Mine Pool Geothermal Resources - Phase I Engineering Study

Prepared for:
West Virginia Division of Energy

September 2022

STATUS REPORT

By

Christine Risch, Director of Resource & Energy Economics
Center for Business & Economic Research

Andrew Nichols, Research Professor
Department of Civil Engineering

Mehdi Esmaeilpour, Assistant Professor
Department of Mechanical Engineering

Richard Begley, Mining Engineer/Consultant

Sinaya Dayan, GIS Consultant

Contents

Project Overview

This report describes the status of work conducted for the West Virginia Office of Energy (WVOE) by the Marshall University Center for Business and Economic Research (MU CBER) and faculty at the Marshall University College of Engineering and Computer Sciences (MU CECS) to further the development of mine pool geothermal resources in West Virginia. The project is titled “Mine Pool Geothermal Resources - Phase I Engineering Study” and began in May 2022.

This engineering study will continue through September 2023 and this report serves as a status update. The study team has submitted a work plan that details the remaining work to be completed by September 2023.

The goals of the project are to (a) identify candidate mine pools that can be utilized for geothermal applications, (b) identify two or three facilities above favorable mine pools that are well-suited to utilize the mine water for heating and cooling, and (c) create a plan to test the candidate mine pool water via drilling from the surface. If shown to be feasible, a mine pool geothermal system should reduce energy consumption for the user facility. In a time of rising energy prices and environmental concern, such a system will help alleviate both, as well as provide productive use of a former mining area that is usually seen as a liability rather than an asset.

Resources used for this study include maps of prospective mines, geological data, water quality data, topographical contour data, interviews with engineers involved with similar projects, area maps of commercial activity, and research on geothermal heat pumps and heat exchangers. The plan will form the basis of a larger-scale project to physically assess the resource. Tasks associated with this project and the status of these tasks are as follows. The remaining sections of the report provide additional information that has been obtained during the execution of these tasks.

1. Identify Data Availability and Needs

The study team worked with the West Virginia Geological and Economic Survey (WVGES) to acquire maps of mines that were identified as potentially developable sites in a previous study titled “Mine Pool Geothermal: Opportunities in West Virginia.” The team also met with staff from the West Virginia offices of the United States Geological Survey (USGS) to learn about testing of mine discharges and water quality data available for individual mines. The current project builds on previous work by the WVGES that estimated volumes of water in underground mine voids in West Virginia.

2. Study Projects in Place

The study team contacted personnel affiliated with three operating mine pool projects in the United States, and two projects that are no longer in operation. This involved a series of in-depth interviews with facility operators, and some of the original engineers and scientists involved with design of the systems. Plans to visit the remaining coal mine pool geothermal system in Pennsylvania were postponed based on information obtained in the interviews. Instead, the team plans to visit a facility in Missouri that is believed to be more informative to observe.

3. Review Geological and Engineering Data

Much of this effort was focused on understanding the information contained in the mine maps, many of which are several decades old, and prioritizing digitization of information for the top candidate mines. Because water samples have not been taken for every mine under evaluation, efforts are focused on identifying samples near these mines.

4. Plan for Energy Savings Estimation

A Mine Pool Geothermal Protocol Survey was developed to distribute to identified partners who show interest in using mine pool water for climate control in their facilities. The survey was designed to collect facility-level energy consumption information that can be used to calculate the potential energy savings from incorporating mine water into heating and cooling needs. The method of calculating energy savings is also being studied to connect the likely impact of the mine pool with energy use.

5. Communicate with Potential Users

The study team identified two potential partners who are interested in studying the potential to use the mine pools below their facilities. These partners are in the cities of Welch and Oak Hill. The study team is working with these partners to acquire facility data to estimate energy savings.

6. Score Candidate Mines

A decision matrix was created based on a list of physical mine characteristics to rank mines for potential development. Characteristics include seam location, use of mine water for potable water, presence of an aquifer above the mine, seam (void) height, pool volume estimates, and presence of subsidence.

7. Identify Field Assessment Tools

To evaluate the water in the candidate mine sites, it will most likely be necessary to drill vertically from the surface. This involves precise selection of a drilling location to ensure the void is accessed, rather than a support pillar. This task involves identifying the procedures to precisely locate the drilling location, the optimal equipment to conduct the drilling, and the water sampling techniques. USGS has previously sampled water from mines in southern WV and will likely serve as an asset in this effort. This task is ongoing.

8. Select Mines to Assess

Two mines have been identified as candidates for physical assessment in the next phase of the project. A third site may be added, depending on interest from nearby facilities and available funding. The final selection will occur after analysis of mine maps, water quality data, and competing use is complete.

9. Plan for Access

To be completed by September 30, 2023.

10. Draft an Engineering Assessment Plan

To be completed by September 30, 2023.

Examples of Projects in Place

The study team is aware of three operating geothermal mine pool projects in the United States. Of these, only one is associated with a former coal mine. One uses water from a closed lead mine and the other uses water from an abandoned copper mine. The project team contacted personnel affiliated with each of the three projects. This resulted in a series of in-depth interviews with facility operators, and some of the original engineers and scientists involved with the design of the systems.

The operating facilities no longer track energy savings associated with the mine pool systems. This is due to the age of the system and the lack of gauges to measure savings. The three operating facilities were all built new, with the mine pool incorporated into the original building and HVAC design, thus there is no baseline energy consumption to use for comparison.

The study team is evaluating which of these projects is the best candidate to visit, based on which would provide the best information. The project in Missouri is the most likely destination.

Marywood University, School of Architecture – Scranton, Pennsylvania

This facility has an operating coal mine pool geothermal system. It was determined that visiting the building would be of limited benefit to the study team due to its small size, usage of the mine pool is seasonal, and the chilled beam technology used in the building to cool the air has limited application. The pool accessed is groundwater located above the mine pool and connected to the mine through fissures.

The interviews with project engineers were extremely valuable and provided guidance for efforts to develop the resource in West Virginia. The study team spoke with Myron Marcinek, Director of Buildings & Grounds Maintenance at Marywood University and Steve Daiute, P.E. of GPI Engineering who was a key engineer involved with design of the original project.

- Built in 2009 using a $500,000 grant from the Pennsylvania DEP.
- Used as a teaching tool for Marywood University.
- Plate and frame style heat exchanger. System is “open”, so the actual mine water flows through the heat exchanger.
- Pump water from one well and discharge into a separate one. Now pumping about 20 to 26 gallons per minute (gpm).
- Accessing water 435 feet below the surface.
- Holes are drilled about 100 feet from the school and recharge wells 50 or 60 feet apart.
- System is primarily used for providing air conditioning on “shoulder” days when weather is mild, and the main air conditioning system isn’t needed (Sept through Nov).
- Looked at installing similar systems in other buildings, but would have required more piping and pipe upgrades, so it would have been cost prohibitive.
- Had meters to calculate energy savings, but meaningful data was hard to measure, so they stopped trying.
- System requires very precise humidity levels to operate correctly. Operation is sensitive and requires special attention.

City of Park Hills, Missouri - City Hall Building

The City of Park Hills is located above a mine pool that is part of an extensive network of lead mines that operated from the 1880s until the 1970s. The lead mine pool is also used for municipal drinking water and is of high quality. Several towns in this part of Missouri access the former lead mines for municipal water. The study team spoke with Mark McFarland, City Administrator for the City of Park Hills, MO.

- Built in 1995 as part of a new City Hall building.
- It is a primary source of heating and cooling for the City Hall, a 3-level building, and operates year-round.
- The system includes 3 wells, 1 for source, and 2 for return to the pool.
- The source well is about 20 feet from the building.
- The depth to the water pool is only around 37 feet.
- The system cost was $60,000 in 1995, of which the city and the local utility each paid for half.
- There is a back-up HVAC system.
- As of 2022, the system is still in operation and has had no major problems over the years.

Although the Park Hills system has required minimal maintenance over the years, a city administrator expressed concern about the lack of knowledge by city staff and local HVAC contractors if it were to stop working or need significant maintenance. Because there are so few systems like this, there is no base of maintenance expertise.

Due to the shallow depth, access to this mine pool is likely much simpler than accessing pools in Appalachian coal mines. It is also assumed that the shallowness of that pool contributed to a relatively low system cost.

Michigan Technical University, Keweenaw Research Center - Houghton, Michigan

Houghton, MI and the surrounding area is located above a series of mine pools that are part of a large network of former copper mines. The mines closed around 1970, but hundreds of capped mineshafts exist throughout the area. Several communities now use the mines as a source of public drinking water. The Keweenaw Research Center at MTU was responsible for identification of the mine water as an energy efficient resource and the design of the system that utilizes the water for heating and cooling.

The study team spoke with Dr. Jay Meldrum, Executive Director and Liaison to the Grand Traverse Area for Michigan Technological University, former Director of the Keweenaw Research Center, and one of the lead designers of the mine water system.

- Built in 2010 as part of a new 11,000 ft^2 building that included the mine pool heating and cooling system.
- The mine water is accessed via an old mineshaft, so did not have to drill a well.
- It is a primary source of heating and cooling for the building and operates year-round.
- Includes a backup natural gas system that is also used in winter.
- Accesses the mine water at 40 feet below the surface but pump it from 300 feet below to access stable 52^{o} F temperatures.
- Open loop system, with return pipes to the mine pool.
- Operates on a 10hp motor at 50%.

- Water runs through a plate heat exchanger but does not mix with the inside heat pump water, which contains ethylene glycol so that the pipes don't freeze.
- Runs via 18 heat pumps throughout the center's main building.
- Cost of project was $100,000, which was largely the cost of the heat pumps.
- Payback estimated from three and five years when compared to natural gas usage.

Documents provided by Dr. Meldrum:

- "A Community Guide To Mine Water Geothermal Heating and Cooling" by Michigan Technological University, Department of Social Sciences (2015). Louie, E., Macleod, E., Masterton, A., Michaelson, M., Occhietti, D., Slagle, N., Tran, T., Anna, D., Blumberg, K., Garrod, A., Savage, D., Warsko, K.

Closed Facilities in Kingston, Pennsylvania

Two older mine pool geothermal systems operating at facilities in Kingston, Pennsylvania are now closed. The Nesbitt Hospital and the Kingston Community Center both installed mine pool geothermal systems in 1980 and both systems are no longer operating. The Kingston Community Center stopped using its system in 2020 after a chiller, and two pumps in the mine pool failed. However, the system operated reliably for decades. A maintenance engineer stated that the center never had to use the back-up unit, but the decision to not replace the system was due to the low cost of conventional systems using natural gas.[1] It is not known when Nesbitt Hospital stopped using its system.

The study team talked to Brian Redmond, a consulting hydrogeologist who was part of the original team when the two projects were built. He provided several documents that he and others authored in 1980 and 1981 that describe the engineering involved with those two projects. These include:

- "Kingston Recreation Center Mine Water Supply Project" dated February 23, 1981, by Brian Redmond, Consulting Hydrogeologist
- "Variations in Groundwater Levels Report Nesbit Memorial Hospital" dated September 10, 1980, by Brian Redmond, Consulting Hydrogeologist
- "Groundwater Supply Report Nesbitt Memorial Hospital" dated June 17, 1980, by Brian Redmond, Consulting Hydrogeologist
- "Mine Condition Report Nesbitt Memorial Hospital" dated February 27, 1980, by Robert W. Bell, Civil and Mining Engineer
- "Well Field Analysis Nesbitt Hospital" dated October 7, 1981, by Brian Redmond, Hydrogeologist

Although these systems are no longer operational, these documents will assist with planning and evaluation.

---

[1] Interview with Lee Landmesser, a facility engineer with PSU Mechanical.

Site Specific Mine Pool Assessments

A series of team meetings with the USGS, the WVGES, and individuals responsible for designing a successful hydrothermal system in PA provided valuable information to the project team. These meetings contributed to the generation of the site selection decision matrix shown in the following table.

Selection of Candidate Mines

These site specific mine features are the basis for ranking criteria and support preliminary findings.

DECISION MATRIX	
Site Specific Features	**Comments/etc.**
1. Previous use of mine pool water for potable water.	Water quality is favorable for the geothermal system, which will minimize corrosion and fouling of the HVAC equipment and pumps.
2. Mine in Pocahontas Seams	Water quality is favorable for the geothermal system per comments from USGS water quality experts.
3. Mine in Sewell Seams	https://www.usgs.gov/publications/availability-low-sulfur-coal-fayette-county-west-virginia
4. Mine in Southern WV	Generally accepted fact: Low sulfur coals are more prevalent in Southern WV when compared to coal seams in Northern WV. High sulfur coal implies pyrite could be present in the coal seam leading to the development of sulfuric acid when exposed to air and water, e.g. acid mine drainage (AMD), which requires the addition of a flocculant creating a solid precipitate in a settling pond prior to discharge of water to the local streams.
5. Presence of a major aquifer above the coal seam	Natural generator of ground water flow and repository that could be higher quality than water that has been exposed to coal mine workings.
6. Presence of multiple seam mining	Increased permeability of the region promoting recharge of higher quality water.
7. Seam height greater than 4 feet	A larger mined seam height has a direct correlation to the resultant voids created by the extraction of the coal. Also increases the likelihood of significant cave-ins of the immediate mine roof increasing permeability of the location.
8. Previous mine pool volume estimates greater than 1,000,000 gal	Leverages the assessments previously calculated by WVGES. Higher mine pool volumes will ensure the longevity of the resource.
9. Presence of surface subsidence	Subsidence is caused when the mine (and overburden) collapses, which increases permeability of the site.
10. Presence of second mining	Increases permeability of the site.
11. Flooded areas mapped previously	Implies the mine was generating significant water during operation due to site-specific conditions and would likely have continued to do so after mining has ceased in perpetuity.

12. Proximity to a major stream	Suggests the mine has an abundance of ground water to maintain a stream complimented with runoff from precipitation events.
13. Lineaments mapped	Defines deep fissures are present which supported underground mine designs suggesting regions of potentially unstable mining conditions as well as an increased flow of ground water into the mine workings.

Relevant publications were also assessed to justify the items in the decision matrix. White (n.d.) discusses the distribution of sulfur in West Virginia coals and supports the existing theory that sulfur increases in coal in an east-to-west direction. This evidence not only holds true for groups and series in West Virginia, but also for individual beds of West Virginia coal. Figures 1, 2 and 3 show illustrations by King (2016) delineating Northern vs. Southern WV coal fields, and variations of sulfur content.

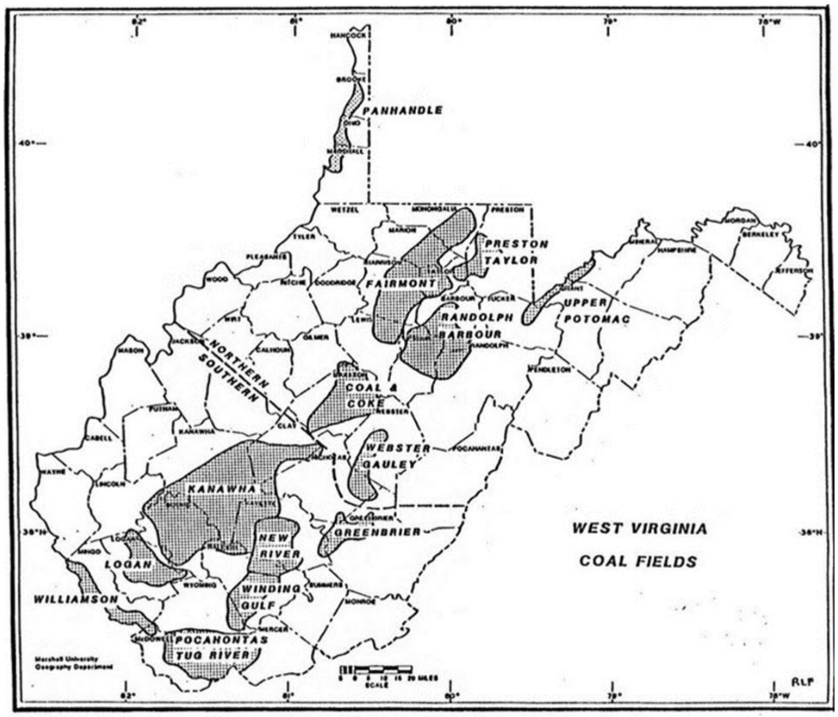


Figure 1. The delineation of the Northern and Southern Coal Fields in WV (King 2016).

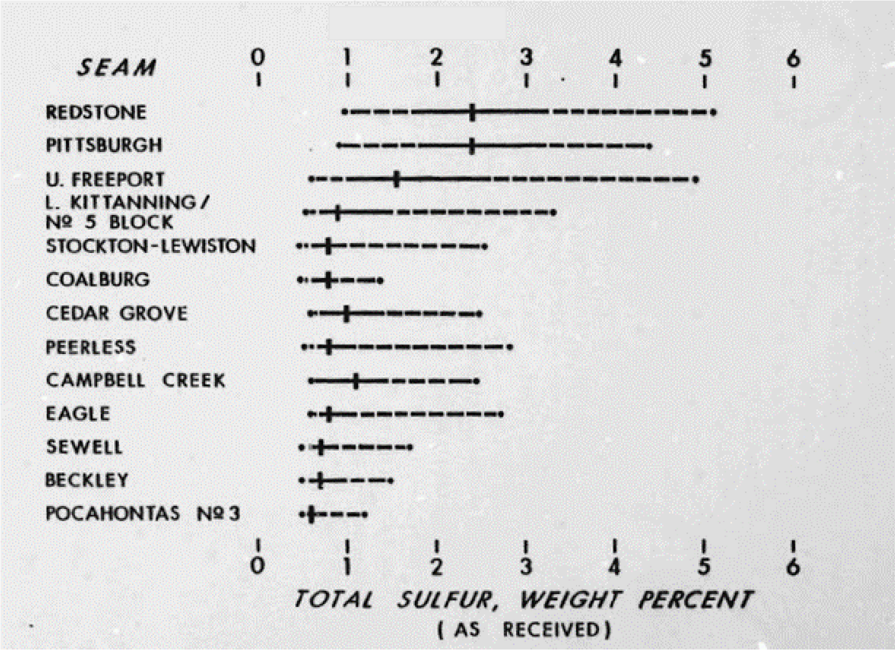


Figure 2. Sulfur amounts by coal seam. Note: Seams are arranged from South (Bottom) to North (Top).

Figure 3 shows that the seams and areas of interest are likely to lie in the band of "exclusively narrow-range coals" in terms of sulfur content. Because a narrow range of sulfur content is favorable for utilization of mine pool water, this supports focus on the Sewell, Beckley, and Pocahontas seams.

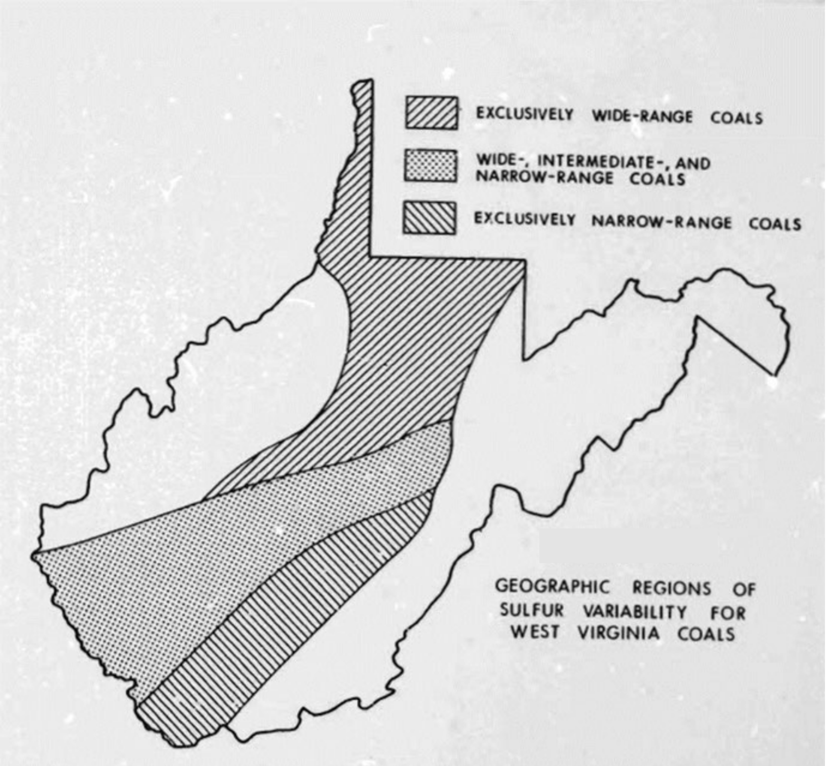


Figure 3. Range of variations of Sulfur that can be present in the coal seams (King 2016).

Preliminary Findings

- The analyses above led to the selection of four seams of interest - **Sewell** in Fayette County, **Pocahontas 3** and **Pocahontas 4** in McDowell County, and the **Beckley** seam in Raleigh County.
- Mines of interest within these seams were selected for detailed mapping efforts due to their location below potential institutional users. These are the **Whipple** mine in Oak Hill, the **Poca 3** and **Gary 4** mines near Welch, and the **Skelton** mine in Beckley. The resultant maps are presented in Figures 4-6.
- These locations and seams were also confirmed as good candidates through discussions with the USGS and the WVGES.
- These maps show the location of potential surface facilities that could benefit from energy savings, as well as economically plausible entities. Public entities are preferred due to longevity of the organization.
- The top four items in the decision matrix were the primary factors with these choices, in addition to adequate urban activity over the coal seams
- The additional items in the decision matrix could be useful for detailed site analyses, as needed.
- A pictorial summary of the mining practices common in WV was prepared as a tool to help the study team understand the structure of underground mines and the location of water in flooded mines. Those graphics are provided in an Appendix. In the next phase, structural information from mine maps will be studied to inform the analysis and finalize the mines selected for testing.

GIS & Data Analysis

GIS Data work

The GIS work environment used during this project was ArcGIS Pro 3.0. Feature classes used to visualize and evaluate abandoned coal mines were retrieved from WVGES Coal Bed Mapping Program and were loaded onto the project platform. The feature classes included:

- Coal mining boundaries.
- Structure elevation contours of the coal beds
- Cropline to clip data to desired extent.
- Scanned mine maps used to evaluate undigitized features of interest.

The datasets included the distribution of potential totally and partially flooded mines in each coal seam by mine footprint area. WVGES estimates of mine pool volume are included in the maps. Additional feature classes were retrieved from the WV GIS Tech Center (WVGISTC).

- Schools K-12 (WVGISTC/WV Dept of Education)
- County boundaries (U.S. Geological Survey/WV Department of Environmental Protection)
- Surface elevation contours (WV SAMB)

Groundwater quality data associated with abandoned underground coal mine aquifers in West Virginia was retrieved from USGS and West Virginia Department of Environmental Protection (WVDEP) to determine the quality of the underground water at sampling locations relative to the abandoned coal mines. Data about nearby sites in the Abandoned Mine Lands (AML) program are part of this analysis.

All data was added to the ArcGIS Pro platform as part of the exploratory phase in the project. The data was used to generate maps that illustrate the mine footprints relative to sites of interests (public schools, and AML subsidence sites), as well as the surface elevation and coal bed structure elevation to determine the depth of drilling that may be required to access groundwater as a source for geothermal activity. A subset of water quality sample locations was extracted based on a set of location queries; identified sample locations that intersected with underground mines within the seams of interest.

The same data was also used to generate a GIS web application with interactive tools that enable querying, elevation profile generation, dynamic infographics, and other data display, sharing, etc.[2] Additional data available from the WVGES can be added in the next phase. Future work can include:

- Develop data dashboard to query, chart, and display water quality data.
- Geo-reference and digitize mine maps and key features for further analysis.
- Spatial analysis to determine optimal locations using the decision matrix
- Additional mapping
- GIS Web integration

---

[2] https://marshalledu.maps.arcgis.com/apps/webappviewer/index.html?id=d0df9e2ab75a407689e0ce60af63fa5c

Fayette County Schools

The Fayette County schools of interest are Oak Hill High School, Oak Hill Middle School, New River Intermediate School, and Fayette Institute of Technology. These schools are part of a complex of building located above the Whipple Mine, which operated until the late 1950s. The complex setting is of particular interest due to the potential for multiple buildings to access water from the mine if the resource is proven to be usable and a good match for these buildings.

An expected depth to the mine pool from the school complex is about 500 feet, based on the relative middle elevations of the seam structure and the complex.

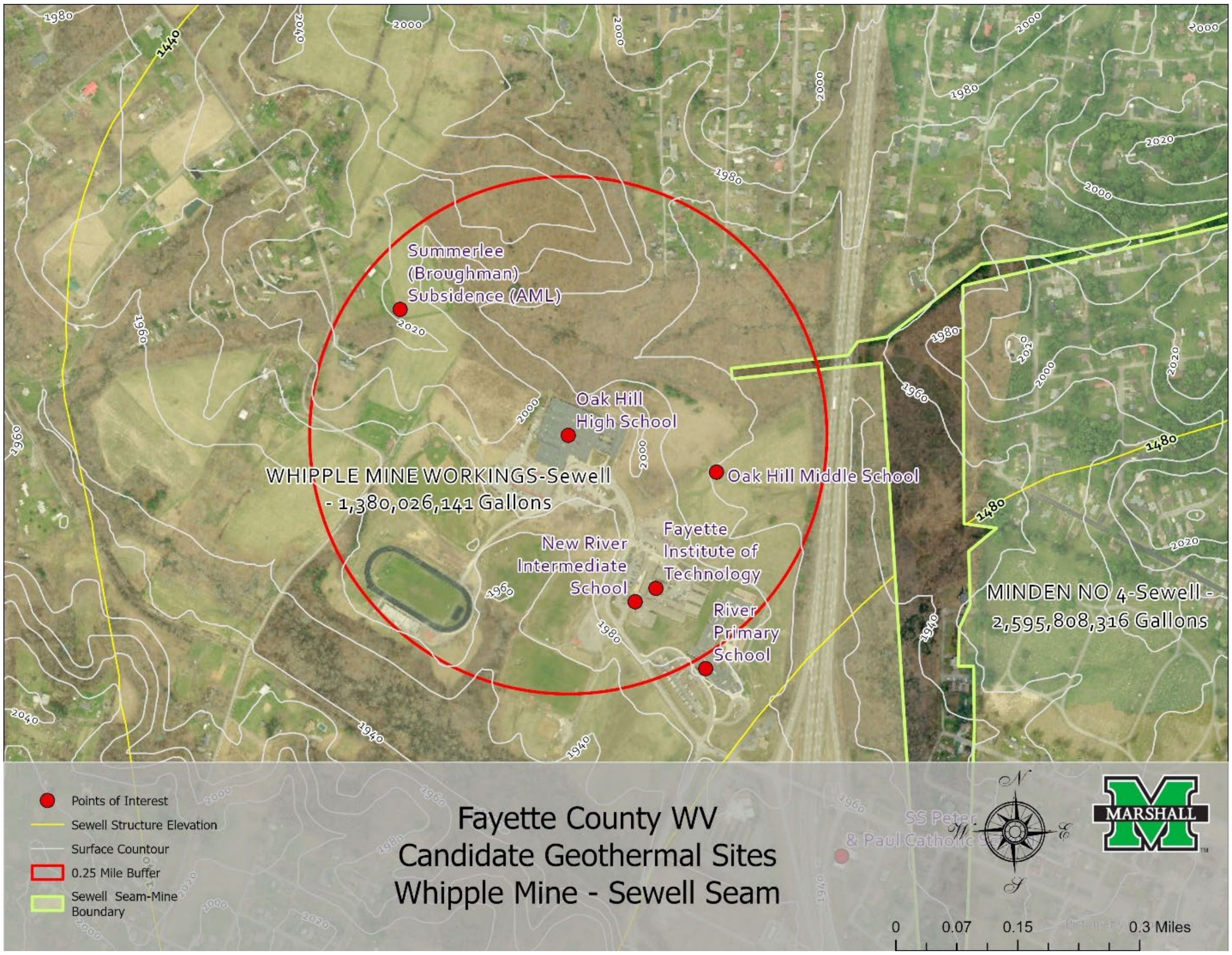


Figure 4. Whipple Mine – Oak Hill

McDowell County Schools

The McDowell County schools of interest are the co-located Mount View High School and Mount View Middle School. The schools are located above the Gary No. 4 and Poca No. 3 mines, in the Pocahontas 4 and Pocahontas 3 coal seams, respectively. The Poca 3 mine operated until 1986, while Gary 4 operated until 1990.

An expected depth to the Gary 4 mine pool from the school complex is about 760 feet, based on the relative elevations of the Pocahontas #4 seam structure and the complex. The depth to the Poca 3 mine would be deeper, as the Pocahontas #3 seam lies below Pocahontas #4.

The Town of Welch and the area surrounding Welch already have a history of using mine water for municipal purposes. This makes the mines in this area good candidates, as development may require no additional costs to avoid issues associated with poor water quality.

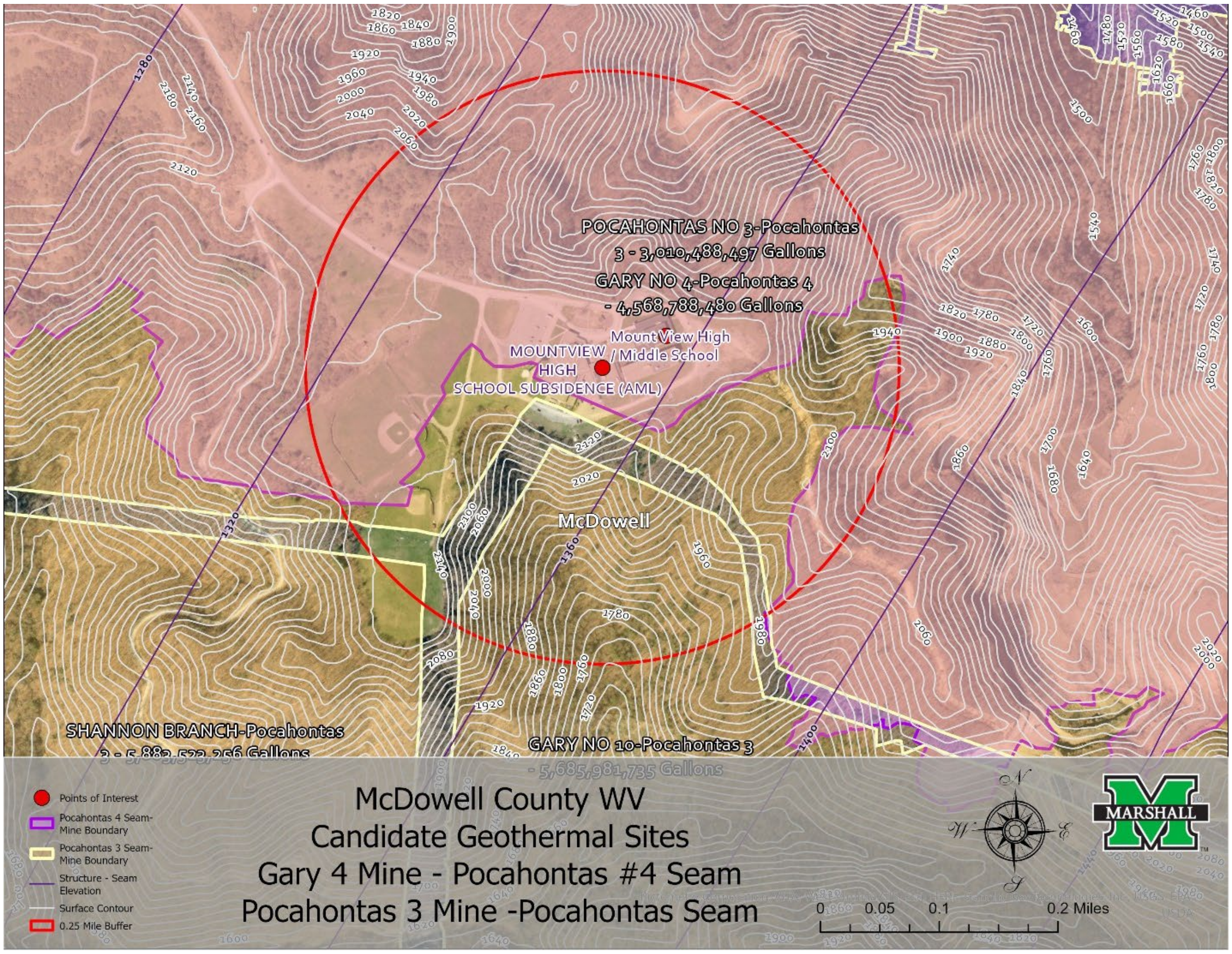


Figure 5. Poca 3 and Gary 4 Mines - McDowell County

Beckley Area

Raleigh County is another area with potential, due to the presence of several large mine pools and good water quality. The City of Beckley, and by default several of its schools and other institutions, are located above the Skelton Mine in the Beckley coal seam. The Skelton mine operated until 1985.

Woodrow Wilson High School (2,360 feet), and the Academy of Careers and Technology Center (2,340 feet), may both be in a suitable location to access the Skelton mine pool (about 2,120 feet). The expected depth to the mine pool from the two schools is 220 to 240 feet, based on the relative middle elevations of the seam structure and the schools.

Like the Town of Welch, some Public Service Districts in the Beckley area have a history of using mine water for municipal purposes. This area may be added to the list of sites for physical assessment if the county school system or another public entity shows interest in the project.

Figure 6. Skelton Mine – Beckley

Development of Potential Partners

The study team identified two potential partners who are interested in pursuing adoption of the mine pool resource as part of their facility's energy system. These potential partners are Fayette County Schools and McDowell County Schools.

Public entities are a preferred type of partner due to longevity of the organization. It is important to have a partner with a long-term interest in energy efficiency. Schools are also a preferred type of facility due to their larger size, which equates to higher energy demands.

The team has established communication with the Director of Operations for Fayette County Schools and with the Facilities Director for McDowell County Schools. Both school systems are interested in the project and said that they are amenable to drilling wells on the school property to assess the mine pool at that location when the project gets to that stage.

Both contacts have been sent requests for facility energy consumption data to enable energy savings estimation to support the evaluation. The study team anticipates receiving that data in November or December 2022.

The study team is also planning to visit sites in both counties that these contacts identify as the best prospects for a geothermal system. Site visits will also be a preliminary assessment of the areas surrounding the potential user facilities.

The study team has communicated the goal to avoid financial outlays from a public partner, such as a county school system. Once determined to be physically feasible, the plan is to seek grant funding to pursue development of the project.

Energy Savings Estimation

It is common to use conventional geothermal heat pump (GHP) systems for residential and light commercial buildings and with different configurations. For large commercial buildings, however, GHP systems can be used with a wider variety of alternative configurations which enables greater energy savings and reduces overall costs. A mine water geothermal system, extracting heat from (or rejecting heat to) flooded mine water as a thermal source in a heat pump system, is one of these alternatives. Mine water GHP systems can be considered as a subset of GHP systems (Banks, 2008; Yang et al., 2010) for larger buildings, which means it is vital to understand the conventional GHP systems in detail first.

GHP System Configuration & Cost

The heat pump used in a GHP system reverses the heat flow (thermal energy naturally tends to flow from the source of high energy to that of low energy) by transferring thermal energy from sources of low energy to sources of high energy at the price of input work. There are two types of heat pumps for heating and cooling, water-to-water and water-to-air systems. The water-to-water type produces hot water for domestic hot water, hydronic systems, or pools, while the water-to-air system delivers heated and cooled air through duct systems for conditioning purposes.

Depending on the type of ground loop heat exchanger, GHPs can also be divided into closed loop and open loop systems. A closed loop system is a common type of installation in which the ground loop heat exchanger is placed horizontally, vertically, or slinky in the ground or a lake or pond. The installation is limited by the amount of land required. The vertical system is more feasible for smaller properties; however, it requires significant drilling costs.

In a vertical system, a borehole drilled vertically downward carries a pair (or two) of pipes with a return bend at the bottom of the loop. Each borehole with a depth of approximately 100-300 ft and pipe lengths of 200-600 ft provides a ton of cooling-heating capacity (Rafferty, 2008). The major advantage of this system is that the pipe loop reaches into a more thermally stable zone where the temperature is more consistent.

In the case that space is not an issue, the horizontal system can be the cheapest of all installations. In this system, the pipe loops are typically buried 4-6 ft below the ground surface at lengths ranging from 125 to 300 ft of trench per ton of cooling-heating capacity (Rafferty, 2008). Although this system represents a less expensive type due to less digging, it is more exposed to seasonal fluctuations and requires much more space.

The cheapest of all types is the pond loop with no digging in which piping is coiled in stacks and sunk to the bottom of the pond. This system can use either a closed-loop or open-loop system, requiring a pond with depths of at least 10-12 feet. The major issue of this system is that the performance strongly depends on the weather and temperature is more exposed to seasonal fluctuations.

An open-loop system is a system in which the water is pumped from a water source close to the surface into the heat pump and then discharged back to the same or another water source. This system typically has a lower installation cost; however, it requires more attention to water quality and long-term system maintenance. A two-well or single-well with a surface disposal system can be used for the open-loop system and each ton of capacity requires about 1.5 to 2gpm. Highly contaminated water can cause corrosion issues of the equipment, so a closed-loop system would be a better choice.

In mine water GHP systems, both closed- and open-loop systems can be considered, depending on parameters such as energy demand, water quality, water flow rate, and even the thermal conductivity of rocks in the mine. The usage of mine water, either in heating or cooling, includes all advantages that exist in different configurations of conventional GHP systems, such as less digging in a horizontal closed-loop system or vertical open-loop which makes the system cheaper, or using a thermally stable zone in a vertical closed-loop due to consistent temperature of the water.

A geothermal system typically requires a higher initial investment than that of a conventional system, but with lower operating costs. The higher initial cost is due to the drilling, additional site work, and the cost of components such as heat pump and circulating pump while the operational costs are generally low, limited to electricity cost for running the heat pumps and water pumps. It is therefore of interest to determine whether the initial cost can be offset by the lowered operating cost.

The initial cost of the system varies according to the size of the building, the features of the equipment, and the performance of the GHP system. Heating performance, defined by the dimensionless coefficient of performance (COP), is the heating effect produced by the unit divided by the energy equivalent of the electrical input. Cooling performance, defined by Energy Efficiency Ratio (EER), is the cooling effect produced by the unit divided by the electrical input. Both the COP and EER values for GHPs are valid only at the specific test conditions used in the rating. Electrical input includes operating the compressor, fans, and pumping in the groundwater system. A presentation with more information about GHPs is included as an appendix.

Case Studies

The geothermal mine water system in Park Hills, Missouri is a system for both heating and cooling of a two-story building with an area of about 8,000 ft^2. The 14°Cmine water is pumped from a depth of 120m at a rate of 280 liters/min to the heat pump system with 9 heat pumps (113 capacity) and the used water is discharged back to the mine. In 1996, the initial cost of installing such a system was about 20% more than a conventional system (natural gas for heating and regular air conditioner for cooling), with a payback period of about 4.6 years using energy costs from 1996. The installed system had a 30% operating cost saving over a conventional heating and cooling system (Watzlaf and Ackman, 2006).

No details on the total initial cost - including the drilling, equipment, duct work, thermostat control, interior piping, and maintenance costs - can be found for any mine water geothermal system. However, energy and cost analysis can be estimated by studying a conventional GHP system since detailed information on the initial, operating, and maintenance costs of such systems are reported in the literature.

In an energy and cost analysis done by Tapia (Tapia, 2017), the initial cost of a residential GHP installation in Louisiana was compared with a conventional air conditioning system. This is a notable example showing that GHP systems can be retrofitted to existing homes and have good performance in humid climates where the system requires extra energy to overcome humidity issues. Study info:

- 3,000 ft^2 residential house located in the state of Louisiana and built in 2000.
- Used a 7-ton heating/cooling conventional HVAC system for 13 years
- Conventional system replaced with a vertical closed-loop GHP system with a 4-ton heating/cooling conventional system.
- Water pump had a capacity of 368 Watts

- Heat pump unit had a flow rate of 12 gpm, with a heating mode of 4.0 COP and 38,200 Btu/hr, and a cooling mode of 19.3 EER and 50,800 Btu/hr.
- Initial cost of a conventional system including both material and installation was about $24,509 (including AC unit, duct system, materials, labor cost, and permits)
- Cost of the GHP system was about $42,098; $28,348 for GHP system cost (including heap pump, water pump, duct system, thermostat control, and interior piping) and $13,750 for site work cost (including drilling, grouting, piping and fitting, and exterior headers) which means about 33% of the total GHP system cost belonged to the ground loop installation cost.

For this project, the initial cost of a GHP system was about twice the cost of a conventional AC system. In the case of a mine water system, heat exchanger and treatment costs must be added to the cost analysis which can increase the cost of the project.

Payback Period

The payback period is a concern limiting mine water geothermal system acceptance in the market. The payback (return-on-investment) period presents the time required for the initial cost of the geothermal system to become more cost-effective than a conventional system. According to Liu (2010), a geothermal system retrofit project has a payback period of about 8-14 years in the U.S. while installing a geothermal system for a new construction building has a shorter period of about 5 years (Hughes, 2008).

For the house in Louisiana, monthly energy bills were compared before and after installing the GHP system to determine energy savings. Figure 7 shows energy usage and cost for both the conventional and GHP systems for this all-electric home. Comparing average electricity cost ($342/month for the conventional system and $126.44/month for the GHP system) and kWh consumed, shows about a 63% reduction in monthly costs and kWh with the GHP vs. the conventional system.

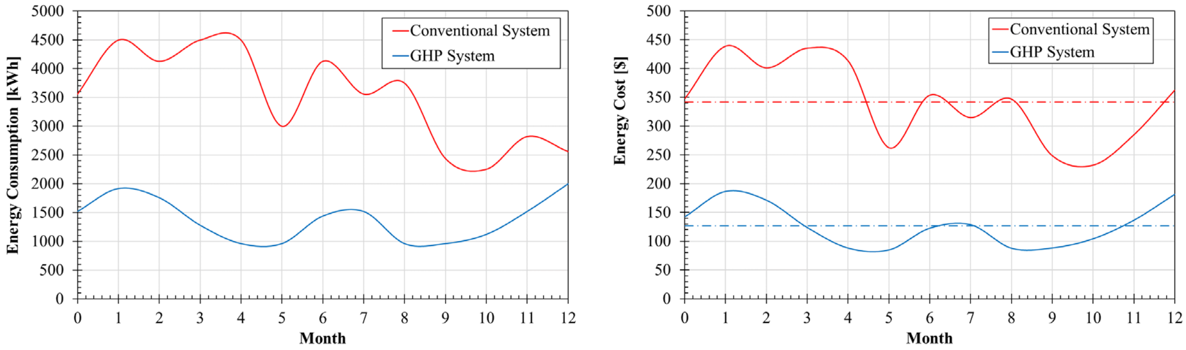


Figure 7. kWh (left) and cost (right) for conventional vs. GHP (Tapia, 2017) from July 2014 to July 2015 for the conventional system and July 2015 to July 2016 for the GHP system in Louisiana.

When installing a GHP system, it is recommended to include two electrical meters to separately measure the GHP system's electricity consumption and the electricity consumption of other appliances in the building. This enables the most accurate estimates of reductions in energy consumption.

Federal tax credits significantly shorten the payback period for a GHP. In a work by Tapia (Tapia, 2017), it was found that the payback period for a GHP system is about two years with government incentives and seven years without. The initial residential federal tax credit, via the Energy Policy Act of 2005, was 30% of the cost of purchase and installation. Currently, the residential tax credit is 26% through 2022 and will decrease to 22% in 2023. The commercial tax credit is 10%. Ground coupled and ground water geothermal equipment are both eligible.

Potential User Energy Savings

The study team is working with interested partners to acquire facility data that can be used to estimate potential energy savings. In July, a **Mine Pool Geothermal Survey** was provided to both Fayette County Schools and McDowell County Schools detailing the facility data needed to estimate energy savings from using water from the mine to heat and/or cool one building on the candidate complex. The full survey is shown as an Appendix. It is anticipated that data from the survey will be provided in November or December of 2022.

Key variables are:

- Building information – year built, floor area, # occupants, type and # of light bulbs
- Building material and insulation
- Quantity of appliances
- HVAC model, equipment, and installation cost
- Maintenance cost – scheduled and unscheduled
- Monthly electricity and natural gas consumption data for 2020 and 2021

The building energy usage data will be combined with data about features of the underlying mine that influence the exchange of heat and the estimated cost of the system. These features include depth to the mine water, the depth of the pool, the temperature of the water, and other mine features.

Conclusions and Recommendations for Next Steps

1. The site-specific variabilities with reference to the presence of sulfur in the coal seams may imply that a water sampling endeavor should proceed once the final site is selected. The currently available water quality data should be investigated further to determine the most cost-effective investment for future water sampling.
2. Conclusions regarding whether a closed or open loop system and final costs will benefit from the enhanced water sampling. Preliminarily, the open loop system will be the most cost-effective due to the ease of installation, so mines with good water quality will be the primary target.
3. A survey was developed to assist with the facility's economic savings analyses, as shown in the appendix. Minimal responses have been returned to date. Additional time is needed to acquire this data and assess the economic justifications for a successful demonstration project.
4. Further detailed mapping analysis of the final site should also be performed that includes the use of more precise surface elevation data and features to assist with accurate location of well drilling. This should also include detailed digitization of the coal pillars to aid in guiding a drill to a mine void as opposed to a solid coal pillar. A recent project in Monongalia County can be used as a best practice.
5. Create new elevation, thickness, and overburden grids on the mine scale rather than the regional scale. It is likely that additional data points can be added that can produce a more accurate grid.
6. Visit the City of Park Hills, Missouri facility to observe the system used in the city hall building and interview the operators.
7. Visit the sites of interested partners in Oak Hill and Welch to discuss possible drilling of test wells and have follow-up conversations about the facility survey submissions.
8. Ensure there are no conflicts with public water sourcing from the targeted mines by conferring with relevant Public Service Districts.
9. Create a plan to access the properties and the mines, with input from land-owning partners, mine owners, and mineral rights owners.
10. Work to understand the requirements to obtain WVDEP permits, including for test wells, and possibly an injection well to dispose of circulated water, if an open-loop system.

Contacts

James Britton
Manager Coal Program
WV Geological & Economic Survey
1 Mont Chateau Rd
Morgantown, WV 26508
(304) 594-2331
britton@wvgs.wvnet.edu

Jessica Moore
Director and State Geologist
WV Geological & Economic Survey
jmoore@wvgs.wvnet.edu

Phil Dinterman
Geoscience and Mapping
Deputy Director / Program Manager
WV Geological & Economic Survey
pdinterman@wvgs.wvnet.edu

Mark D. Kozar
Hydrologist – USGS
mdkozar@usgs.gov
304-542-2594

Mitch McAdoo
Hydrologist - USGS
Virginia and West Virginia Water Science Center
mmcadoo@usgs.gov
Phone 304-347-5130 Ext. 0286

Steve Daiute
GPI Engineering
52 Glenmaura National Blvd, Suite 302
Scranton, PA 18507
Phone: (570) 342-3700
E-Mail: sdaiute@gpinet.com

Dr. Brian Redmond
Professor Emeritus of Geology & Chemistry
Wilkes University, Wilkes-Barre, PA
brian.redmond@wilkes.edu

Myron Marcinek
Director of Buildings & Grounds Maintenance
Marywood University

570-961-4786
mmarcinek@marywood.edu

Jay Meldrum
Director of the Keweenaw Research Center (KRC)
Michigan Technological University
Houghton, MI
jmeldrum@mtu.edu

Mark McFarland
City Administrator
City of Park Hills, MO
(573) 431-3577 x12
cityadmin@parkhillsmo.net

Micah Whitlow
Director
WV Department of Education
Office of School Operations & Finance
micah.whitlow@k12.wv.us
phone 304-558-6300

Timothy J. Payton
Director of Operations
Fayette County Schools
111 Fayette Avenue
Fayetteville, WV 25840
P 304-574-1176 ext: 2155
C 304-6607117
tpayton@k12.wv.us

William E. Chapman, II
Facilities Director
McDowell County Schools
p: 681-201-2235
Cell:304-887-1206
wechapman@k12.wv.us

References

Banks, D. (2008). An Introduction to Thermogeology: Ground Source Heating and Cooling. Blackwell Publishing Ltd.: Oxford, UK, p. 339.

Hughes, P.J. (1998). Methodology for the Evaluation of a 4000-Home Geothermal Heat Pump Retrofit at Fort Polk. Louisiana. Technical report ORNL/CON-462, Oak Ridge National Laboratory.

King, II Hobart M. ---- Roy Long (2019). THE MODE OF OCCURRENCE AND DISTRIBUTION OF SULFUR IN WEST VIRGINIA COALS AND DEVONIAN SHALES, 2016-09-29, https://edx.netl.doe.gov/dataset/the-mode-of-occurrence-and-distribution-of-sulfur-in-west-virginia-coals-and-devonian-.

Liu, X. (2010). Assessment of national benefits from retrofitting existing single-family homes with ground source heat pump systems. Technical report ORNL/TM-2010/122, Oak Ridge National Laboratory.

Rafferty, K. (2008). An information survival kit for the prospective geothermal heat pump owner. HeatSpring Learning Institute, Cambridge, MA.

Tapia, C.L.D (2017). Analysis of Cost and Energy Performance of Geothermal Heat Pump Systems in Southern Louisiana, Master Thesis, Louisiana State University.

Watzlaf, G.R., Ackman, T.E. (2006). Underground Mine Water for Heating and Cooling using Geothermal Heat Pump Systems. Mine Water and the Environment 25, 1-14.

White, I C (n.d.). Geographic distribution of sulfur in West Virginia coal beds. United States: N. p., 1919. Web.

Yang, W., Zhou, J., Xu, W., Zhang, G. (2010). Current status of ground-source heat pumps in China. Energy Policy 38, 323-332.

Appendix A - Energy Use Survey

Mine Pool Geothermal Protocol Survey

Building information:

1. Owner full name:

2. Address/City/State/Zip Code:

3. Type of building (residential, commercial, etc.):

4. Year building constructed:

5. Floor area, [ft^2]:

6. Number of stories:

7. Total occupants:

8. Type of light bulbs (mark all that apply):

9. An approximate number of light bulbs:

10. The material and insulation (if applicable):

Building envelope	**Material**	**Type of insulation**
Walls		
Windows		
Floor		
Roof		

11. The quantity of appliances (This table can be used for <u>residential</u> applications)

Appliance	**Quantity**	**Appliance**	**Quantity**
Refrigerator		Iron	
Microwave		Hair dryer	
Stove & oven-electric		Vacuum cleaner	
Stove & oven- gas		Ceiling/portable fan	
Coffee machine		TV	
Washing machine		Desktop computer	
Water heater		Laptop computer	
Clothes dryer-electric		Printer/scanner	
Clothes dryer-gas		Stereo	
Dishwasher		Clock radio	
Sink waste disposal		Cable box	
Toaster		Internet router	
Electric kettle/pans		Battery charges	
Blender			
Other, please list:		Other, please list:	

HVAC Installation Cost:

Item	**Model/Type**	**Equipment/Material**	**Model/Type**	**Labor**
A/C Unit				
Ductwork	▨			
Controls				
Other				
Total HVAC Installation Cost				$

Maintenance Cost:

		Scheduled		**Unscheduled**	
		Maintenance	**Description**	**Maintenance**	**Description**
2021	Labor	**$**		**$**	
	Material				
2020	Labor	**$**		**$**	
	Material				

Available data:

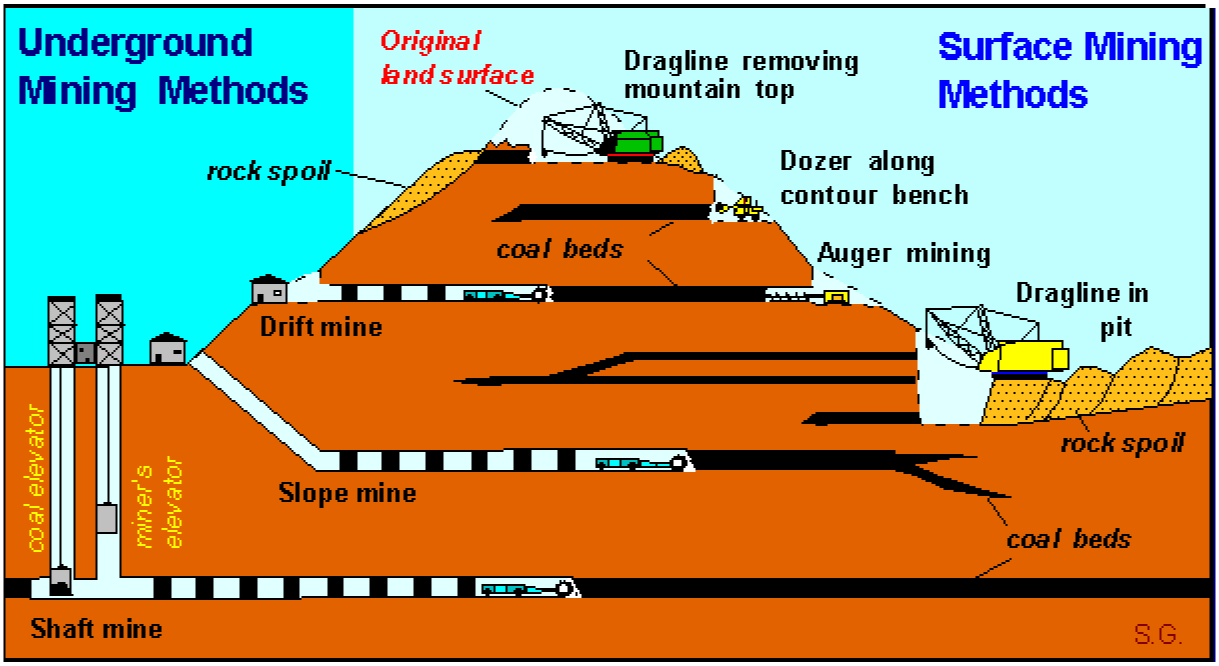
Electricity consumption data and price [KWh] – [$]:

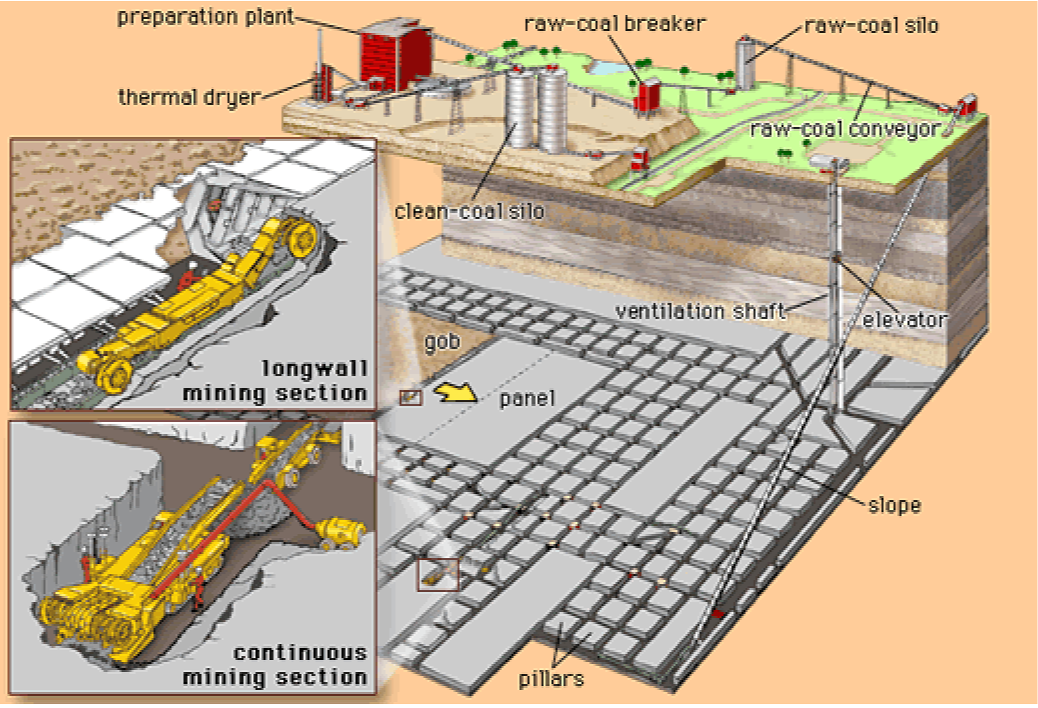
	2021		**2020**	
	KWh	$	KWh	$
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

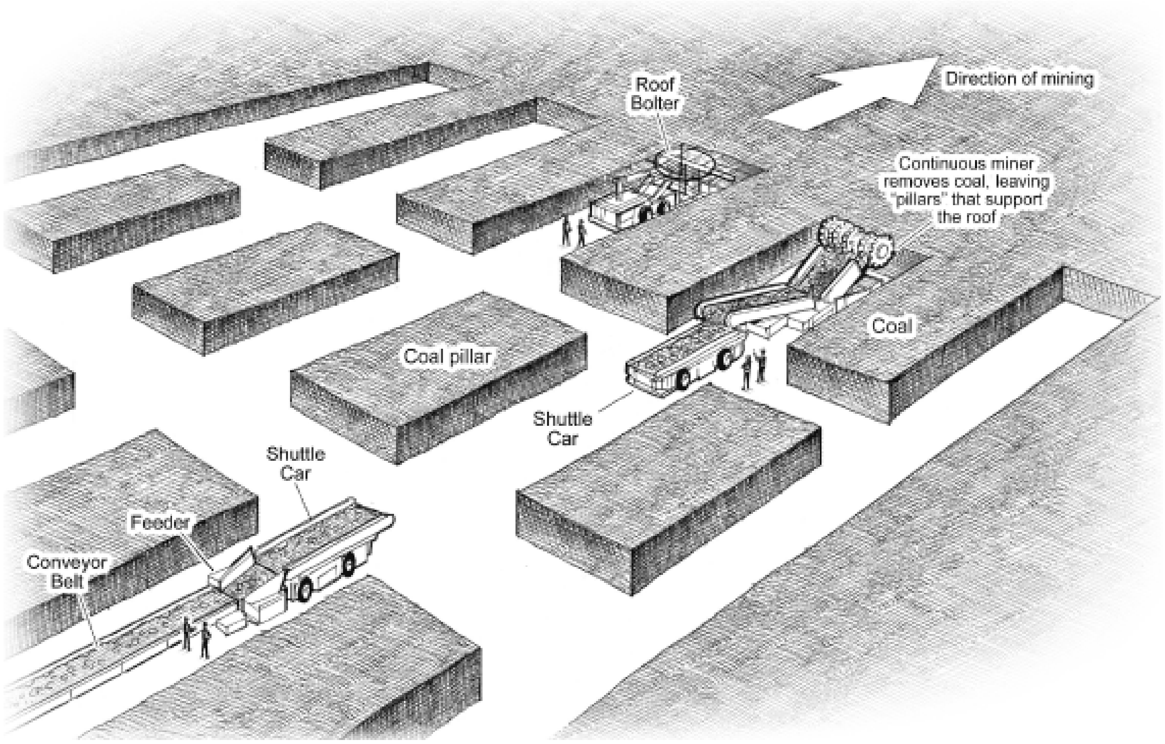
Gas consumption data and price [ft^3] – [\$]:

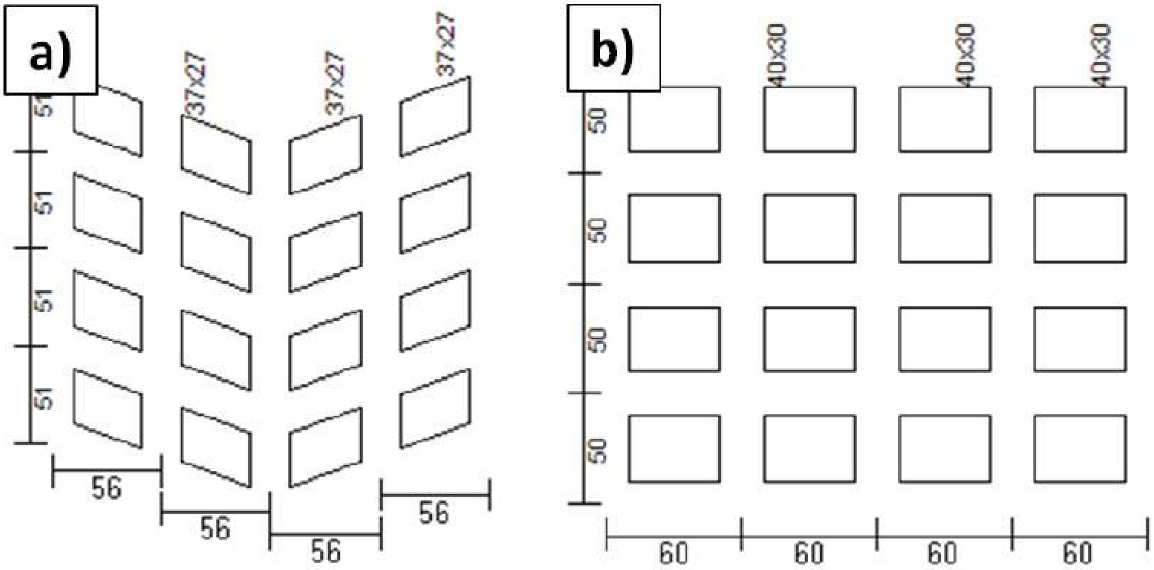
	2021		**2020**	
	ft^3	\$	ft^3	\$
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

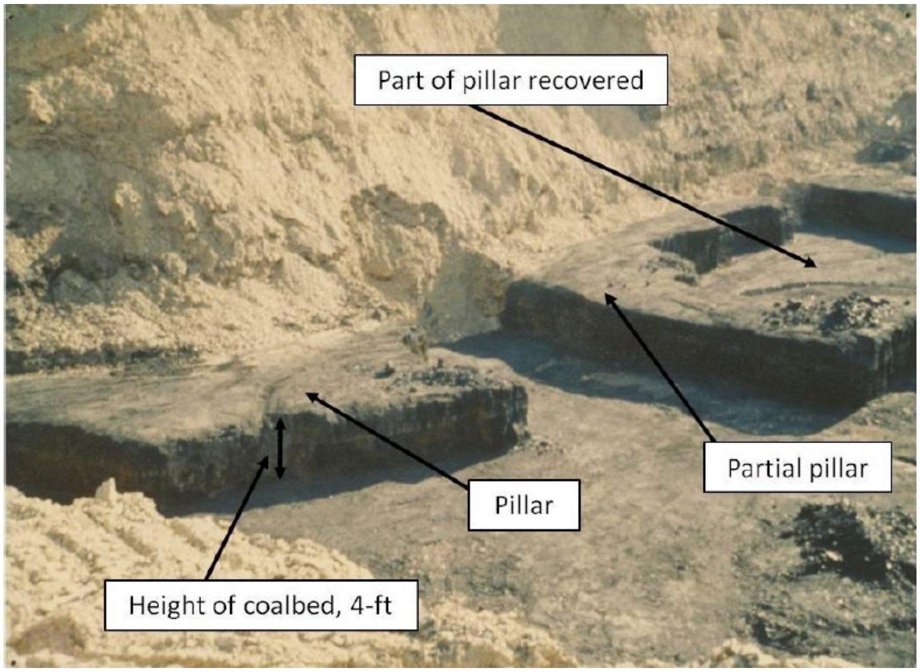
Appendix B – Review of Mining Methods

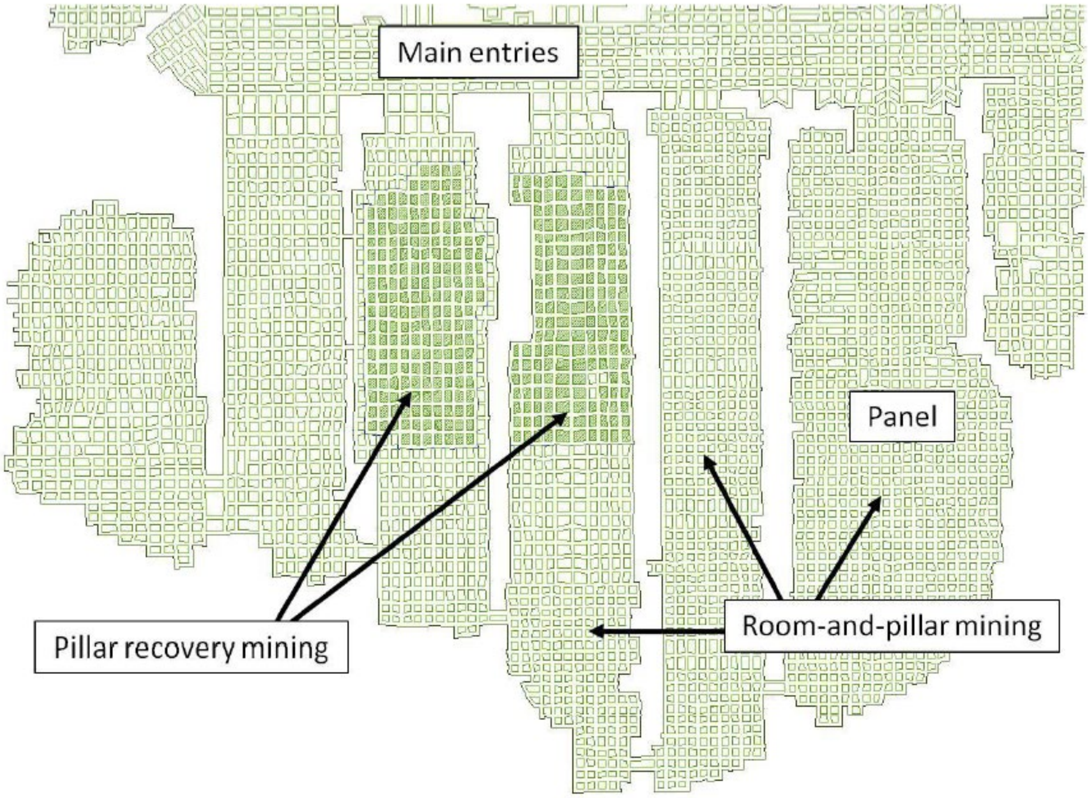


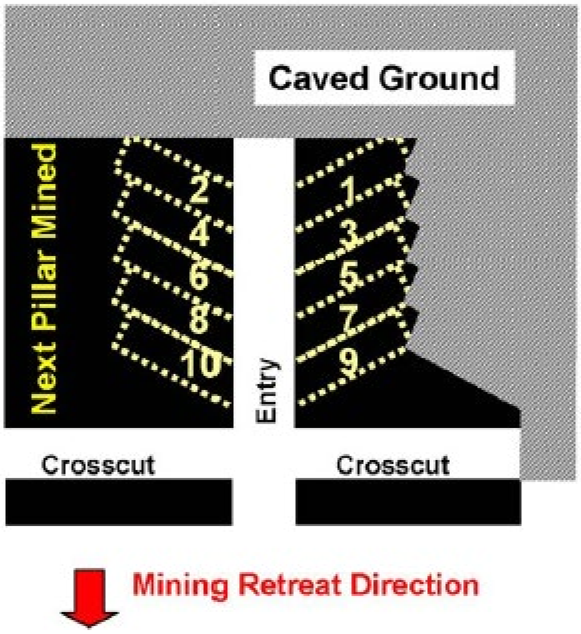



Direction of mining
Roof Bolter
Continuous miner removes coal, leaving "pillars" that support the roof
Coal
Coal pillar
Shuttle Car
Shuttle Car
Feeder
Conveyor Belt

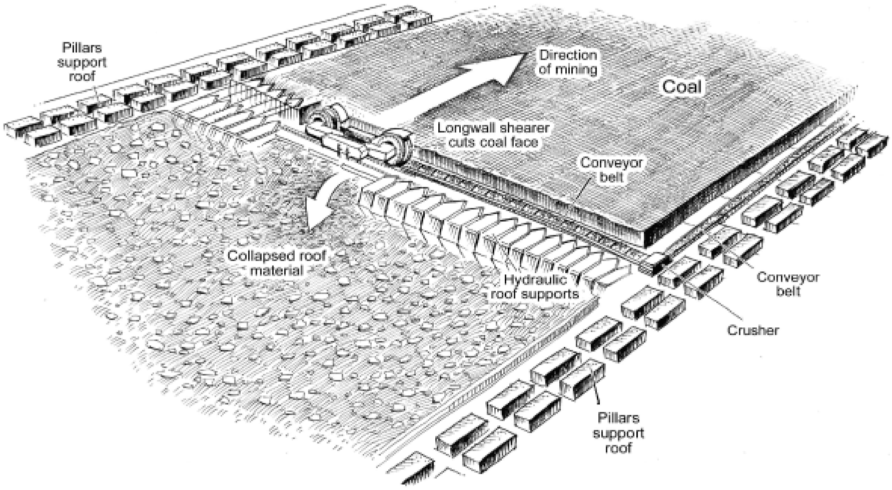

a)
37x27
37x27
37x27
51
51
51
51
56
56
56
56
b)
40x30
40x30
40x30
50
50
50
50
60
60
60
60


Part of pillar recovered
Partial pillar
Pillar
Height of coalbed, 4-ft

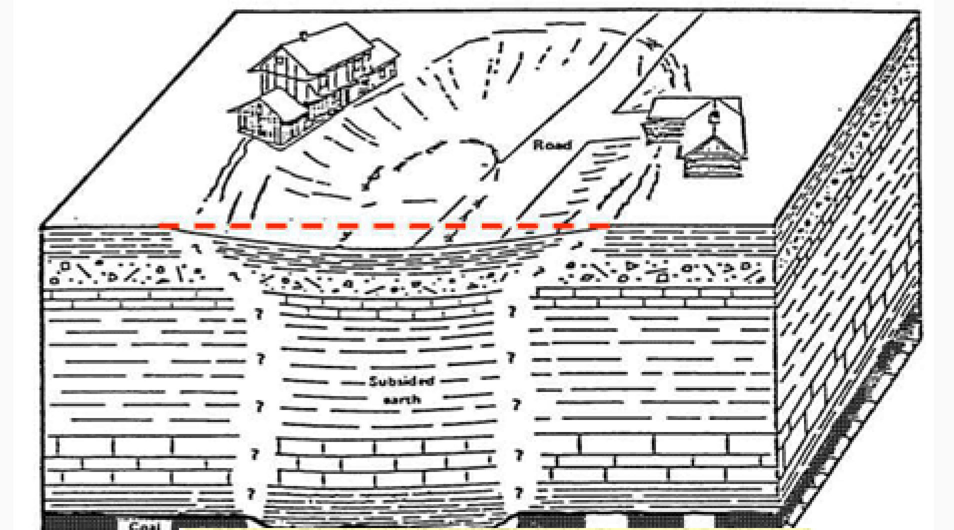

Main entries
Panel
Room-and-pillar mining
Pillar recovery mining

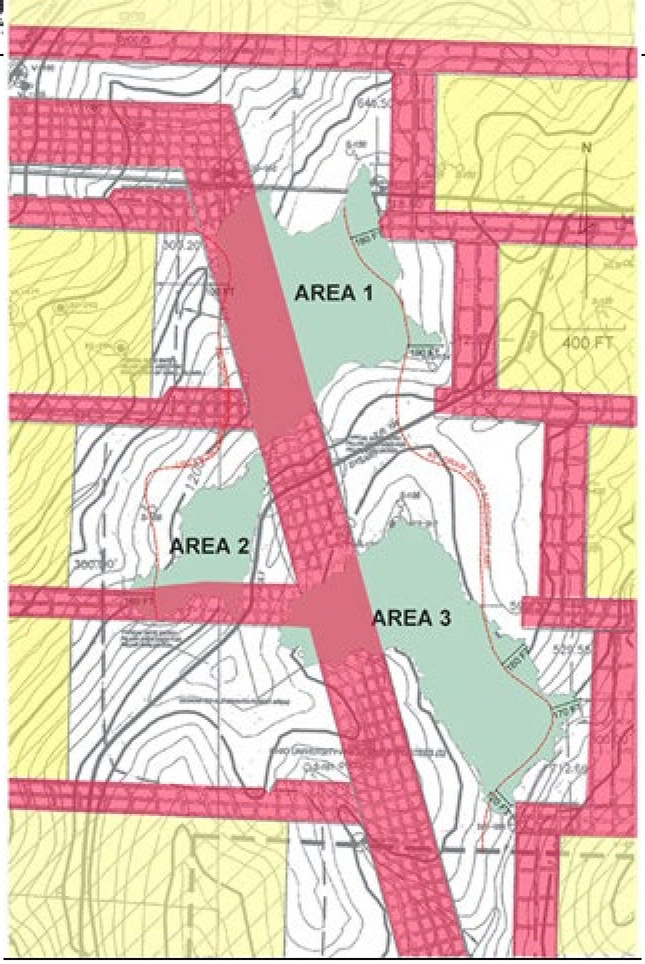


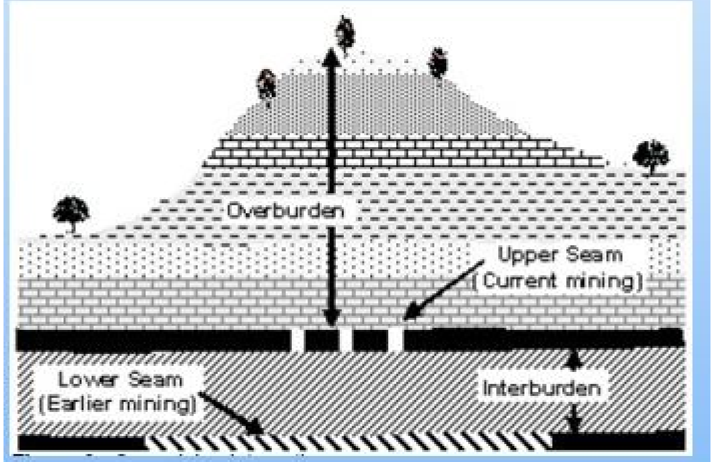
“Christmas Tree” Cut Sequence



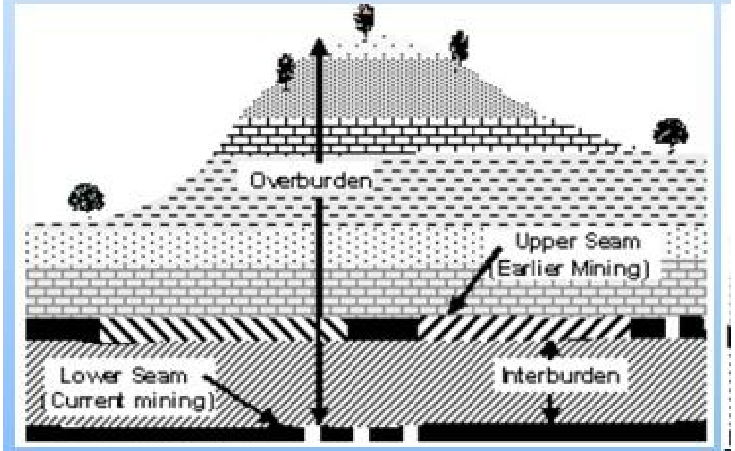
TROUGH SUBSIDENCE





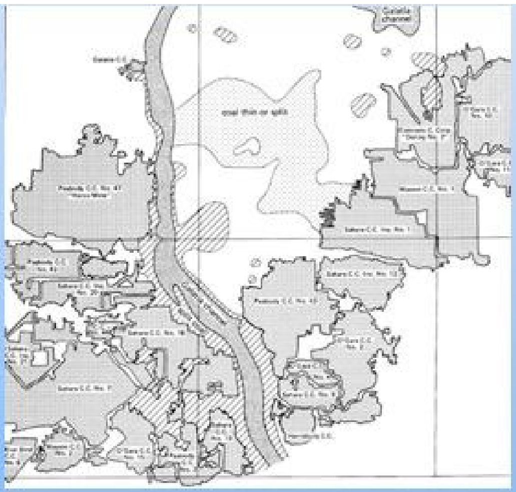


Over Mining

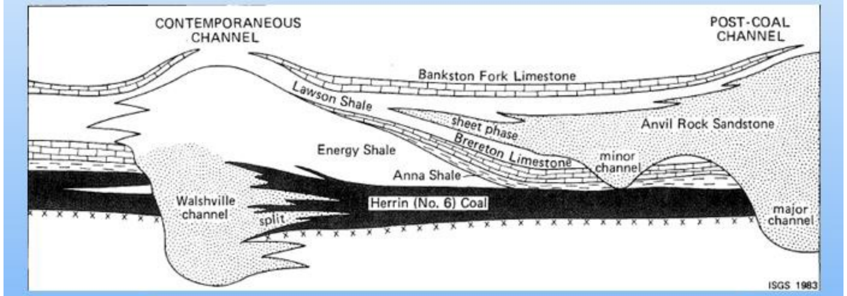


Under Mining

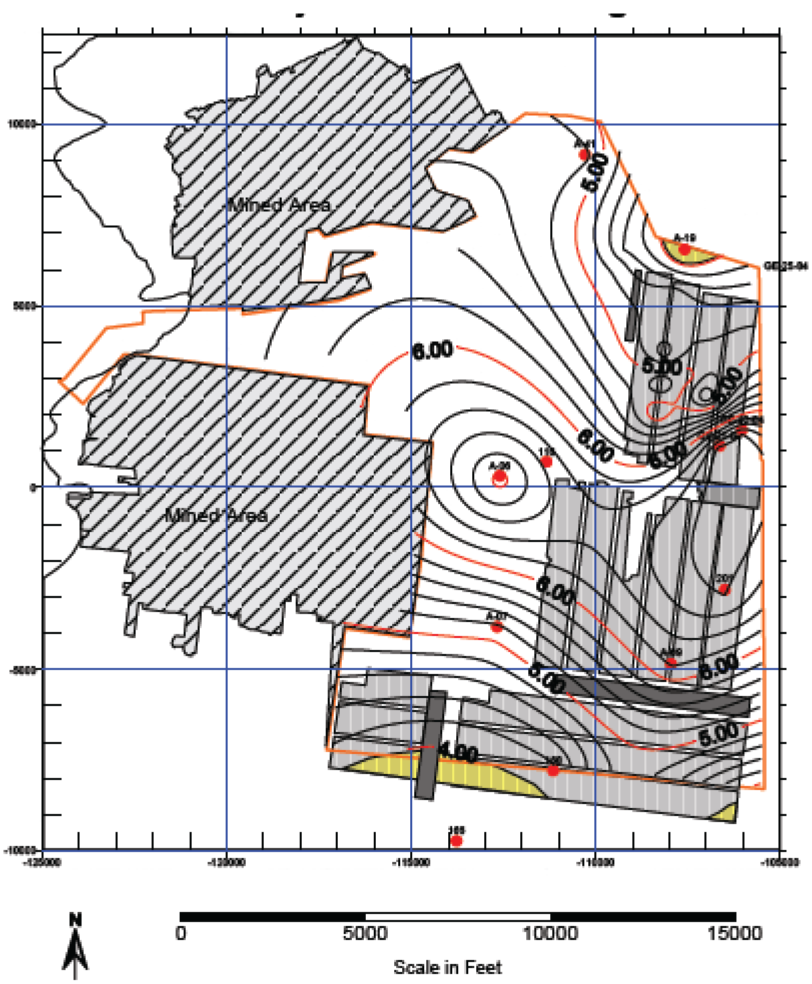
Present Beach and Swamp



Presence of Rivers in Coal Swamps Can Affect Mine Layouts and Produce Many Safety Hazards



Presence of Rivers in Coal Swamps Can Affect Mine Layouts and Produce Many Safety Hazards



Appendix C – Slides from Presentation “Potential Energy from Abandoned Underground Coal Mines in West Virginia”

MARSHALL UNIVERSITY

Potential Energy from Abandoned Underground Coal Mines in West Virginia

Summer 2022

Geothermal Plants with Mine Water

- There are several geothermal installations worldwide that recover energy from mine water available in abandoned coal mines. The mine water is passed through heat pumps and the thermal energy produced in the condenser is used for heating and cooling of buildings.

Summary of geothermal plants with mine water under operation.

Mine site	Power (kW)	Mine water temperature	COP
Nova Scotia (Canada)	3.73	18 °C	3.5
Heerlen (Netherlands)	700	30–35 °C	5.6
Marienberg (Germany)	690	12 °C	N/A
Freiberg (Germany)	N/A	10.2 °C	3.5
Park Hills (Missouri, USA)	112	14 °C	N/A
Hope Shaft (UK)	10	14 °C	3.95
Barredo Shaft (Asturias, Spain)	3,500	23 °C	5.5

Geothermal Plants with Mine Water

Nova Scotia, Canada

- ✓ Open-loop system design,
- ✓ 11 heat pumps,
- ✓ 16,700m^2 of buildings,
- ✓ Each heat pump has a motor rated at 3.73 kW
- ✓ Provides space heating and cooling taking water from the closed mine at a depth of 140m and at the temperature of 18 ℃.
- ✓ The estimated COP for the system is 3.5.

Geothermal Plants with Mine Water

Heerlen, Netherlands

- ✓ Open-loop system,
- ✓ Drilled boreholes 700m deep into flooded coal mine,
- ✓ Space heating and cooling for 350 dwellings, 3,800m^2 of commercial areas and 16,200 m^2 of community buildings,
- ✓ Four heat pumps with a capacity of 700 kW,
- ✓ The temperature of the mine water is 30-35 ℃ in the winter and 16-19℃ in the summer,
- ✓ Due to the high temperatures in the winter, a COP of 5.6 is reached.

Geothermal Plants with Mine Water

Marienberg, Germany

- ✓ Water at a temperature of 12℃,
- ✓ Capacity of over $120m^3/h$,
- ✓ The system provides a heat capacity of 690kW,
- ✓ A closed-loop configuration.

Geothermal Plants with Mine Water

Park Hills, Missouri, USA

- ✓ An open-loop system with submersible pump,
- ✓ 9 heat pumps,
- ✓ Capacity of 112 kW,
- ✓ Provide space heating to $750m^2$ of buildings.

Feasibility of Using Mine Water

- The feasibility of using mine water for heating and cooling of buildings depends mainly on the following characteristics:
  - ✓ The static energy storage associated to the mine water,
  - ✓ Thermal energy demand and installed power,
  - ✓ Distance from closed mine to potential users,
  - ✓ Temperature of the mine water,
  - ✓ Hydrochemical composition of mine water,
  - ✓ Discharge of mine water,
  - ✓ Seasonal evolution of the mine water temperature.

Obstacles to the uptake of mine water

- Risk of ochre clogging of pumps, heat exchangers, pipelines and reinjection wells,
- Risk of reinjected thermally spent water “breaking through” open mine pathways to the abstraction shaft or well,
- Uncertainty over legal and licensing issues and the legal risk of accruing future liability for mine water pollution,
- Presence of a suitably dense long-term heating and cooling demand, with suitable heat emitters, in the vicinity of the mine,
- Difficulties of identifying suitable ownership, economic and distribution models.

Potential Thermal Energy Reserve

- The static energy storage associated to the mine water is given by the following equation:

$$E_s = \eta c \rho V (T_h - T_c)$$

  - E_s: the static energy (kWh);
  - $\eta = 2.7 \times 10^{-4}$: the unit conversion factor (kWh/kJ);
  - c: the specific heat of the mine water, assumed to be $4.18\frac{kJ}{kg.K}$;
  - T_c: the mine water temperature after heat extraction via a tubular heat exchanger;
  - T_h: the temperature of the mine water;
  - ρ: the density of the mine water ($1000 kg/m^3$);
  - V: the volume of the mine water (m^3) or estimated voids volume.

Comment:
In our first step, we may need to find the energy storage associated with each available mine in West Virginia.

As you can see in the equation, the only unknown term is V.

Potential Thermal Energy Reserve

- The geothermal capacity of the water in the mines depends on:
  - ✓ Volume,
  - ✓ Temperature.

- The amount of energy produced will depend on the
  - ✓ Size,
  - ✓ Number of heat pumps that are installed.

Hydrochemical Composition of Mine Water

- The hydrochemistry of the mine water should be monitored on monthly basis, with the following parameters determined in the field:
  - ✓ pH (measure of the acidity or alkalinity of a solution),
  - ✓ dissolved O_2,
  - ✓ Eh (measure of the redox (oxidation-reduction)),
  - ✓ total alkalinity,
  - ✓ temperature,
  - ✓ Electrical conductivity

Hydrochemical Composition of Mine Water

Water Quality for Heat Exchanger

- Water chemistry for hydraulic fluid-to-water heat exchangers, is critical for a successful heat exchange system.
- Municipal drinking water that is pollution free, bacteriologically safe, and has a neutral pH is perfectly acceptable for hydraulic fluid-to-water heat exchangers.

- Cooling tower water and natural water sources, such as wells, rivers, or ponds, must be free of pollutants and treated to reduce contaminants to the same levels as municipal drinking water.

Hydrochemical Composition of Mine Water

Water Quality for Heat Exchanger

- Softened or distilled water may not be suitable as a cooling liquid because although most of the minerals have been removed there is a higher than desirable level of carbon dioxide and oxygen present in the water. High levels of carbon dioxide and oxygen will act to decrease the protective layer of minerals that form on the surface of the tube and increase the formation of copper oxide.

- If the source of cooling water is a cooling tower, the presence of contaminants that are corrosive to metals will vary over time.

Hydrochemical Composition of Mine Water

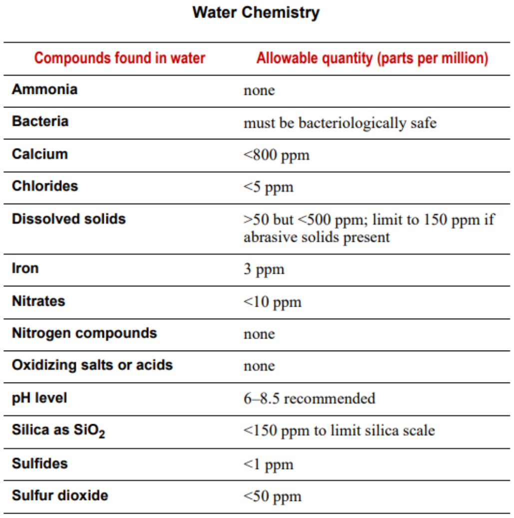
Water Quality for Heat Exchanger

- Contaminants must be controlled to the levels listed in the Table.

- Ideally, the pH level should be maintained in the 6.5–8.0 range for most applications.

- Chlorine should be used to limit the growth of microbiological organisms that are generated by protein decay.

- The chloride concentration in the cooling water must be kept to less than 5 ppm.



Water Chemistry

Compounds found in water	Allowable quantity (parts per million)
Ammonia	none
Bacteria	must be bacteriologically safe
Calcium	<800 ppm
Chlorides	<5 ppm
Dissolved solids	>50 but <500 ppm; limit to 150 ppm if abrasive solids present
Iron	3 ppm
Nitrates	<10 ppm
Nitrogen compounds	none
Oxidizing salts or acids	none
pH level	6–8.5 recommended
Silica as SiO_2	<150 ppm to limit silica scale
Sulfides	<1 ppm
Sulfur dioxide	<50 ppm

Hydrochemical Composition of Mine Water

Water quality of water coming from the mine

- If water coming from the mine is of high enough quality, then it would be ideal to utilize an open-loop system for the heat pump. The reason for this is that higher COPs are obtained with open loops versus closed-loop systems. The table displays the requirements for entering water quality for open-loop heat pumps.

Heat pump water quality requirements for open loops

Heat Pump	pH	Total Hardness	Ferrous Iron	Total Iron	Suspended Solids
Waterfurnace - Copper	7-9	< 350 ppm	< 0.2 ppm	N/A	< 10 ppm
Waterfurnace - 90/10 Cupro Nickel	7-9	< 350 ppm	< 0.2 ppm	N/A	< 10 ppm
Roth - Copper	7-9	< 350 ppm	< 1 ppm	N/A	< 10 ppm
Roth - Cupro-Nickel	5-9	< 350 ppm	< 1 ppm	N/A	< 10 ppm

Hydrochemical Composition of Mine Water

Water quality of water coming from the mine

- Mine water analysis from a Vale mine in Sudbury indicated pH values closer to 4 than 5, meaning standard open loops are not a viable option. However, the values provided by the manufacturers are guidelines for the standard materials found in residential units. It may be possible to utilize other materials in the heat pump which can stand the low pH of the mine water. Cast iron is used in pumps and pipes alike for most dewatering systems, while the Heerlen geothermal installation utilized plastic pipes and titanium primary heat exchangers.

Hydrochemical Composition of Mine Water

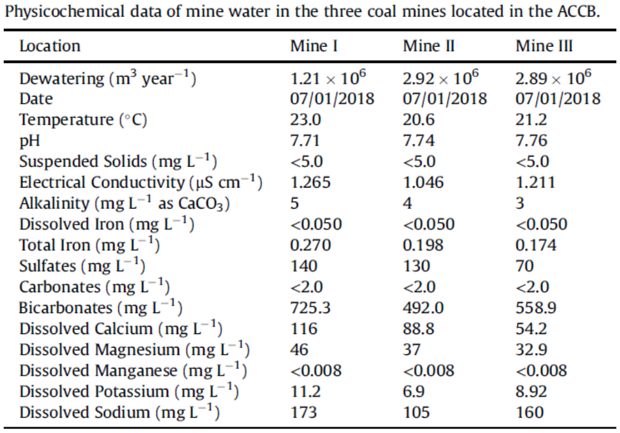
Water quality of water coming from the mine

- An alternative to changing the heat pump material is to raise the pH of the water prior to it entering the heat pumps. Mine water must be neutralized prior to release into the environment, so no additional costs would be added for reagents.

- Assuming that one of these two option is feasible, open-loop heat pumps can then be utilized for energy recovery from Sudbury mines. Open-loop systems yield higher COP values than closed-loop, and confirm that flow rate capacities for the heat pump can be used to determine the maximum number of heat pumps, as all water exiting the mine could be directed to flow through a heat pump prior to treatment.

Hydrochemical Composition of Mine Water

- **Examples of Hydrochemical Composition of Mine Water in Asturian Central Coal Basin (ACCB), Spain**



Physicochemical data of mine water in the three coal mines located in the ACCB.

Location	Mine I	Mine II	Mine III
Dewatering (m^3 $year^{-1}$)	1.21×10^6	2.92×10^6	2.89×10^6
Date	07/01/2018	07/01/2018	07/01/2018
Temperature (°C)	23.0	20.6	21.2
pH	7.71	7.74	7.76
Suspended Solids (mg L^{-1})	<5.0	<5.0	<5.0
Electrical Conductivity (μS cm^{-1})	1.265	1.046	1.211
Alkalinity (mg L^{-1} as $CaCO_3$)	5	4	3
Dissolved Iron (mg L^{-1})	<0.050	<0.050	<0.050
Total Iron (mg L^{-1})	0.270	0.198	0.174
Sulfates (mg L^{-1})	140	130	70
Carbonates (mg L^{-1})	<2.0	<2.0	<2.0
Bicarbonates (mg L^{-1})	725.3	492.0	558.9
Dissolved Calcium (mg L^{-1})	116	88.8	54.2
Dissolved Magnesium (mg L^{-1})	46	37	32.9
Dissolved Manganese (mg L^{-1})	<0.008	<0.008	<0.008
Dissolved Potassium (mg L^{-1})	11.2	6.9	8.92
Dissolved Sodium (mg L^{-1})	173	105	160

Reference

- A. Hall. Renewable Energy Recovery From Underground Mines. Master of Applied Science (M.A.Sc.) Thesis in Engineering, Laurentian University, Sudbury, Ontario.

- D. Banks, A. Athresh, A. Al-Habaibeh, N. Burnside. Water from abandoned mines as a heat source: practical experiences of open- and closed-loop strategies, United Kingdom. Sustain. Water Resour. Manag. (2019) 5:29–50.

- Heat Exchanger Care and Water Quality Guide, 2005 MTS Systems Corporation.

- J. Menendez, A. Ordonez, J. M. Fernandez-Oro, J. Loredo, M. B. Díaz-Aguado. Feasibility analysis of using mine water from abandoned coal mines in Spain for heating and cooling of buildings. Renewable Energy 146 (2020) 1166-1176.