/geothermal/pdfs/egs_basics.pdf
[3] Blackwell, D. D. and M. Richards. 2004. Geothermal Map of North America. Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma, 1 sheet, scale 1:6,500,000.
[4] https://www1.eere.energy.gov/geothermal/pdfs/egs_basics.pdf

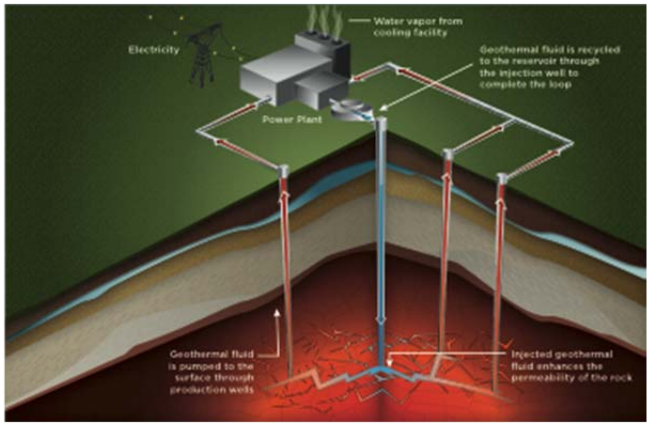

Figure 2: Enhanced Geothermal System where fluid injection enables low-permeability hot rock to become a geothermal resource[4]

Geothermal energy has two typical uses: direct use of heat or electricity generation. Heat generation by geothermal energy is fairly straightforward. Fluid is cycled through a closed loop that runs between Earth's crust and a building to be heated. While the fluid is in the crust, it picks up the heat that naturally exists there and brings it to the surface. The heated fluid is then used to supply space or process heating.

Electricity generation works by a slightly different mechanism. In its most general case, warm water is pushed into the crust. Geothermal energy heats up the water, forming steam. That steam is then used to turn a turbine which generates electricity. The steam then cools into water and while it is still hot it is put back into the crust[5]. There are other variations that can be implemented based on regional requirements.

While EGS technologies are young and still under development, EGS has been successfully realized on a pilot scale in Europe and now at several DOE-funded demonstration projects in the United States[6]. One of the well-known projects is Altarock Energy in Bend, Oregon. At Altarock Energy, three separate zones of fluid flow were created from a single well. There are other demonstration areas in Churchill County, Nevada, Middletown, California, and Raft River, Idaho. It can be noted that none of these sites are located near the Northeastern United States. Geothermal energy of this scale would be a pilot program for this region.

2. Potential

Figure 3 shows the estimated geothermal gradient for New York State and Pennsylvania[7]. Tompkins County records modest gradients, greater than 25 ^{o}C/km and with a precision within 1 ^{o}C/km, indicating that ground temperatures within the County reach around ~140 ^{o}C at 5 km. In comparison, the average estimated geothermal gradient for New York State is 22.5℃/km, and the

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[5] http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-geothermal-energy-works.html#.VHi_wbRGh5Q
[6] http://energy.gov/eere/geothermal/enhanced-geothermal-systems-demonstration-projects
[7] Aguirre, G.A., 2014, Geothermal Resource Assessment: A Case Study of Spatial Variability and Uncertainty Analysis for the State of New York and Pennsylvania, A Master of Science Thesis presented to the Faculty of the Graduate School of Cornell University.

average estimated geothermal gradient for Pennsylvania is 23.9℃/km. Relative to other areas in Eastern U.S., Tompkins County has above-average gradient, but much lower than the gradients seen in the Western U.S[8] Because temperatures do not reach as high as areas in the Western and Southern United States, geothermal electricity generation is most likely not economically competitive for the County, however direct use of geothermal heat for space heating could be a viable option for the County. In perspective, about 30% of US energy use occurs at temperatures < 160°C[8] and most of it comes from burning natural gas and oil.

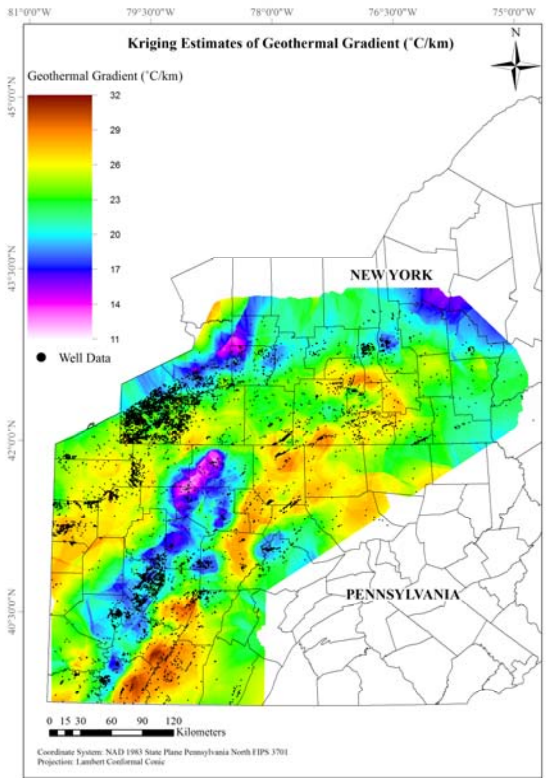
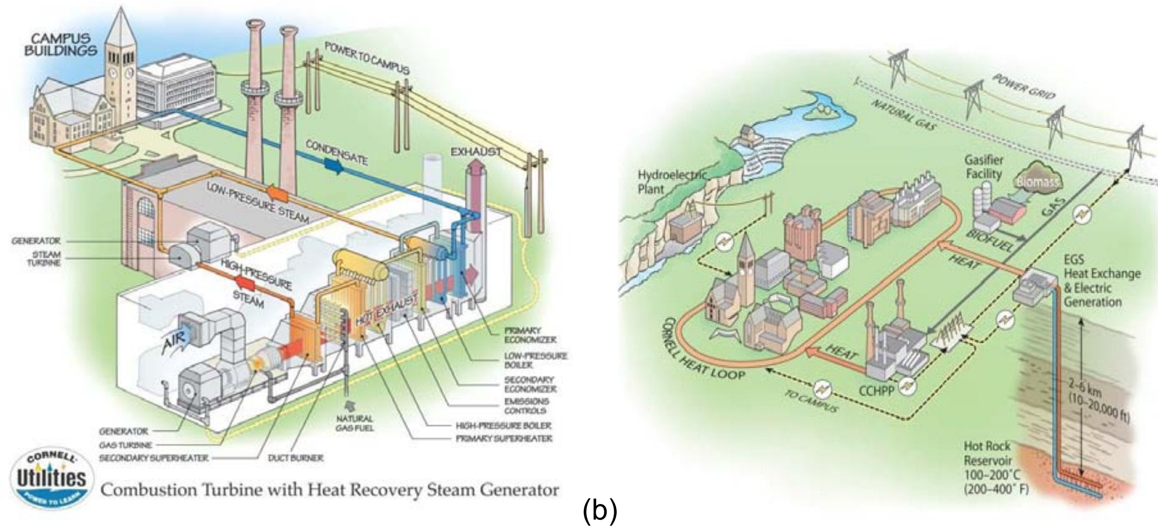


Figure 3: Kriging estimates of geothermal gradient (℃/km) for New York State and Pennsylvania, with individual well locations shown as black diamonds. Data sources: SMU; PA Geological Survey; NYS Museum; NYSDEC, 2011. The blank areas indicate no estimates.

[8] Fox, D. B., Sutter, D., Beckers, K. F., Lukawski, M. Z., Koch, D. L., Anderson, B. J., Tester, J. W. (2013), "Sustainable heat farming: Modeling extraction and recovery in discretely fractured geothermal reservoirs", Geothermics, 46, 42– 54



(a) (b)

Figure 4. (a) The current district heating system with CHP at Cornell University[9]; (b) The proposed district heating system with EGS and biomass[9].

Currently, Cornell University owns and operates a combined heat and power (CHP) plant and a district heating system, illustrated in Figure 4a, which utilizes two dual-fueled combustion turbines (mostly running on natural gas), designed to operate under full load. This current system is capable of covering 90% of the peak heat demand, and 70% of total electricity demand. The remaining heat is covered by peaking boilers and the electricity can be purchased from the grid. District heat is delivered as superheated steam to campus buildings. The steam passes through heat exchangers, condenses and returns to the CHP plant.

The 2009 Cornell University Climate Action Plan (CAP) proposes a Hybrid Enhanced Geothermal System (HEGS) to reduce the reliance on natural gas for heating on campus[10]. The HEGS is critical to Cornell's goal to become carbon neutral by 2050. It is assumed that by 2050, the district heating system will extend to all of the campus buildings and that all natural gas consumption will be eliminated. In Figure 4b, the proposed HEGS combines two demonstration-scale research projects: EGS and Biomass Gasification[10]. The EGS would include two well pairs and heat extraction/delivery systems, tied into the campus distribution system for direct use of geothermal heat. The Biomass Gasification system would convert the feedstock produced on Cornell-owned land to biogas, which would be then used to supply the additional heating needs of campus when the ambient temperature drops below -8^{o}C, the design value of EGS at which EGS alone can cover the total heat demand. In other words, EGS would be the base-load heat provider, and biomass would serve as an auxiliary heating source for cold winter days[11].

In addition, to avoid having the system be less productive during the summer, 7% of electricity demand would be generated using an Organic Rankine Cycle (ORC). The remaining heat, after the

[9] http://energyandsustainability.fs.cornell.edu/util/heating/production/cep.cfm
[10] http://www.sustainablecampus.cornell.edu/initiatives/enhanced-geothermal-system
[11] Beckers et Al. 2015, Hybrid Low-Grade Geothermal-Biomass Systems for Direct-Use and Co-generation from Campus Demonstration for Nationwide Energy Player

district heating system or the ORC extracts it, would be used to dry the biomass. Cornell land offers a variety of biomass feedstock, such as food waste, manure, harvested forest products and bio-energy crops including willow and switchgrass.[11] However, the main biomass source is willow, because it can be sustainably cultivated on Cornell land, has high yields, and low carbon intensity in the processes of production, harvest, transportation, and conversion.

3. Opportunities and Challenges

3.1 Utilization of low-grade geothermal resources

Utilization of low-grade geothermal resources provides both challenges and opportunities for Tompkins County.

Heat instead of electricity

In general, geothermal resources in the Eastern U.S. are large in terms of their stored thermal energy but they are at greater depth than those available in the Western U.S. Thus, wells need to be deeper (and costlier) in the East than in the West to tap the same amount of thermal energy. Moreover, converting low-grade thermal energy to electric power is typically inefficient, so use of geothermal to produce electricity in the Eastern U.S. is not effective. In contrast, integrating EGS into a district heating system for direct use of geothermal heat makes the geothermal resource available in the East more economically attractive.

Minimal greenhouse gas emissions

In Tompkins County, heating demand accounts for approximately 40% of the primary energy consumption. EGS has the potential to serve the heating demand in the County cost effectively with small amounts of greenhouse gases emissions if fossil fuels are used to power EGS (e.g., pumping, injecting, etc.).

Land use and visual impacts

Furthermore, compared to biomass heating, EGS requires a much smaller land use footprint. EGS is one of the few renewable energy resources that can provide continuous base-load energy with minimal visual and other environmental impacts (discussed in Section 3).

Price fluctuations for fossil fuels

In the shorter term, having a significant portion of our base load supplied by geothermal sources would provide a buffer against the instabilities of gas price fluctuations and supply disruptions, as well as nuclear plant retirements.

Need for additional research

Although EGS technology has advanced since its infancy in the 1970s, Research, Development, and Demonstration (RD&D) in certain critical areas, such as drilling technology, power conversion technology, and reservoir technology, could greatly enhance the overall competitiveness of EGS[12]. For example, the main constraint for EGS is creating sufficient connectivity within the injection and

[12] Tester, J. W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., et al. (2006). The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. Massachusetts Institute of Technology, 372

production well system in the stimulated region of the EGS reservoir to allow for high per-well production rates without reducing reservoir life by rapid cooling. Increasing production flow rates by targeting specific zones for stimulation and improving downhole lift systems for higher temperatures, and increasing swept areas and volumes to improve heat-removal efficiencies in fractured rock systems will lead to immediate cost reductions by increasing output per well and extending reservoir lifetimes.

3.2 Lack of governmental incentives

There are currently many incentives at both the federal and state level available to installers of solar photovoltaics, solar thermal, hydroelectric, wind power, biomass, anaerobic digestion, geothermal heat pumps, and many more. While geothermal heat pumps are eligible for many of these incentives, there are currently no similar incentives for commercial scale EGS-based district heating systems. The creation of incentives to encourage growth of EGS could act to dramatically increase installation and development. For example, a recent report indicates that government or state incentives that would cover 30 percent of the capital costs would make retrofitting for EGS-based district heating systems immediately economically viable in a number of New York State communities. The 30 percent incentive level is typical of what is currently offered for other renewable energy technologies[13].

In addition, creative implementation strategies would also help overcome the cost barriers that exist today for EGS by focusing initially on developing the infrastructure needed for district heating and CHP systems at a community scale. These district energy systems could be designed to initially utilize conventional fuels and waste biomass feedstock and later transition to using geothermal energy as their primary energy source[14].

3.3 Public Perception of EGS

As there are no EGS demonstration projects anywhere near the Eastern U.S., the public understanding of EGS has been limited compared to other forms of renewable energy generation.

Cornell has conducted significant research in the local community to gain a better understanding of the public sentiment with respect to their Climate Action Plan (CAP). In April and May of 2009, questionnaires were mailed to 2,200 local property owners in Tompkins County[15]. The overall response rate was 34% (N=677). Respondents received one of six versions of a questionnaire seeking to measure their attitudes toward Cornell's CAP, which included EGS. Specifically related to EGS, the results found that respondents generally considered themselves least familiar with EGS compared to other approaches. In terms of beliefs, EGS was perceived as the costliest of the elements, somewhat 'limited' (39% versus 18% responding 'not limited'), somewhat 'safe' (43% versus 15% responding 'dangerous'), reliable (45% versus 13% responding 'unreliable'), 'able' to solve energy problems (53% 'able' versus 15% 'unable'), a 'good way' to address climate change (53% versus 13% 'bad way'). The results found moderate support if it were to occur somewhere in

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[13] Reber, Timothy J., Koenraad F. Beckers, and Jefferson W. Tester. "The transformative potential of geothermal heating in the US energy market: A regional study of New York and Pennsylvania." Energy Policy 70 (2014): 30-44.
[14] Beckers, Koenraad F., et al. "Levelized costs of electricity and direct-use heat from Enhanced Geothermal Systems." Journal of Renewable and Sustainable Energy 6.1 (2014): 013141.
[15] McComas, K. A., Stedman, R., & Sol Hart, P. (2011). Community support for campus approaches to sustainable energy use: The role of "town–gown" relationships. Energy Policy, 39(5), 2310-2318.

Tompkins County (but not near where they live): 14% oppose (strongly or slightly), and 45% favor (slightly or strongly). This level of support decreased somewhat when asked if it were near where they live (18% oppose and 38% favor). Support increased slightly if it were to only be on Cornell lands: 11% opposed and 53% supported. Support increased fairly strongly if it were to produce community benefits: only 5% opposed and 62% supported.

3.4 Radioactive waste

There is some concern over radioactivity when considering a geothermal system. As explained above, the primary source of heat in geothermal energy comes from radioactive decay. When drilling holes for geothermal, there is a danger of exposure to radioactive materials. The EPA lists geothermal drilling as a potential source for Technologically-Enhanced, Naturally-Occurring Radioactive Materials (TENORMs), similar to those associated with oil and gas production[16] There is a protocol for safe handling of TENORMs and radiation doses from them are expected to be very low. With the highest radiation levels expected to be around 250 picoCuries per gram, for comparison a 150 gram banana emits almost 520 picoCuries[17]. Consequently, this danger can be regarded as low and with proper planning should not have any major impact on health.

The other concern for radioactivity is the contamination of the geothermal fluid. On open loop systems, the fluid that runs through the rock can acquire trace amounts of radioactive elements. This risk can be mitigated by using a heat exchanger for the geothermal fluid and preventing the fluid from entering buildings. It can be avoided entirely by using a closed loop system where fluid never comes in direct contact with the rock.

3.5 Microseismic activities

The Ithaca area is bordered by the Clarendon-Linden fault zone to the west, the Adirondack Mountain to the northeast, the NW-SE Boston-Ottawa seismic belt, and the SW-NE seismic region related to Appalachian structures. The regions considered for developing these systems have historically had no seismic events, and indicate a high degree of tectonic stability. Even though no intraplate region can be considered risk-free, it is acceptable to assume that this area under consideration is aseismic on both the local and regional scale. The potential for induced seismicity is low, relative to sites that are tectonically unstable. In preparation for EGS development, the following investigations should be carried out to minimize risk:

- Microzonation of the region, i.e. subdividing possible seismic zones with respect to their geological characteristics
- Monitoring of background seismicity.
- Geophysical mapping of bedrock structure[18]

A successful geological site assessment and seismic monitoring would be necessary to geothermal development and public acceptance.

3.6 “Fracking” for EGS

Creating artificial geothermal reservoirs for an EGS involves using hydraulic pressure to create a network of small, interconnected fractures in the rock that act as a radiator, transferring the heat in

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[16] http://www.epa.gov/radiation/tenorm/geothermal.html
[17] http://truenorthreports.com/facts-and-information-about-radiation-exposure
[18] Co-generation opportunities for lower grade geothermal resources in the Northeast

the rock to water circulating through the system[19]. Although similar on its face, natural gas fracking and EGS fracking are fundamentally different. The oil and gas industry injects water and a proppant (a mix of sand and chemicals), at a very high pressure of around 9,000 psi or more, which breaks through the rock and holds the cracks open[20]. In contrast, EGS uses water to shear the rock and cause a "slip", often referred to as “hydroshearing”. Fractures form where there are existing deformities in the rocks. With very small fractures very deep in the earth and chemical-free fracking fluid, the long-term impact of hydroshearing is typically negligible.

Acknowledgment

We would like to acknowledge the valuable discussions with Mr. Lanny Joyce, Prof. Katherine McComas, Prof. Jeff Tester and members of his research group, Koenraad Beckers, Maciej Z. Lukawski and Aaron Benedict at Cornell University.

[19] http://altarockenergy.com/technology/enhanced-geothermal-systems/
[20] http://www.renewableenergyworld.com/rea/news/article/2013/07/is-fracking-for-enhanced-geothermal-systems-the-same-as-fracking-for-natural-gas