Geothermal District Heating Investigation Of Retired Oil/Gas Wells as Higher-temperature Renewable Heat Sources

Hongshan Guo, PhD Candidate

Dr. Forrest Meggers, Asst. Professor

School of Architecture & Andlinger Center of Energy and the Environment,
Princeton University

16.06.2016

WORLD Sustainable Built Environment Conference

hongshan@princeton.edu

How do we estimate the geothermal potential in PA?

It's worth noticing that only approximately 17,460 wells' data released through NGDS was used in this study, while in fact there are currently a total of more than 60,000 oil/gas wells in the state of Pennsylvania alone.

hongshan@princeton.edu

- Introduction
- Background
  - GDHS in the United States
- Methodology
  - Visualizing Geothermal Potential
  - Identifying Available Heat
  - Estimating Range of Households within reach
- Results and Analysis

Introduction

Geothermal energy is commonly harvested in the United States at either a shallower depths (<600ft, or 182.88m) for residential (or in rare cases commercial) purposes in conjunction with GSHP systems or deeper depths (>6500ft, or 2000m) with higher pressure profile for power generation with Enhanced Geothermal Systems (EGS). The lack of the exploration of the in-between depths is usually attributed to costs associated with drilling with well depths going beyond 600 ft (182.88m).

Enlisting the post-production oil/gas wells for geothermal production appears to be a viable option to bypass this restriction, harvesting heat from low-temperature heat source without investing heavily on the drilling process.

The data released by the National Geothermal Database System, thus, enabled a re-thinking of the in-between depths, for which we're presenting a preliminary feasibility study's case today.

Background – Geothermal Potential

The state of Pennsylvania has a long history of harvesting oil and gas from the underground[1]. The Marcellus Shale basin was, in fact, found among the conventional boreholes that were thought to have been depleted once [2]. First recognized by the USGS in [3] in 2003, the actual capacity of Marcellus Shale basin is expected to reach a mean undiscovered natural gas resource of 84,198 billion cubic feet according to the USGS fact sheet[4].

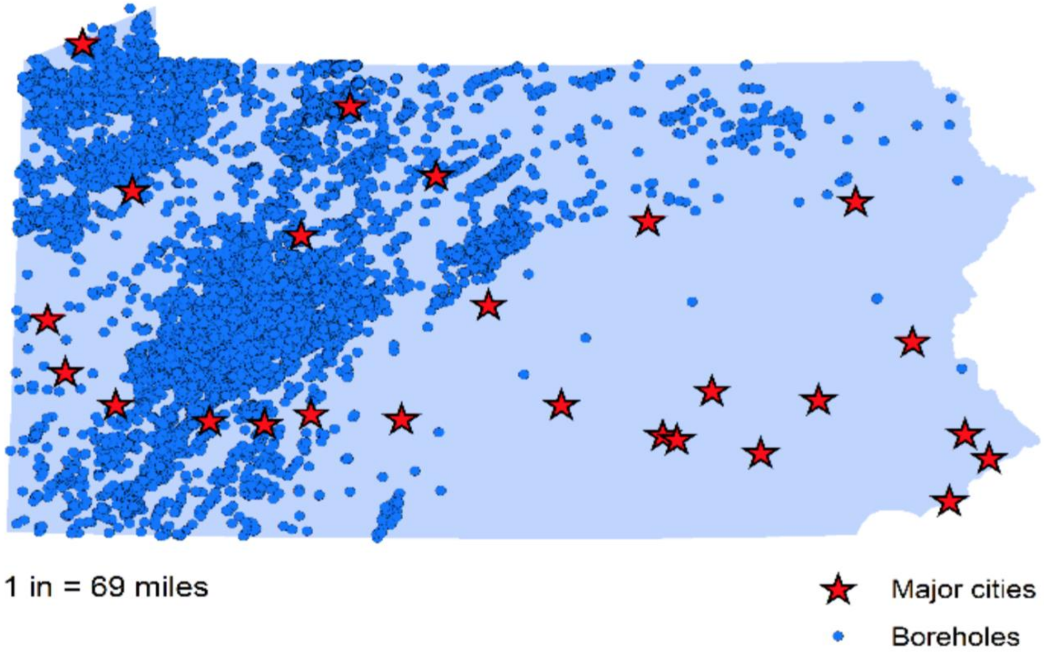

Figure 1. Borehole locations against major cities in Pennsylvania

1. Robert A Vargo and Kennth L Frye Jr. An Examination of Pennsylvania's Oil and Gas Industry. Technical report, March 2005.
2. Paul F Ziemkiewicz and Y Thomas He. Evolution of water chemistry during Marcellus Shale gas development: A case study in West Virginia. Chemo- sphere, 134(C):224–231, September 2015.
3. United States Geological Survey. Assessment of Undiscovered Oil and Gas Resources of the Appalachian Basin Province, 2002. Technical report, January 2003.
4. United States Geological Survey. Assessment of Undiscovered Oil and Gas Resources of the Devonian Marcellus Shale of the Appalachian Basin Province, 2011. Technical report, August 2011.

hongshan@princeton.edu

Background – Environmental Concerns

A 2014 dissertation from Kang [1] on the status-quo of the boreholes in Pennsylvania also pointed out the existence of fugitive gas leaking from post-production boreholes that were previously plugged with concrete and considered sealed off – the research also pointed out these emissions could be coming out from the bottom of the boreholes. Combining the environmental concerns with the premises explored by Watzlaf & Ackman in 2006[2] where the heating potential of mine water was considered.

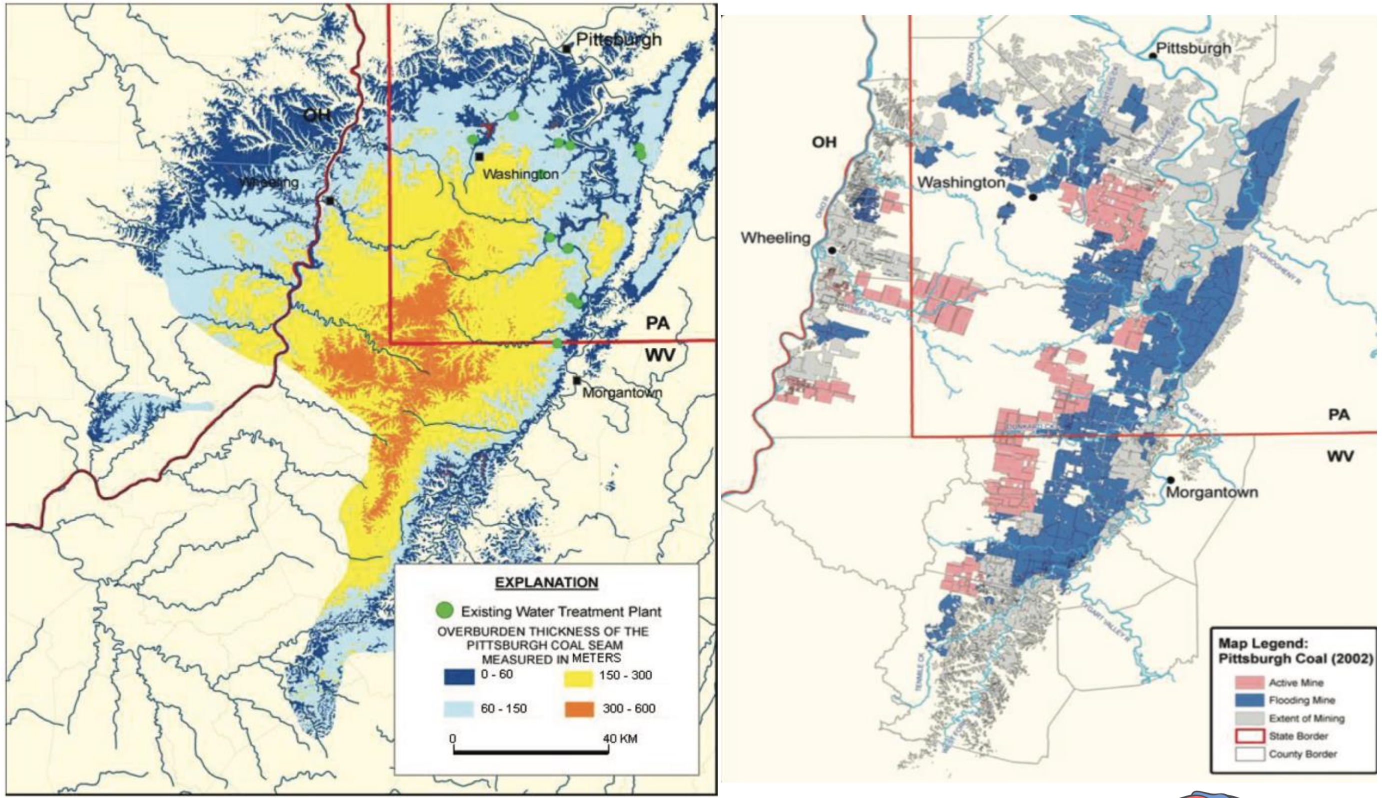

Figure 2. Overburden depths above the Pittsburgh coal seam in Pennsylvania, West Virginia and Ohio and location of existing water treatment facilities in Pennsylvania(left) and mining status at (around) PIttsburgh.

hongshan@princeton.edu

1. Kang, M. (2014, May 4). *CO2, Methane, and Brine Leakage through Subsurface Pathways: Exploring Modeling, Measurement, and Policy Options*. (M. A. Celia, Ed.). Princeton University.
2. George R Watzlaf and Terry E Ackman. Underground Mine Water for Heating and Cooling using Geothermal Heat Pump Systems. Mine Water and the Environment, pages 1–14, March 2006.

Methodology - Visualizing Geothermal Potential

To achieve a 3D visualization of the geothermal potential available, the ground surface temperatures and the bottom of borehole temperatures were used for obtaining an estimated geothermal gradient for all borehole locations to estimate the temperature at different depth profile of the wells, visually reconstructing the geothermal potential that was previously not exploited fully. This linear interpolation is purely done to provide visualization of the increase of geothermal potential with the geothermal gradient with relation to the boreholes once they are post-production.

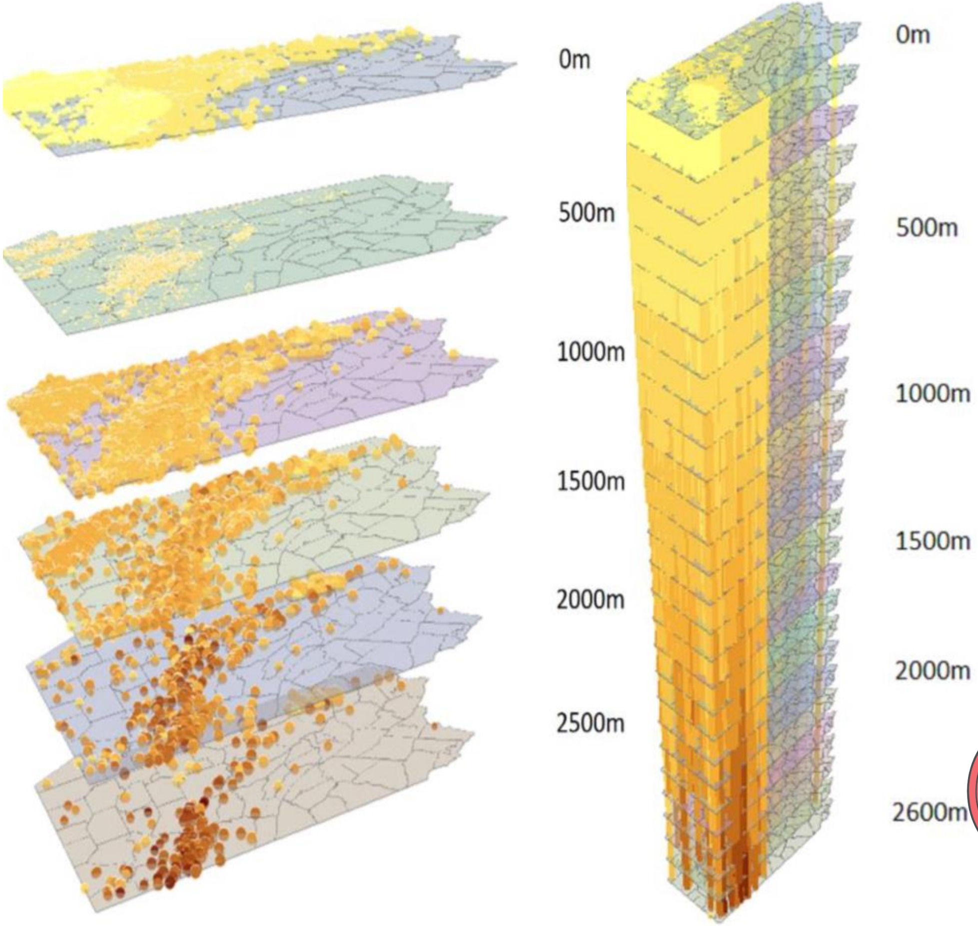

Figure 3. Geothermal potential visualization from 17,467 boreholes through linear extrapolation in ArcScene in Pennsylvania, United States .

hongshan@princeton.edu

Methodology – Identifying Available Heat

To estimate the supply temperature from boreholes, three cases were established based on different assumptions were used to cover the industry convention, academic estimation and ideal production conditions: For Case 1, the heat extraction rate from the boreholes was assumed to be 50W/m[1], which would allow the calculation of the flow rates for different boreholes. Case 2 builds on the estimation of the heat extraction from the geothermal heat flow estimation from Pollack et al. at 87 MW/m 2 [2] to obtain the temperature available from boreholes with the flow rates obtained from Case 1. Case 3 then combines the assumptions from Case 1 and 2 with the 2Sol Coaxial Borehole Heat Exchanger from 2Sol [3] and propose an idealized model that idealize the temperature extracted from the boreholes.

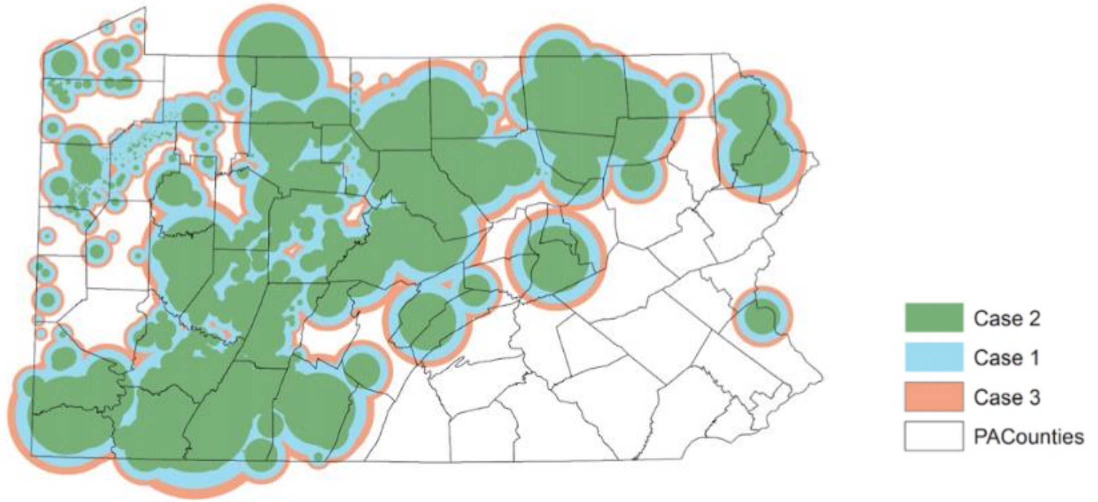

Figure 4. Coverage of suppling working fluid with temperature at 17 ˚C for heat pump assisted heating in Pennsylvania

1. You Shuang, Li Xiangyu, Gao Yu, and Tang Wendi. Methodology of Shallow Geothermal Energy Projects. Energy Science Journal, pages 169–175, December 2014.An Assessment The Ope Fuels
2. Henry N Pollack, Suzanne J Hurter, and Jeffrey R Johnson. HEAT FLOW FROM THE EARTH'S INTERIOR: ANALYSIS O F THE GLOBAL DATA SET. Reviews of Geophysics, 31(3):267–280, Augus 1993.
3. Jose Antonio Sanchez. Enhancing the quality of ground coupled heat . PhD thesis, January 2014.

hongshan@princeton.edu

Methodology – Estimating Households Covered

To better understand the scope of the problem, the demographic profile of Pennsylvania from the 2010 US census is used to compare against the supply distances from Case 2 to determine the possibility of coverage of the supplied areas. Of the total households of 4,777,003 in Pennsylvania, the total amount of house- holds that can be supplied with different temperature availabilities are therefore determined as indicated in Figure 5, or Table 1.

Supply Temperature (˚C)	17	30	45
Percentage of Total Households (%)	858,487	199,019	15,043
Primary Energy Saved (TBTU)	30.3584	6.78	0.53
Million Dolalrs Saved (Million US$)	632.458	141.25	11.04

Table 1. Comparison of performance under three supply criteria assuming Case 2 scenario.

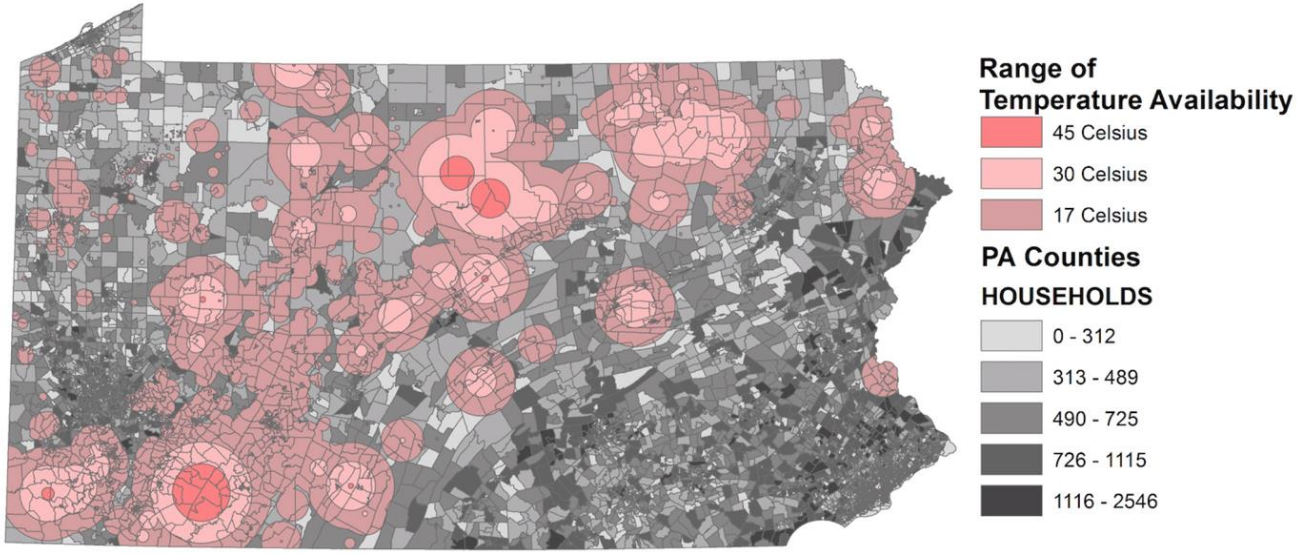

Figure 5. Potential households coverage map using different
Figure 5. Potential households coverage map using different supply criteria assuming Case 2 scenario.
supply criteria assuming Case 2 scenario.

Emerging possibility of recovering heat from CCS

CO_2 as working fluid - Relatively well-researched and is often used in enhanced geothermal system

Possibility of using the saline recovered from CCS as a heat source – NDRC Department of Climate Change entitled Roadmap for Carbon Capture and Storage in the People's Republic of China

Helps avoiding high incremental costs from CCS

Requires significant exergy analysis to avoid 'storing the hot water in the summer, and using it to replace coal district heating in the winter', but rather have the system optimized to the point where exergy is minimized.

Using the same wells we've seen before – would switching to pumping CO_2 back in gain more traction in the preceding of the project.

Results and Discussions

- Using simplified assumptions on the power output from the boreholes and the heat loss along assumed distribution lines, it is estimated that using one-fifth of the boreholes (once they are depleted of oil/gas) available in Pennsylvania, up to **17%** of the population of Pennsylvania can be supported using small-scale heat pumps, or a **5%** of households can be heated without any additional costs of electricity using low temperature district heating.
- Calculation does not include consideration of the construction and thermal costs to distribute the harvested heat.
- Future works could be focused on
  - Identify key sites for feasibility studies, estimate thermal performance with predicted thermal demands through Time Series Analysis
  - Potential of including thermal storage into the model
  - Dynamic Simulation through TRNSYS-like bottom-up calculation of district system.

hongshan@princeton.edu

Thanks for listening… Qs?

hongshan@princeton.edu