



A COMMUNITY GUIDE TO

Mine Water Geothermal Heating and Cooling

**A Community Guide To Mine
Water Geothermal Heating
and Cooling**

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Preface

This guidebook covers the basics of heating and cooling buildings with geothermal energy from mine water. It is intended to give communities the necessary tools to make an informed decision about investing in this technology. The fundamental message of this guidebook is that large, underground thermal reservoirs are available to be utilized now and in the future.

This guide is written for a broad audience including community members, leaders, small businesses, contractors, and groups interested in renewable energy resources. Included are strategies and tools for community-assessment and participatory planning, thinking through ownership structures, and innovative funding mechanisms.

The instructions and tests featured in this guidebook were developed and tested in collaboration with the community of Calumet, Michigan. Examples from Calumet and other communities illustrating how to apply ideas, concepts, and steps described generally in the guidebook are featured in call out boxes.



Introduction

“The first step toward getting somewhere is to decide that you are not going to stay where you are.”
– John Pierpont Morgan

Millions of people live near a closed underground mine. Former mining communities often face a multitude of economic, social, and environmental challenges [1,2]. Reusing the flooded mine shafts for heating and cooling buildings can be a tremendous economic, social, and environmental opportunity [3]. Tapping into to water filling old mines for geothermal energy is one way to take advantage of reuse.

Mine water geothermal systems can be both financially and environmentally efficient means of heating and cooling buildings. Benefits can include reduced costs and reduced vulnerability to market fluctuations in energy prices as well as significantly reduced carbon emissions. Mine water geothermal systems also have the potential to create local jobs and increase local energy independence.

The sheer size of the thermal reservoir in a flooded underground mine opens the possibility of using the water for district heating and cooling, industrial parks, or large manufacturing facilities. However, small scale projects such as a single building or home are also possible.

There are seven main sections to this guidebook:

- 1: Details on geothermal heat pumps and the unique opportunities they can offer when paired with mine water
- 2: How to spread the word about geothermal energy and heat pumps, build support and leadership, and assemble a planning team
- 3: What data needs to be gathered and methods to do so
- 4: Analyzing data and what it means
- 5: Determining the best system configuration for a community
- 6: Exploring available funding assistance and potential legal concerns
- 7: Finding experienced, qualified geothermal professionals and HVAC experts

This guidebook would not be possible without the inspiration and lessons learned from Calumet. Calumet is located in Houghton County, Michigan, in the middle of the Upper Peninsula's Copper Country district along the shores of Lake Superior. It was once at the center of the copper mining industry during the mid - 1800's until the mines officially shut down in 1968.

There are twenty-seven mine shafts and associated stopes in the town that have since filled with water that may be a potential source for a low-grade geothermal energy project. Documentation of the mine shafts contain information about the inclination, diameter, depth, and rock type of the mines which have been stored away in the town's archives.

WHAT IS MINE WATER GEOTHERMAL?

An underground mine consists of one or more mine shafts used to access the mineral resource. Underground mining creates voids in the bedrock. Water from the ground or surface percolates into these hollows. When mines are being worked, this water is pumped or drained out to allow miners access to the ore seams. In most cases, when mine works are closed, pumping stops and the mined areas fill with water (Figure 1).

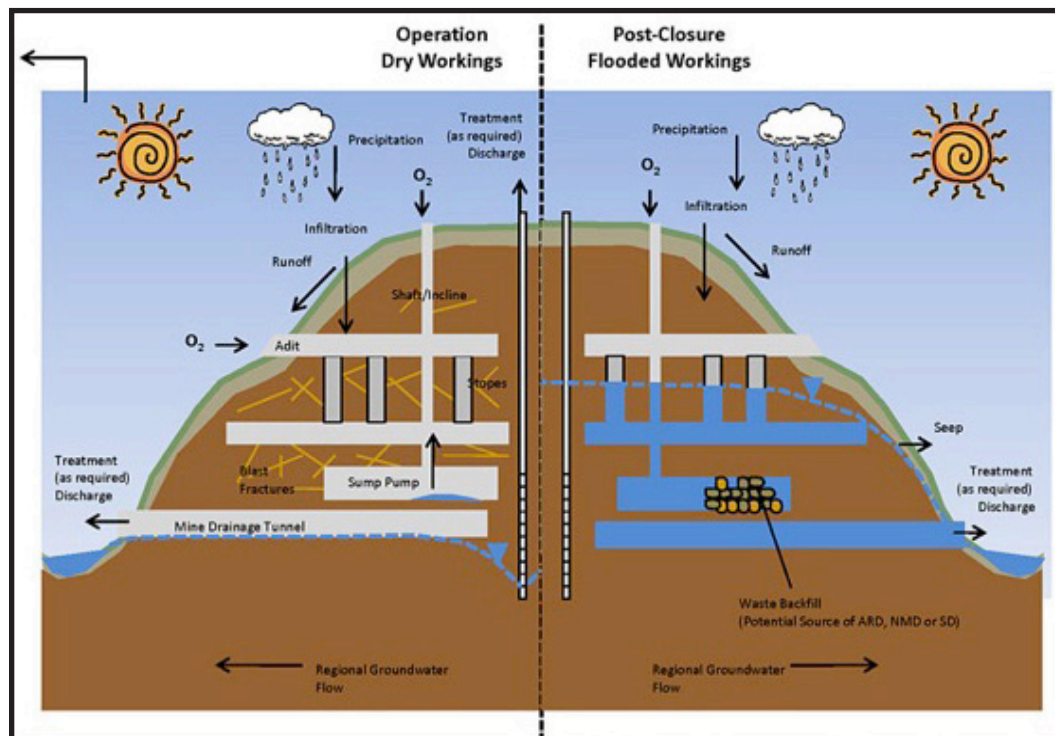


FIGURE 1. Water management in active and closed mines [1].

Each flooded mine can contain millions to trillions of gallons of water. The surrounding bedrock conducts the earth's heat into the water and insulates it from wide seasonal variations which keeps the mine water warmer than the ambient air temperature in winter and cooler in the summer, making it an excellent thermal resource [8]. The heat in the water can be utilized through a geothermal heat pump to provide a highly efficient way of heating and cooling buildings.



Geothermal Heat Pump System

A geothermal heat pump uses the heat from the earth to heat or cool a building. Water in underground mine shafts has been insulated and warmed by the earth's heat to a constant temperature of 45° F to 75° F depending on the location. These are ideal temperatures for a geothermal heat pump system. These are ideal temperatures for a geothermal heat pump system, which can concentrate heat to warm a building.

Geothermal heat pumps are more efficient than air source heat pumps because they exchange heat with the ground or water, both of which contain vastly more heat for the same volume than air. As a result, less energy is needed to concentrate the heat. Additionally ground temperatures are far more stable year round than air temperatures.

Geothermal energy at these temperatures (45°F to 75°F) is considered low-grade. Medium (80°F to 250°F) and high (300°F to 700°F) grade geothermal energy is found only at limited places on Earth such as in Yellowstone National Park. High and medium grade geothermal energy can be used to heat water into steam to generate electricity or heat buildings without the assistance of a heat pump. While not as versatile, low grade geothermal energy is available everywhere in the world; however, it is much easier and more cost effective to access it in places with flooded underground mines.

Geothermal heat pumps can exchange heat with the ground and water sources in a variety of configurations as shown in Figure 3. Typically, these systems require a large amount of drilling or excavation to access the geothermal heat source.

Mine water geothermal is an innovative approach that uses the enormous thermal reservoir of a flooded underground mine as a heat source/sink [3]. This allows for greater heating and cooling capacities than other types of geothermal system configurations with little to no drilling required.

Geothermal heat pump systems are categorized into open and closed loop systems[16, 17]. Closed loop systems circulate an antifreeze solution inside sealed, closed loop pipes which can be submerged in mine water. Heat from the mine water is then transferred through the wall of the pipe into the antifreeze solution and brought to the heat exchanger (Figure 3, row one).



Economic Benefits – Ball State University & Marywood University



A dramatic difference is evident in the comparison between the geothermal system at Ball State University and Marywood University.

At Ball State University 3,600 400 to 500 feet deep wells were drilled to create the geothermal exchange interface for their closed loop heat pump system [13]. This closed loop system also required 10 miles of pipe.

In contrast, at Marywood University a similar sized geothermal heat pump system utilizing a flooded underground mine required two boreholes and 2,000 feet of pipe [14, 15].

The dramatic reduction in drilling costs is possible due to the much larger thermal capacity of a flooded mine. A geothermal heat pump system that exchanges heat with the ground in a vertical setup requires a 100 to 300 foot well to be drilled for every ton of heating/cooling; for a large system, that translates to many wells. In some situations, it may be possible to use existing mine shafts as access points. In other cases, it may be more convenient and cost effective to drill a new access point.

In this system configuration, the mine water never leaves the mine. It can be used even when the water quality is poor as in areas with acid mine drainage. However, since the heat from the water must go through more heat transfer steps, a closed loop system requires more piping and may be less efficient than an open loop system.

In an open loop system, the mine water is pumped into a pipe that brings the water out of the mine to directly contact a heat exchanger (Figure 3, row two). Afterwards the water is returned through the same mine shaft or through another shaft dedicated to return water.

If the water is returned to the same shaft, it must be returned at a different depth than from where the water is withdrawn. If the withdraw point and the return point are too close together, the water being withdrawn will not have had the time to equilibrate with the earth's temperature. This will cause a significant decrease in the efficiency of the heat pump.

Open loop systems require that the water be plentiful, relatively clean and non-corrosive so that it doesn't damage the heat exchanger. Installing open-loop systems require that all local discharge codes and regulations are considered.

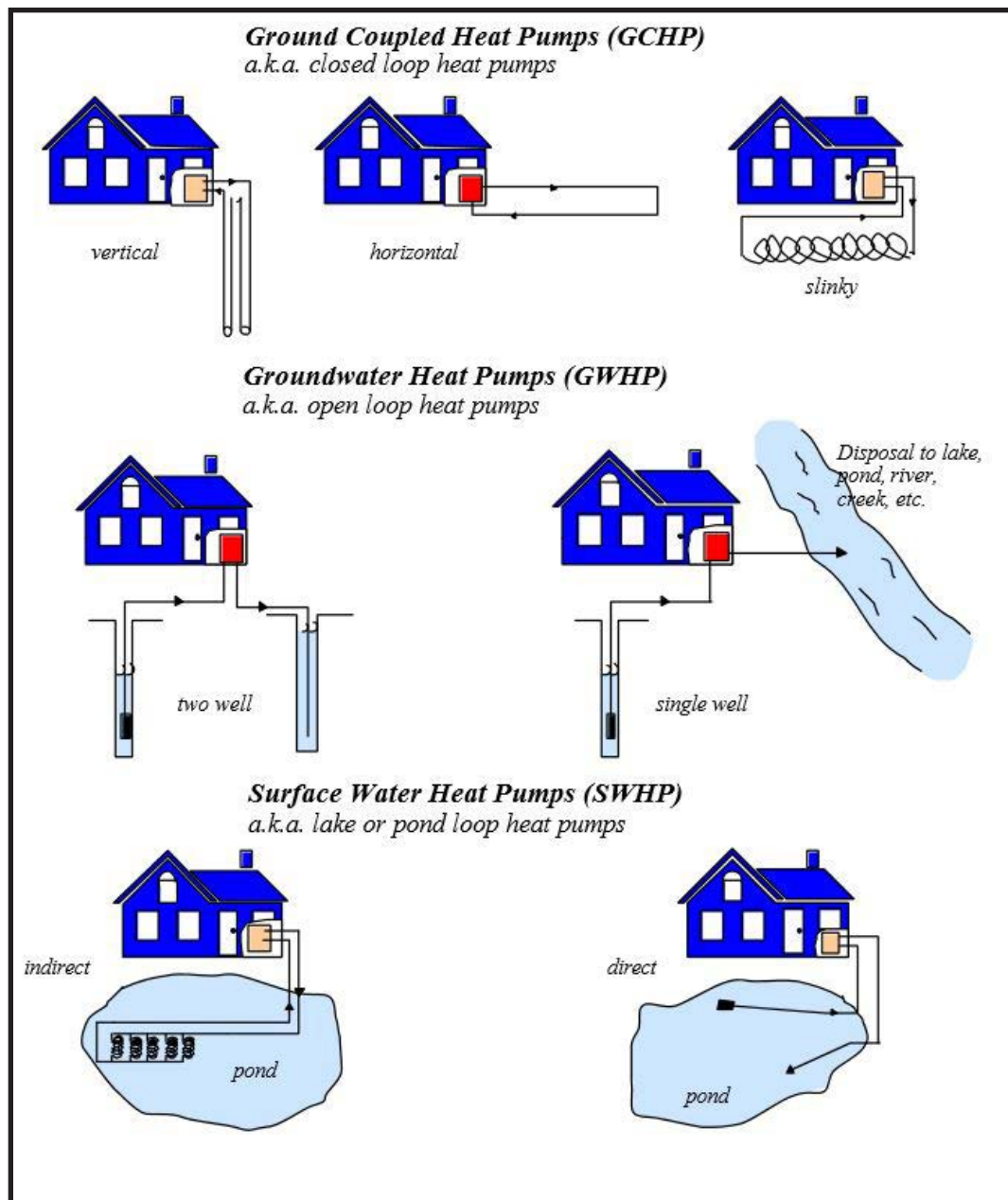


FIGURE 3. The figure above illustrates different ways and sources a geothermal heat pump system can extract heat [6].

Heat pumps can be used with a variety of heating, ventilation, and cooling (HVAC) systems. Forced air systems and radiant heating systems are two systems easily converted to heat pump systems.

Steam boiler systems can be retrofitted with a water to water heat pump system; however, it is not recommended as heat pumps cannot concentrate heat enough to generate steam or extremely hot water [18].

A surprising number of communities have access to mine water geothermal energy. Throughout the United States there are at least 23,000 closed, inactive underground mine shafts on private and federal lands; most of these are already flooded [19].

There are at least 2,300 shafts in the state of Michigan alone (2013 Allan Johnson personal communication; unreferenced). Overlaying population data from the 2010 U.S. Census onto USGS data on the location of underground mines shows that over 764,000 Americans in 370,000 homes live within a half mile of a closed, inactive mine shaft.

The three states with greatest populations in the vicinity of a closed underground mine are Missouri, California, and Colorado with 194,000, 107,000, and 79,000 people respectively living within a half-mile of a mineshaft.

Thus a significant number of people could potentially harness the heat from nearby mine water using a geothermal heat pump. An overview of the location of these former mines is shown in Figure 4.

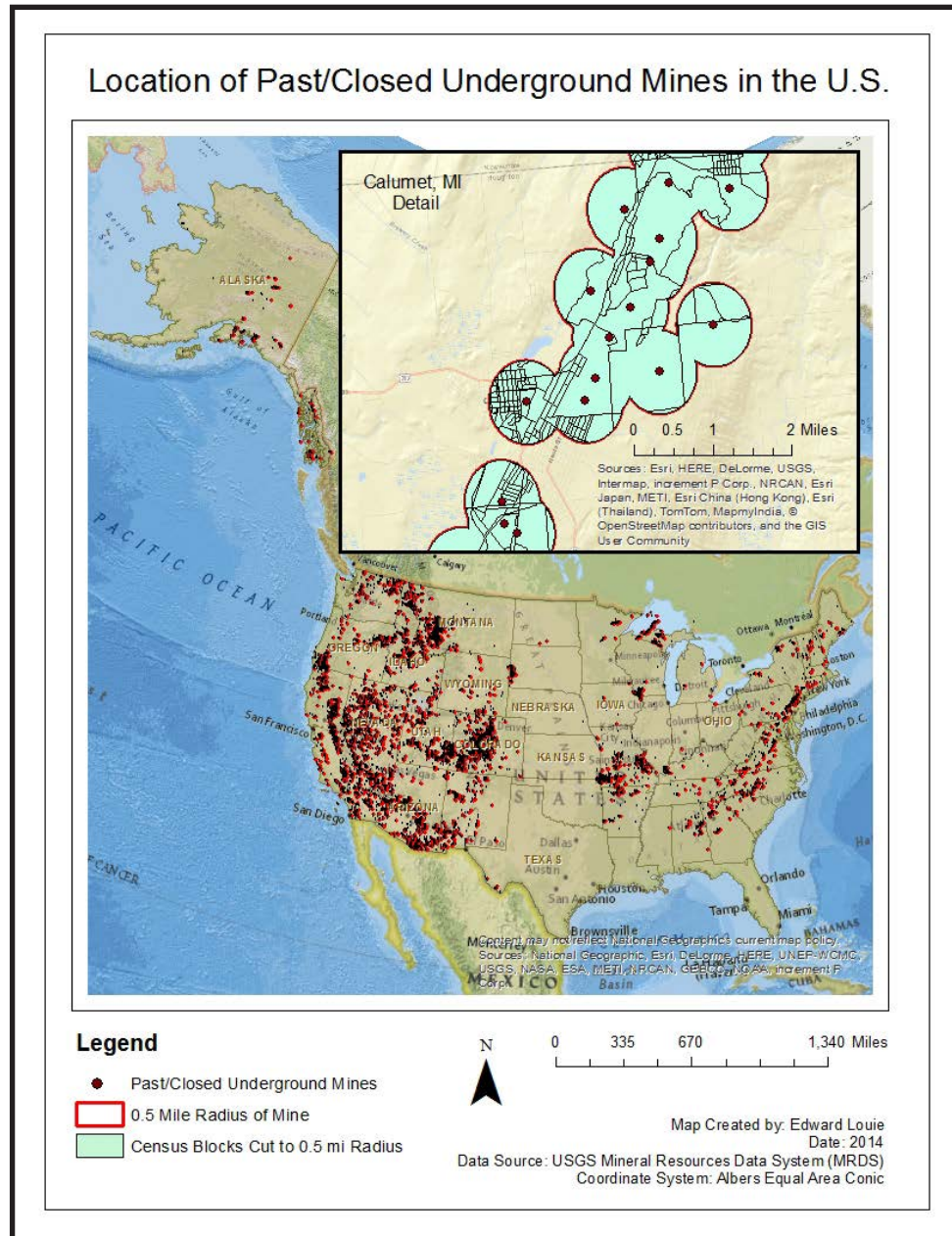


FIGURE 4. Illustrated above is a U.S. map of closed/past underground mines with a 0.5 mile radius buffer to show which census population blocks are within. Data Source: [7] and [9].

Despite the great potential of mine water geothermal across the U.S., globally there are less than 20 documented systems; details on these systems can be found in Appendix A. The National Energy Technology Laboratory regards unused mine water as “a terrible thing to waste” [7], and yet mine water is a severely underutilized resource.

How does a heat pump work?

Heat naturally flows from hot to cold. In order to get heat to flow from cold to hot, energy must be used. A heat pump is a mechanical device that uses a small amount of electricity to move and concentrate heat. The most common heat pump is a refrigerator. A refrigerator is not actually chilled through cooling, but rather heat is absorbed by a refrigerant which runs through the inside of the first of two heat exchangers. The second heat exchanger on the outside of the refrigerator exchanges the heat captured by the refrigerant to the air in the room. The heat coming from the back side of a refrigerator is the concentrated heat being removed from the inside of the refrigerator.

A geothermal heat pump operates in the exact same way except that it can run in both directions allowing it to heat and cool a building. It either takes heat from the ground (mine water) and moves and concentrates it into a building or takes heat from a building and releases it into the ground (Figure 2).

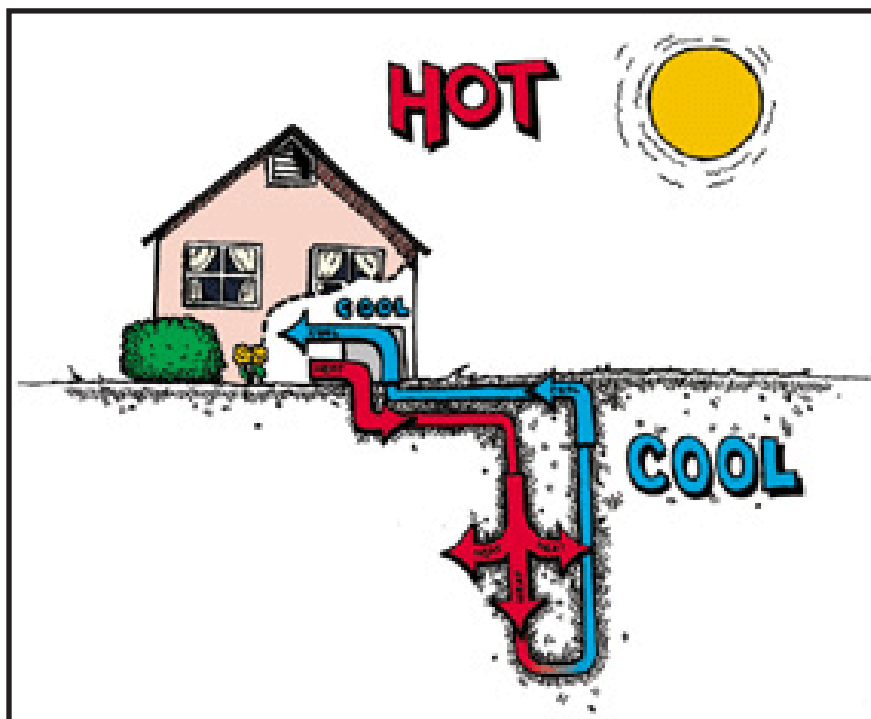


FIGURE 2. Basic operations of a geothermal heat pump system [3].

The cooling mode is even more efficient because it takes less energy to move from hot to cold. Heat pumps are three to five times more efficient than conventional heating and cooling systems.

As heating and cooling accounts for nearly half of the energy consumed in households [4] and the highest energy cost component in commercial buildings (27%) [10], changing one's heating and cooling system presents significant savings potential.

ENVIRONMENTAL BENEFITS OF GEOTHERMAL TECHNOLOGIES

The EPA conducted a study in 1993 comparing the economic and environmental impacts of different heating and cooling technologies. The study found that geothermal heat pumps have the lowest operational cost and produce the lowest CO₂ emissions compared to other technologies (Figure 5).

According to the EPA study, geothermal heat pumps "can reduce energy consumption and, correspondingly, emissions by 23-44% compared to air sourced heat pumps, and by 63-72% compared to electric resistance/standard air conditioning equipment" [21].

Despite these clear energy and CO₂ savings, low energy costs combined with a lack of experienced installers comfortable with the increased complexity of installing a geothermal heat pump system have combined to slow the growth of this technology.



Key Terminology - Energy and Exergy



Energy is the power to do work derived from the utilization of resources to provide heat or work. Exergy is the maximum useful work possible from a resource.

From powering computers to running lights and appliances, electricity has very high exergy because its energy can be used in many different ways.

Heating and cooling has very low exergy requirements since the temperature desired is typically around 70°F. As a result, a building can be heated using an energy source with low exergy.

Efficient heating and cooling is achieved by matching low exergy demand and supply in order to conserve high exergy potential.

Low grade geothermal energy from mine water is an excellent low exergy energy source for efficiently heating and cooling buildings, a low exergy demand.

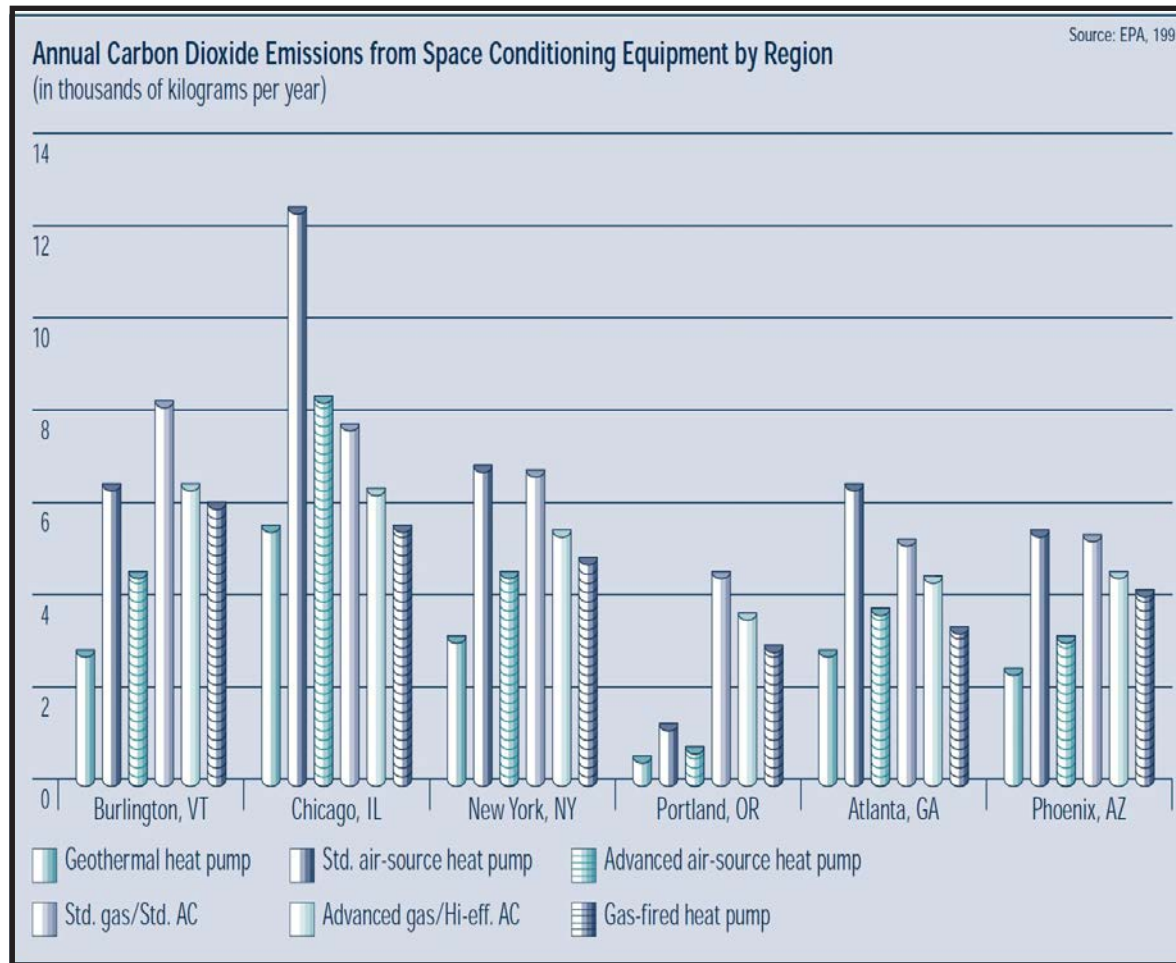


FIGURE 5. CO₂ Emissions of space conditioning technologies [21].

Armed with a basic understanding of what mine water geothermal is, the following sections will describe the benefits of using community participatory planning to evaluate opportunities for mine water geothermal in your community.



What is Community Participatory Planning?

BACKGROUND

Former mining communities frequently encounter various economic, social and environmental challenges. Facing these challenges can begin with engaged, visionary, inspirational, and passionate citizens advocating for a community participatory planning model.

Community participatory planning is an organizational model where citizens lead the organization and generate ideas and solutions for their own future. Solutions and ideas defined and generated by engaged citizens are more often successful because community members are in the best position to assess the needs of their local area and have vested interest in the success of a project.

PPSCD AND MINE WATER GEOTHERMAL

Interest in using mine water for various applications differs from location to location. Since mine water is considered a public resource it is important for a community to understand the many options for use and to critically evaluate the potential positive and negative outcomes in their local context. Participatory Planning for Sustainable Community Development (PPSCD) provides a framework to guide communities through the process of deciding how to utilize this resource.

The following sections draw upon the PPSCD approach to give suggestions on how communities can assess the feasibility of using mine water for geothermal heating and cooling before involving expensive outside consultants or contractors who may have their own interests.

The feasibility study has the potential to build skills in community mapping, water testing, archival research, interviewing, business development, energy auditing, energy efficiency, design and installation. It can also build broad community support for a project and to help ensure that any project would be structured in such a way to provide the greatest benefit to the local community. To begin, it is necessary to build a planning team.

Building a Planning Team

The main function of a planning team is to generate interest, encourage participation, and educate people in the community. A planning team is made up of community members representing a broad range of interest groups and provides leadership and accountability throughout the planning process. Team members willingly commit time to a variety of tasks including:

- Coordinating interest and working groups
- Gathering information
- Forming networks
- Communication

Community members who possess local knowledge, technical, leadership, and communication skills are encouraged to participate. An integral part of the planning process is being sure to include many forms of knowledge, both expert and local, as it may help ensure that discussions and decisions are not dominated by one set of voices. The number of members in the planning team will likely grow as more stakeholders are identified.

GENERATING COMMUNITY INTEREST

People are the most important part of community development. The planning team will want to generate community interest by talking to friends, family members, and workmates to get more people involved.

Conversations about energy efficiency or mine water geothermal systems will often bring new ideas and concerns to light. Holding a community meeting to address these initial ideas and concerns provides a forum for continued discussion and brainstorming. Convening regular meetings will keep the community up-to-date on current developments, any progress made, and show where further support is needed.

Most communities have volunteer groups, churches, city or township officials, and established service or non-profit organizations actively engaged in community development. Networking and collaborating with existing groups such as these saves time and resources and gets information out to more people faster.

Involving local media and social media to highlight project ideas and announce meeting dates, times, and locations will inform others who may not be able to be reached by word of mouth. Flyers can also increase broad interest.



Participatory Planning – Calumet, Michigan



For two years (2013–2015), the authors of this guidebook worked closely with the community of Calumet, Michigan to explore the feasibility of a mine water geothermal system in their community. The community casually discussed interest in such a system for a number of years but was unsure if or how to move forward with the idea.

Members of Main Street Calumet (a local volunteer-run community organization aimed at promoting community and economic development in downtown Calumet) approached faculty at Michigan Technological University with their idea, and the community organization formed a working partnership with the university to get a better sense of how feasible this idea might be. The project started with a social feasibility study which looked at the potential of using the mines for geothermal energy to spur holistic and sustainable community development.

The team gathered archival and energy use data as well as information through interviews, community meetings, and a survey. We found near universal social interest as residents felt mine water geothermal could celebrate its mining legacy, make use of a common resource, and point the community towards a progressive future. The potential we found, along with the concerns and questions raised by the community made it clear that a general guidebook that communities could use to learn about and consider mine water geothermal development could be useful for many communities

In response, Michigan Tech submitted and won a grant proposal to the Environmental Protection Agency's P3 Student Design Competition aimed at promoting people, prosperity, and the planet to support the development of this guidebook.

The development and testing of all parts of this guidebook would not be possible without the continual close partnership, participation, and support of social organizations, primarily Main Street Calumet, and the active participation of various community leaders.

Community Assessment

In order to move forward with a community-based project, it is important to know what people, organizations, and infrastructure already exist in the community that can help get a project started.

Community assessment tools are designed to help gather and analyze information about the community. Examples of these tools are:

- Needs assessments
- Community asset mapping
- Oral histories

Areas and questions that communities may want to explore as they assess their strengths include:

The Human Dimension: Whose expertise do we need in order to answer our questions? Who has the training, education, local knowledge, or background to help us with this problem? How can we find solutions locally? Answers to these questions can be found by conducting a community skills survey.

The Social Dimension: What groups and organizations already exist and are willing to assist with a project? What groups or organizations can help gather and spread information to other groups inside and outside of the community? Who do we know from outside the community who will be willing to collaborate with us? To understand this dimension, communities can conduct a community institutions review.

The Built Environment: What infrastructure already exists that can be improved or built upon? Is the accessibility of this infrastructure exclusive (available to some) or is it inclusive (available to all)? What is its condition? What are our options for improving or replacing? Is it privately or publicly owned and can that status change? To understand this dimension, communities can conduct an infrastructure assessment.

The Environmental Dimension: How clean or toxic is the mine water? How do community members view the mine water? How do members value and use nature? What are the heating and cooling needs of the community?

The Cultural Dimension: What is the history and place identity in the community? How is it changing? How might tapping into mine water support or challenge the community’s understanding of itself? Where do we want to go? How do our decisions affect various groups in our community? What are our demographics? Who has the greatest heating and cooling needs in our community?

The Political Dimension: Who are the power players in our community? How do power dynamics prevent people from being engaged? How can we change those dynamics? Whose support do we need to get things done? Who do we need to implement a project? Who can stop a project? How do we represent ourselves to the outside? Who sets the agenda? How can the community define the agenda?

The Financial Dimension: What businesses and lending resources are there in our community? Who knows about fund raising? Who understands accounting? In regards to finances, how will this benefit the community?



Tools – Community Assessment Tools



Needs assessments, community asset mapping, and oral histories are tools that communities can use to facilitate a process of discovery and coming together. These tools are described more in Appendix B.

Needs assessments are conducted to discover what needs exist in a community. Community asset mapping is a process through which communities come together to map important elements, or assets, in their communities. Things that may be mapped include:

- important buildings
- landmarks
- neighborhoods
- community/neighborhood skills inventory

Oral histories are techniques that involve older generations telling their stories. These stories can be used to gather data, record history, and connect generations.

Developing Assessment Indicators

The work is not complete once a project is in place. It is important to come up with a way to monitor and evaluate the project from early in the process.

Within the participatory planning process, assessment indicators are developed by community members and are a measurement of what is important to that community (see Appendix B). For example, in a community primarily concerned with the rising costs of energy, indicators may focus on energy savings of a project.

In a community concerned with equitable access to heating and cooling, indicators may focus on the increased number of households with access to affordable heating.

Communities interested in utilizing a mine water geothermal system as an economic development tool may gather data related to jobs or new industries.

Specific assessment indicators to a mine water geothermal system might include:

1. The number of visitors to a building with a mine water geothermal heat pump designed as a showcase piece.
2. The energy bills of buildings with a mine water geothermal system.
3. The business profits of a commercial building retrofitted with a mine water geothermal system.
4. The number of employees of a business that is currently heated and cooled with mine water geothermal.
5. Reduction in the number of employee sick days.

Once assessment indicators have been developed, it is important that each phase of the project is carefully documented and revisited for evaluation. Information in the form of “progress reports” should be considered at each meeting to keep community members updated and projects on schedule.



Data Collection

Once a planning team has been assembled and needs have been assessed, the next step is to gather data on energy costs and options, the accessibility and condition of the water in the mine, the physical condition of the mine, and the heating and cooling needs of buildings.

Each data parameter begins with a background description and how it impacts aspects of the mine water geothermal system followed by an explanation of how to collect that information.

The data needed to evaluate the feasibility of a mine water geothermal system can be divided into three main groups:

- Mine Characteristics
- Water Characteristics
- Structure Characteristics

They are specifically arranged in this order to help assess the feasibility of mine water geothermal and narrow down system options and configurations. Evaluating how the cost of electricity compares with different energy options is key to knowing whether a geothermal heat pump is cost effective.

Mine characteristics help determine which shafts are reusable and thus which buildings are within a feasible distance if no new shafts are drilled. Water characteristics help determine which geothermal system configurations are feasible. Lastly, structure characteristics are necessary for determining the retrofit cost and ease of integration.

Some pieces of data will require specialized equipment, precautions, preparation, and planning to collect. Additionally data collection will be more successful through input and participation by a broad spectrum of community members. For example, long-term community residents likely know a lot about the mines and are willing to share their knowledge and stories.

Local youth can add creativity and energy to the data collection process as well as gain experiential learning regarding energy, energy efficiency, physical sciences, the scientific process, collecting and recording data and oral histories.

For resources on how to include mine water geothermal in science classrooms and how to include community members in the data collection process refer to Appendix C.

This guidebook is accompanied by a spreadsheet calculator tool (see page 51) that will allow communities to estimate geothermal system costs, operational costs, and payback period approximations for different system configurations. The data collection described in the following pages should be entered in the spreadsheet to generate cost estimates.

The startup cost calculations use information including the pipe path distance from the building to the mineshaft, temperature of the mine water, depth to the water, and the angle of the shaft. The current heating system type, number of months of heating, and energy rates are used together with capital costs to estimate the payback period.

Calculator results are rough estimations and are intended to serve as a tool for guiding a community's decision on whether to pursue a professionally designed system. This tool is not meant to replace a formal, professional economic feasibility analysis, but rather to offer an initial sense of the approximate cost comparisons and payback. Neither the data collection process nor the use of the calculator requires any specialized expertise.

The calculator's estimates can be enhanced with input from local well-drillers and contractors. The local public works department can also be a helpful resource with maps of the locations of existing utilities and in providing information about construction costs.

As the planning team and community works through the process of collecting data, effort should be taken to present the information to the community periodically in a way that is easy to understand. This may include the use of Google Earth/Maps, graphs, charts, tables, and flowcharts.

Key aspects that may define the selection of a site or building for the system should be highlighted and their importance explained. The data can be presented at meetings to allow community members to be involved in the process.

SAFETY

Before attempting to measure any of the mine or water characteristics, it is important to consider your safety and that of others. The evaluation and collection of data from mine shafts, flooded or not, presents potential hazards. Many mines have been covered over with unstable materials making the area susceptible to collapse.

Furthermore, though many mines are covered and capped properly, some have remaining openings large enough for a person to fall into and some may contain noxious gases. To mitigate these hazards, use caution and heed all warning signs.

The National Institute for Occupational Safety and Health (NIOSH) offers guidance on safety plans [23], but remember, the most important tool for protecting yourself is common sense.

Should you feel unsafe collecting the data, there are indirect ways to approximate the data such as researching mining company documents and oral histories. Be particularly careful if young people are participating. We encourage the inclusion of students, but we also recommend caution especially if entering the mineshaft is necessary.

WHAT YOU WILL NEED

The following is a non-exhaustive list of equipment for gathering the data described in subsequent sections. Since each mine has its own unique challenges and obstacles, the suggested equipment may or may not be helpful for your situation.

Most of the equipment listed is affordable and easy to obtain; however, there are some pieces of equipment that are expensive and hard to find. Before purchasing equipment, we recommend visiting the mine site to investigate whether specialized equipment like a Kemmerer sampler can even be used in the given situation.

Key Terminology — Kemmerer Sample

The Kemmerer sampler is a cylinder with rubber stoppers at both ends that snap into place when triggered by a messenger, a sliding weight.

To collect a sample, the Kemmerer is lowered into the shaft on a strong rope. Be sure to mark the string with measurements to know the depth at which the water sample is taken. Once lowered to the desired depth, drop the sliding weight down the line to close the cylinder. Then reel the Kemmerer back up to the surface and empty the water into sample containers wearing clean gloves to prevent contamination.



As you work through collecting information, data may not be as easily accessible as expected. Having several people helping to collect information who can think about and problem-solve may bring alternative approaches to mind.

Throughout the data collection process, make sure at least one person is taking notes. When it comes to documenting data, use as much detail and clarity as possible to ensure both you and other readers understand the notes later on. Notes should include the who, what, where, when, and why. Appendix E contains a worksheet to help organize data collection. Be creative and have fun with this process.

RECOMMENDED EQUIPMENT

- Safety equipment — good shoes or boots, gloves, safety glasses, hard hat, phone with service
- Smart phone/GPS/maps
- Camera/waterproof camera/GoPro Camera
- Tape measure
- Thermometer
- Flashlight/head lamp
- Strong rope
- Protractor/inclinometer/Abney level (Note: this type of instrument may be available on a smartphone as an app)
- Watch/stopwatch/timer
- Bottles/jars for water samples
- Notebook
- Pencil/pen/permanent marker
- Kemmerer sampler
- Fishing equipment — sounder, line, rod, bobber
- Mine Shaft Assessment Worksheet (Appendix E)

Mine Characteristics

LOCATING MINE SHAFTS

In some communities, the location and condition of mine shafts may be widely known. However, in many communities this knowledge requires researching historic maps, mining records, and asking the right people.

Once the team knows where the shafts are, the next step is to determine who owns the property and to gain permission to access the shaft. Once you have permission to enter the property, meet with other interested community members and organize the logistics. Make a clear plan for when the data collection will take place, how long it will take, and what resources are needed.

Evaluating the mine shafts will help determine which ones have accessible water and what challenges need to be overcome to access the water.

Mine Company Documents

Most mining companies keep records of their shafts including maps with mine locations. These documents often include diagrams that help determine or validate field measurements of the angle of incline. They can also be used to estimate the volume of water available or potential drilling locations for accessing the mine water. These documents are typically filed with local or state government, local universities or community colleges, or in the possession of former mine employees. For further assistance in locating such documents refer to the U.S. Office of Surface Mining Reclamation and Enforcement's national mine map repository (mmr.osmre.gov). While the actual maps are not available for download, the website gives an inventory of what maps are available and where the actual copy is stored.

Oral Histories

In some cases, retired miners or their family members reside in the mining community. Invite them to discuss their experiences, observations, and descriptions of the mines. In addition to knowing the location of the shafts, they may know a lot about the layout of the mines and qualitative descriptions of the temperature and depth. Conversing with former miners and other mining company employees provides broader understanding and reinforces the participatory process emphasized in this guidebook.

If participants give you permission, record the conversations and interviews so that you can refer back to them. Also take notes and share the knowledge with others working on or interested in the possibility of geothermal technologies. These stories can enhance optimism in mine water geothermal and build community identity across generations.

MINESHAFT SITE EVALUATION

Archived documents and oral histories contain valuable information for locating and pre-surveying mine shafts. Upon arrival at the site, the first thing to record is information about the location itself. Mark the location on a map, or use a GPS enabled smartphone to record the location using a free app like GPS Surveyor or GPS Essentials that will record the latitude and longitude location of the shaft.

These GPS coordinates can then be overlaid onto maps and satellite images available online from sources such as Google Maps. Marking these locations will help you analyze installation costs, and if drilling a new borehole should be considered.

Take notes on how easy or difficult it was to get to the shaft. For example, were you able to walk up to the site or did you need to open a locked gate? This information is important for knowing the possible complications of future data collection. For future reference, take as many pictures as possible and include a tape measure or a common object in the pictures to provide scale.

Pictures should include the surrounding landscape, land use, and proximity to buildings, nearby roads, infrastructure such as street lamps or sewers, etc. Record the date and time since time of year can impact the various measured parameters. This contextual evidence can inform expected seasonal changes. Appendix E contains a worksheet that can be helpful for organizing all of this information.



GPS Locations of Calumet Mine Shafts



In Calumet, the location of several mine shafts was obtained from historic maps and local knowledge. The team visited shaft locations in person and took cell phone GPS readings. The GPS points were then overlaid onto a publicly available Google Map as shown in Figure 6.

This detailed visualization allows the data collection team to share visuals with other community members and improve understanding of possible mine water geothermal locations. It also allows anyone to calculate distances between shaft locations and any other location within the Google Map platform using the measurement tool. This sort of analysis informs discussion about when and where the community might install a mine water geothermal system.

Rather than a few decision makers choosing a location and then presenting a limited set of options to the public, allowing anyone in the community to participate in this planning process enhances transparency and democratic power in decision making. The interactive version of the map in Figure 6 can be accessed via the following link: <https://www.google.com/maps/d/u/0/viewer?mid=z4tp4KtKUUVk.kJFVv08ehSWo>.

GROUND DISTANCE

Ground distance is the distance from the shaft, or potential borehole site, to the building site of interest. Similar to depth, ground distance can drastically change costs associated with the system. Obstacles along this distance can also impact system costs. If pipes must cross a street, additional excavation and repair will be necessary. Securing permits for these activities may also increase costs. Ground distance should be calculated not as the shortest distance but the most feasible route that pipes can be installed.

MEASURING GROUND DISTANCE

An easy way to do this is to use the GPS on a smartphone to record the latitude and longitude of each mineshaft into Google Earth. Overlaying the locations onto Google Earth's satellite image allows one to take into account obstacles, land cover, and terrain when evaluating the horizontal pipe path. The locations of the shafts can be shared amongst the community in the form of a publicly available Google Map. Community members can use the ruler tool to layout and measure the pipe path distances between mine shafts to any location of their choice without having to go on site.

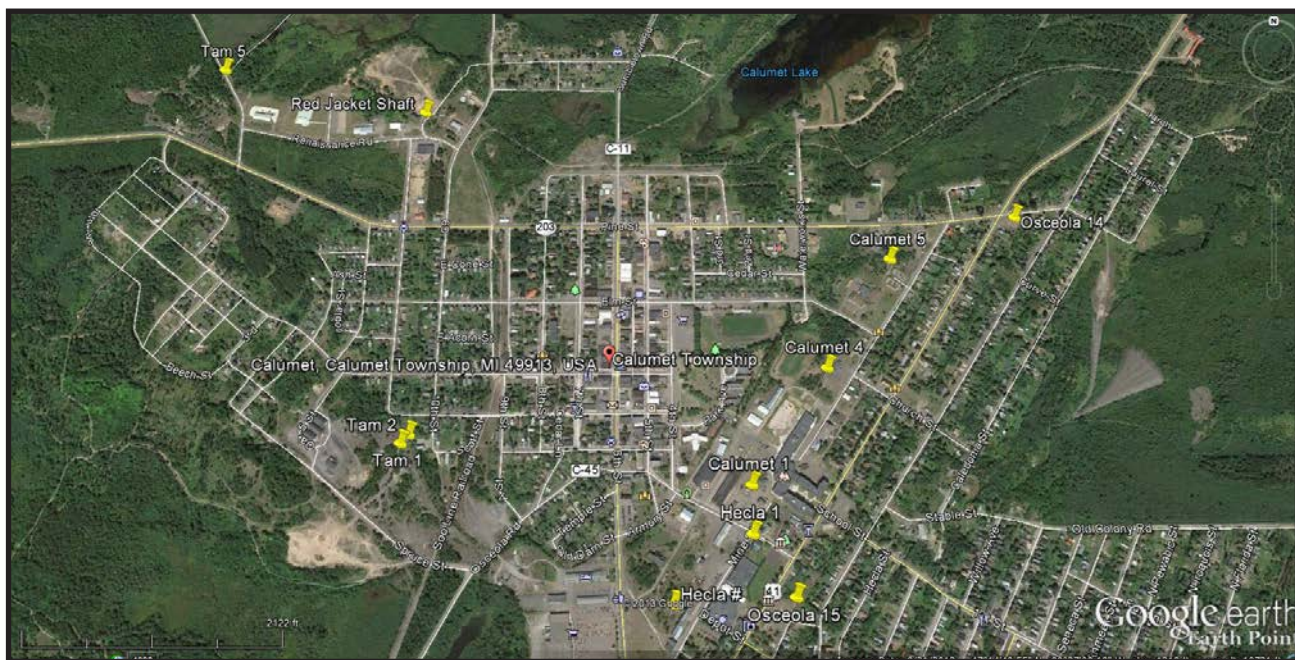


Figure 6. Detailed map of mineshaft locations in relations to present day buildings and infrastructure. Location: Calumet, Michigan [24]. Map data: Google earth, Earth Point, August 21, 2013.

ANGLE OF INCLINE

The angle of incline is the angle that the length of a mineshaft forms with the horizontal ground surface. If an existing inclined shaft is used, the submersible pump will need to be propped off the wall of the shaft. The process of sliding pipes and a pump down an incline littered with mining debris is potentially challenging.

The cost and challenges associated with installing a pump in an existing inclined shaft should be weighed against the cost of drilling a new vertical well to access mine water. The smooth walls of a new well casing would then ease pump installation and associated labor costs.

MEASURING ANGLE OF INCLINE

Using an inclinometer or Abney level will provide the most accurate measure of the incline angle. However, with a smartphone, there are dozens of free apps with adequate precision for measuring angles. The cell phone apps turn the phone into a spirit/bubble level which is useful if there is a representative smooth edge to measure from.

To use the inclinometer simply looking through the inclinometer at a far distant central point of the shaft. The values of the angle appear on the inside of the inclinometer. The Abney level works similarly. Look through the eyepiece at a central point deep in the shaft, then adjust the level on the outside until the level bubble in the viewfinder lines up with the level line. Finally, look at the angle indicated on the exterior markings to determine the angle.

A string and weight tied to a protractor is another simple tool for estimating the shaft's angle of incline. Tie one end of the string to the center point of the protractor. Tie the weight, something as simple as a few washers would do, to the other end of the string. Rotate the protractor until the weighted end of the string lines up with the ninety-degree mark — this is your plumb line. Then, by visual estimation, line up the shaft's trajectory with the straight edge of the protractor and read the angle on the protractor that the free-hanging string touches.

Subtract that angle from 90 — the result is the angle of incline. This process could be enhanced with a longer straight edge, like a meter stick, to compare the shaft's angle to the protractor. In addition, attaching a straw along the straight edge to use as a viewfinder can help line up the protractor with the shaft. Figure 7 below shows the basic set up.

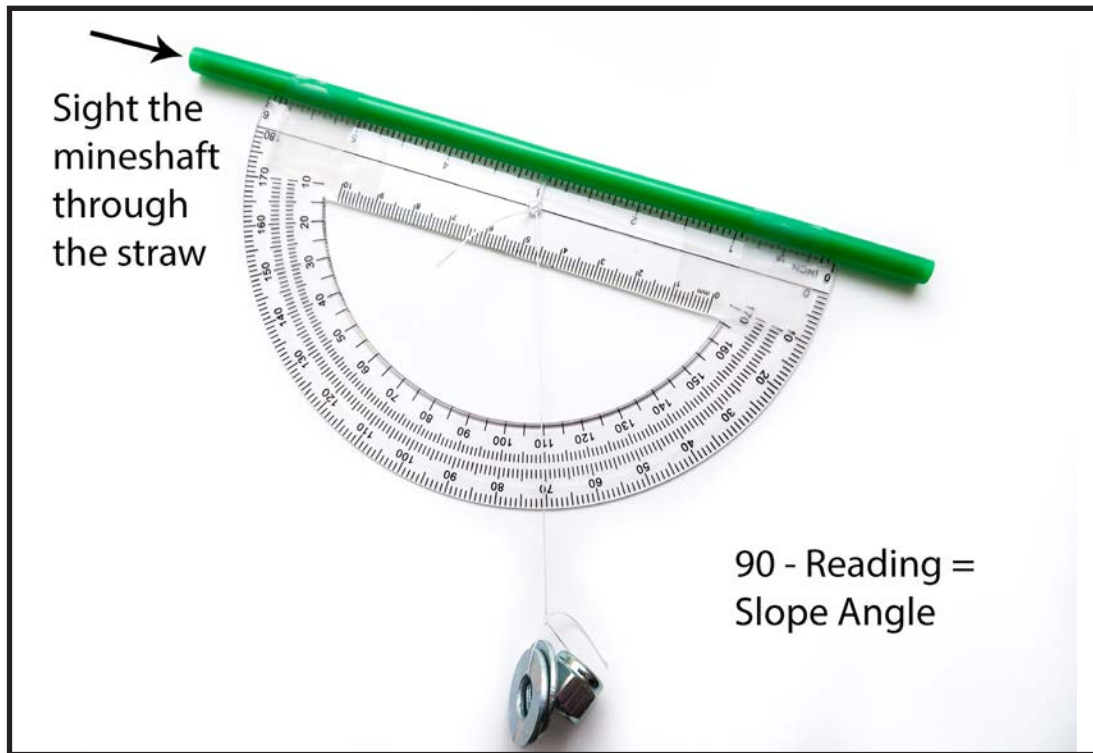


FIGURE 7. A DIY Inclinometer [25]

Water Characteristics

The water characteristics of temperature, temperature gradient, and water level are important regardless of the geothermal system setup selected. If an open loop system is to be considered, refer to the water chemistry section for details on water chemistry analysis and measurement in Appendix F.

TEMPERATURE

Water temperature is one of the most important factors for assessing the feasibility of mine water geothermal. The temperature of the water represents the energy present in the water and thus the energy available for transfer into heating or cooling a building.

When heating a building, the heat pump concentrates heat from the water and transfers it to the building. In the cooling mode, the heat pump concentrates heat from the building and transfers it to the mine water. Geothermal heat pumps are designed to work most efficiently for both heating and cooling when using water with a temperature between 45°F and 75°F [26].

In many cases, mine water temperature typically fluctuates only by a few degrees across the seasons. The stability of mine water temperatures provides a consistent source for heat in the winter and a sink for heat in the summer.

WATER TEMPERATURE GRADIENT

The water temperature gradient is how the water temperature changes with depth. In some locations, the temperature is relatively uniform throughout the depth due to natural convective mixing; however, in other locations, there are large temperature gradients. The only way to know is to measure the temperature of the water at different depths. For places with uniform temperatures, the intake pipe needs to only go as deep as the water's surface. Where the water temperature changes quickly with depth, the design process becomes more complex.

The increased capital cost (more piping and bigger pumps) of accessing deeper water must be compared to the increased heat pump efficiency from using warmer water. The increased heat pump efficiency can result in needing a smaller, less costly heat pump. The volume of water needed to be pumped decreases with warmer water which would decrease costs. On the other hand, lifting water from greater depths increases costs.



Maintaining the Temperature Gradient Heerlen, the Netherlands



The largest and most famous example of a mine water geothermal system can be found in Heerlen, the Netherlands. The mine water in Heerlen has a pronounced water temperature gradient. Because the location and condition of existing mine shafts were not ideal, five new wells were drilled to take full advantage of the temperature gradient.

Two hot wells were drilled 2,300 ft deep to take advantage of the warmer water (82°F) for heating. Two shallower wells were drilled 820 ft deep to take advantage of the cooler (61°F) water for cooling. The fifth well was drilled to 1150 ft and used to return hot water that had been significantly cooled or cold water that had been significantly warmed to a temperature range of 64°F-72°F.

These efforts to carefully manage the temperature and location of the returned water helped Heerlen ensure that the advantageous temperature gradient would remain intact throughout the lifetime of the system. A schematic of this system is shown in Figure 8 [27].

Disturbance to the water temperature gradient can occur if warm water is extracted for heating and then cool water is returned into the same shaft. By replacing the initially warm water with cool water, the temperature begins to shift.

If cooling is the predominant need, returning warm water to the mine may raise the temperature of the water near the top thus affecting the temperature gradient. To preserve the temperature gradient, it may be necessary to use one shaft for withdrawing water and a second shaft for returning water.

At times, it may be best to drill an additional shaft if two shafts with the desired separation distance are not available. Alternatively, it may be feasible to mitigate this problem by withdrawing and returning water at different depths in a shaft.

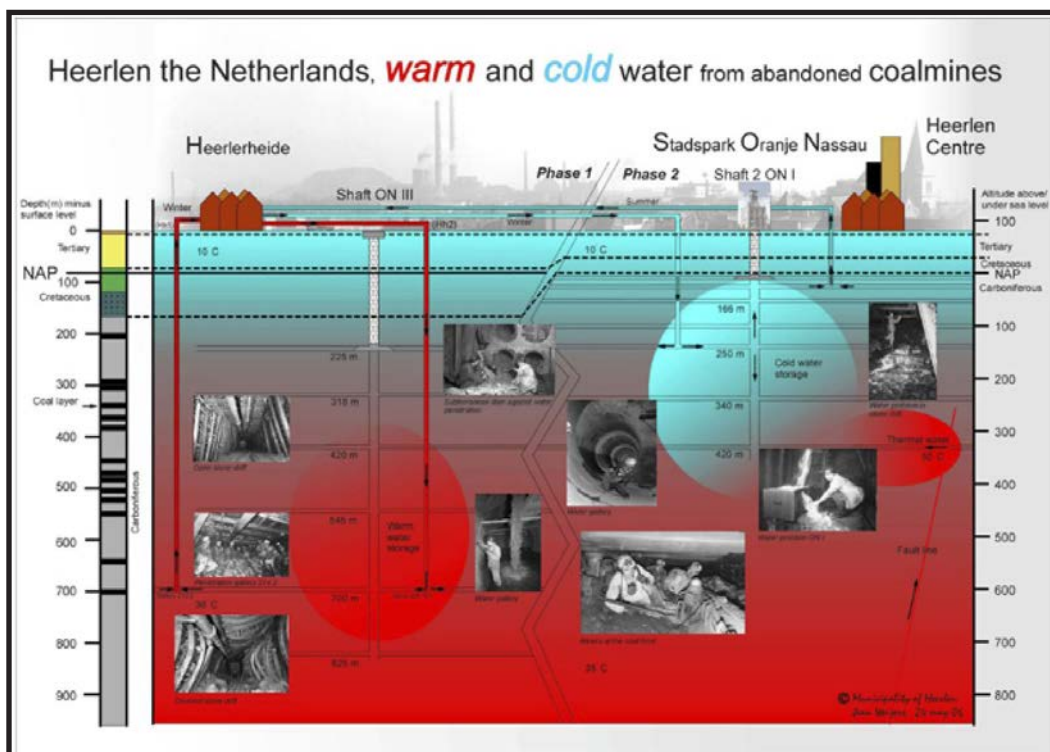


FIGURE 8. Schematic of the Heerlen mine water Geothermal System [27].

MEASURING TEMPERATURE GRADIENT

The mine water temperature can vary with depth as well as with season. The best way to gather this data is with a submersible thermometer with data logging capabilities. This equipment may be too expensive for a community

to purchase, but there are DIY techniques that can help estimate this information.

A logging thermometer will take measurements at a preset interval, record it with time, and store that data internally. Using a logging thermometer in combination with a tape measure and a watch allows you to record the temperature at different water depths. To link temperature with depth, simply lower the logger to the water surface and record the time and the depth at which the logger hits the water surface. Continue to lower the thermometer by set intervals noting the time at each stop.

The thermometer needs a certain amount of time to respond and stabilize so hold the thermometer at a given depth long enough for this to occur. When reading the data, match the time and depth to the time and temperature given by the logger.

If possible, repeat this process for all seasons as the temperature gradient may change depending on the season. If a waterproof data logging thermometer cannot be obtained, there are other homemade versions you can use but that will be less precise.

The Colorado 4H Sport Fishing Program has created a guide for constructing a homemade device to measure water temperature at various depths. The detailed instructions for which can be found at http://www.4hfishing.org/resources/aquatic_ecology_pdfs/7d_homemade_sampling_gear_weighted_thermometer.pdf [28].

The homemade device is a thermometer inside a weighted, perforated container. The weight of the container allows it to sink to a chosen depth. The perforations allow the container to fill with water once submerged and thus helps insulate the thermometer from the air temperature while it is being brought to the surface for reading and recording.

The price of this homemade device is a great advantage, but it does take more effort and time to record the temperature gradient using the homemade device because it must be brought to the surface to read each measurement. Harness the creativity, skills, and resources within your community to consider other methods of collecting information on the temperature gradient.

Water Level

The water level is the vertical distance from the surface of the ground to the top surface of the mine water. The water level represents the minimum amount of vertical piping and relates to the power needed to pump water to the surface, thus affecting the expense of the project. The pump will also

need more power for higher flow rates and more water per minute which will be necessary for less desirable water temperatures.

Measuring Water Level

The water level may or may not be visible by looking down the mine shaft. If the water is visible and relatively shallow, the end of a tape measure can be lowered until it touches the water's surface. For rough or debris ridden inclined shafts where the water is visible, a long PVC pipe is an effective tool for reaching or estimating the distance to the water's surface.

For a deep vertical shaft, fishing equipment may be an affordable DIY tool. Using a fishing line to lower a bobber into the shaft it is possible to measure the length of the line to get the distance. Some fishing reels have a line counter which will measure the distance automatically.

Another tool is a sounder which is specifically made to locate the water surface in wells. It is a reel with a probe at the end that makes a sound once it hits water. The length is marked off like a tape measure for easy recording. Ask around the community to see if anyone owns a sounder.

Inclined shafts where the water is too deep to see are the most difficult to measure. If it is smooth, try to slide connected pieces of PVC pipe down the shaft with a sounder attached. If the walls are rough and/or debris and obstructions are visible, consider foregoing the shaft as an option for mine water geothermal.

Volume of Water

Volume is important because the temperature of the water can change over the life of the system if the volume of water is relatively small. A cooling trend can occur in the mine water if the system is typically used for heating. This happens because the water returned to the mine is colder than the water already in the mine. Over time the colder return water can cool the overall temperature. The opposite effect is observed when the system is used predominantly for cooling buildings.

If the volume of water is small, a separate return well may need to be used to eliminate the risk of changing the temperature of the water. Available water volume can be estimated by examining old mining documents (the available water volume will roughly coincide with the amount of material removed over the life of the mine).

Structure Characteristics

EXISTING SYSTEM

Energy demand is the amount of heating and cooling a building requires. Knowing the current demand is an important building specification because it indicates the size (and number) of heat pumps required as well as the needed thermal capacity of the mine water. It is also a good idea to estimate future use if there is a desire to expand the system. With such predictions, the installed system can be designed to accommodate more users as time goes on.

The existing system refers to the type of heating, ventilation, and air conditioning (HVAC) system currently being used in a building. This information is important in terms of cost because some HVAC systems have components that can easily be retrofitted to a heat pump system.

Forced air and many hot water based systems (those that operate using hot water below 140°F) lend themselves to retrofit integration with a heat pump. Hot water systems include wall mounted radiators or embedded heating coils in the structure. These include radiant heated floor slabs, walls, and ceilings. Hot water radiant heat systems are the easiest to retrofit because very little of the building's existing heating infrastructure needs to be changed. It is simply a matter of replacing the natural gas or electric hot water heater or boiler with a water-to-water geothermal heat pump. A forced air furnace system is also equally easy to retrofit by simply replacing the furnace with a water-to-air heat pump, but it is not as energy efficient.

Cost and ease of retrofit should not be the only factors to consider when evaluating the feasibility of a heat pump system. It is beneficial to examine whether the existing HVAC system adequately provides the occupants with satisfactory year round comfort. In some cases, it may be cost effective to replace the current system with a new, more efficient system. Often times, there are incentives for upgrading to more efficient HVAC systems.

For example, if the existing HVAC system is not able to provide cooling during summer, and this is something that the occupants desire, this fact should be noted. Another important thing to note is whether there are areas that need cooling and heating at the same time. With multiple heat pumps or innovative heat pump designs, heating and cooling can be done simultaneously, a feature not found in any other HVAC system.



Innovations in Heat Pump Design



Traditional water-to-water systems are more efficient than water-to-air systems. With a good pipe layout and an electronically controlled circulating water pump, heat can be delivered at less than a tenth of the energy required to operate a blower delivering the same amount of heat [29]. However, two recent innovations in heat pump design have greatly increased the efficiency of water-to-air systems.

One innovation is the elimination of inefficiencies associated with moving air through ducts. The solution is achieved by moving the heat exchanger and fan where the heat is released to each room and pumping refrigerant via thin, flexible, and insulated pipes from a central compressor. The second innovation has to do with the ability to use excess heat from one part of a building to heat another part, i.e. the ability to simultaneously heat and cool different parts of the building.

A water-to-air system also has the advantage of being able to provide cooling whereas a water-to-water radiant heat system cannot effectively perform cooling.

Measuring the Existing System

ENERGY

Energy costs for the purposes of this guide pertain to understanding and comparing the costs associated with running different heating/cooling systems. Energy comes in many forms: electricity, natural gas, propane, fuel oil, etc.

Comparing them can feel like comparing two completely unrelated things especially since they are measured and billed in different units. For example:

- Electricity is billed by the kilowatt-hour (kWh)
- Natural gas is typically billed in therms (thm)
- Propane and fuel oil are billed in gallons

Besides being in different units of measure, the energy content of each unit is also different. A common unit of measure to convert to is a BTU (British Thermal Unit).

Since geothermal heat pumps use electricity, the cost of electricity compared to other options should be the first evaluation tool. Due to its efficiency, a modern geothermal heat pump can easily move 3.3 or more units of heat energy for every unit of electricity it consumes [30].

The precise efficiency of a heat pump, measured in a term called coefficient of performance (COP), depends on the temperature of the water it is extracting heat from, the temperature it needs to concentrate the heat to, and the efficiency of the heat pump itself.

If the cost of energy from electricity is more than 3.3 times the cost of an alternative source of energy then it is possible that mine water geothermal may not be the most cost effective means to heat and cool buildings.

In the process of writing this guidebook (2014/2015) natural gas prices were at a low while electricity prices were high; even so, 44 out of 50 States had electricity and natural gas price averages which favored the use of geothermal heat pumps [31,32].

It is also important to consider expected future energy costs since a building's HVAC system is a long-term investment. Knowing these costs can help assess the payback period for geothermal systems that generally require high capital cost but low operating costs.

MEASURING ENERGY COSTS

The present cost of energy can be found on utility bills and on the utility's website. The Energy Information Agency has created a useful spreadsheet available online at www.eia.gov/tools/faqs/heatcalc.xls. The spreadsheet converts the unit of measure of all fuels to "Fuel Price Per Million BTU" allowing one to compare the cost of heating across fuel sources.

The values in the yellow cells of the column "Fuel Price Per Unit (dollars)" need to be changed to reflect the local fuel prices. The values in the "Efficiency Rating or Estimate" column should also be changed if more specific values are known. Otherwise, the default values are adequate for a first estimate.

As described above, the default efficiency of a geothermal heat pump, COP of 3.3, is a reasonable value to use when a specific heat pump has not been selected. When a specific heat pump has been selected, the COP of that geothermal heat pump should be entered.

While the cost differential between energy sources is important, it is necessary to know how much energy the building uses for heating and cooling in order to calculate the payback period of a mine water geothermal system for the building.

The current operating costs to heat and cool a building can be estimated from utility bills. Since the utility is often used for purposes other than heating and cooling, a good way to estimate the heating and cooling portion is to take a month with insignificant heating and cooling and subtract it from the rest of the months.

For example if natural gas is used for heating and cooling, by subtracting July's natural gas usage from the other months, it will result in an estimate of how much natural gas is used for heating.

If electric heating is used, the increase in electricity consumption in the winter is primarily due to heating since one does not significantly increase other electricity uses between the seasons. Subtracting the month with the lowest electricity usage, a month with minimal heating and air conditioning, from all other months of electric bills will result in an estimate of the energy used for heating.

This method of estimation is a little tricky to apply to cooling. To do so, identify the month with the lowest electricity usage. If it coincides with a month with minimal heating and cooling needs, it can be used to subtract from the summer months of energy bills. The remaining is an estimate of the energy used for air conditioning.

These annual heating and air conditioning costs are necessary for calculating the payback period of a mine water geothermal energy system using the calculator application. Such estimations may be more difficult for community buildings or businesses where other sources of energy use may be high thus masking the energy used by heating and cooling.

Building operators will often know the details about the building's sources of high energy usage and whether such estimation techniques are applicable.

The size of the existing heating and cooling system is a great starting point for estimating the size of the geothermal heat pump needed. The sizing and capital cost of the geothermal heat pump in the calculator application is based on the size of the existing heating system.

The answers to the following key questions about the size and adequacy of the existing HVAC system is needed to size the heat pump and determine which buildings would most benefit from a mine water geothermal system:

- What equipment is currently being used to heat and cool the building?
- What is the size of the current heating and cooling system?
The heating or cooling unit will have a sticker that states the size in BTU, ton, or watt.
- Is the current system providing satisfactory heating and cooling of all spaces year round?
- At any given time, are there areas that need to be cooled and others that need to be heated simultaneously?
- How old is the HVAC equipment?

The maintenance staff of a municipal or community building will often know the answers to these questions. Similarly, many homeowners and business owners know where to look for the answers to these questions.

If the current heating and cooling equipment is providing the right amount (comfortable) of heating and cooling then it is likely properly sized. If it is not comfortable, for example it is too hot or too cold, the temperature fluctuates, or the air at the vent is too hot, then it is likely that the original equipment was not sized correctly.

The size of a heating and cooling system needed for a building is calculated using a series of equations which are often embedded into spreadsheets or software. The size of the system is determined based on estimates of the heat loss of the building by accounting for dozens of factors including the size and shape of the building, amount of exterior surface, level of insulation in the walls, and the number of windows.

The process of estimating the heat loss of a building is slightly different for residential versus commercial buildings. However the process is standardized into what is called the Manual J methodology which is used to estimate the heat loss of residential buildings and the Manual N methodology for commercial buildings.

While it is a tedious and time consuming process to measure the many factors that go into calculating the heating or cooling load of a building, the process is not difficult. In fact, there are online resources, such as loadcalc.net, that walk you through the parameters one by one.

Using the Spreadsheet Calculator

Accompanying this guidebook is a spreadsheet tool that estimates the approximate capital costs, operational costs, and payback period of a mine water geothermal system compared to the existing system. Potential social and environmental benefits also matter and should not be discounted, but dollar-value cost comparison is the focus here. The tool can be accessed by visiting the following link: <http://aee-mtu.org/geothermal-calculator/>.

The capital cost is comprised of the cost of the piping, the water pump, the geothermal heat pump, and the associated installation costs. The cost of piping and installing the pipe is determined by the depth to the mine water, angle of the mine shaft, and the length of the pipe path from the mine shaft to the building.

The size and cost of the geothermal heat pump is determined by the size of the current heating system. The size of the pump is determined by the depth to the mine water, the length of the horizontal pipe, and the flow rate needed by the heat pump. The flow rate needed takes into consideration the temperature of the mine water. The system factors in the savings realized by the 30% federal tax rebate which is applicable to everyone in all states until the end of 2016.

In order for a mine water geothermal system to make financial sense, it must cost less to operate than the current system. Using the cost of electricity and the COP range of geothermal heat pumps, the calculator will determine estimated operating costs of the heat pump system. The size of the water pump determines how much electricity will be consumed.

The operating costs assume that the geothermal heat pump system will run 50% of the time. Additionally a fixed annual maintenance cost of \$100 is factored in. The payback period is calculated by comparing the operational cost of the geothermal heat pump system divided by the annual cost savings of the geothermal system.

This tool provides approximations and makes a number of assumptions. Details on the assumptions are summarized in the spreadsheet tool. The tool provides useful estimated figures that could help users determine whether or not to invest in a formal design plan and economic analysis with an engineering firm

One drawback is that the calculator assumes the heat pump will be used 50% of the year for heating and does not include air conditioning. Adding cooling would reduce the payback period since a geothermal heat pump is extremely efficient in cooling mode.

The calculator assumes an open system design which has better heat transfer efficiency but may have higher pumping costs. On the other hand, a closed system requires more piping costs which can be offset by a smaller pump.

The tool cannot take full advantage of potential design features that would vary by locality and specific context. This is due to the limited, direct experience and the diverse set of opportunities for cost savings and potential issues that can raise costs as discussed in previous sections of this guidebook.

At best, a geothermal system designer will use cost experience from traditional open and closed loop geothermal heat pump systems to estimate the cost of a system that uses mine water. If the mine water is found to be suitable for an open loop, the cost will be estimated using cost information from open loop geothermal heat pump systems that use water wells as its thermal exchange medium.

For a mine water geothermal system that is a closed loop, the cost of a system can be estimated using cost information from vertical closed loop geothermal heat pump systems which does not include the cost of drilling.

The spreadsheet is designed to size and analyze costs for a system that serves a single building. However, this spreadsheet can also be used to inspire decisions on how to setup a district system. The capital cost and return on investments of a host of buildings can be determined by running data for each building through the spreadsheet one at a time.

Buildings can be prioritized based on capital cost or payback period for inclusion in a district system. The cost of each individual system can also be added to get an estimate of the total cost of a district system. Because this method of estimation assumes each building will have its own set of pipes from the mine water, water pump, and heat pump, it will be a very conservative cost estimate.

Use this estimate knowing that the real cost would likely be significantly lower since, in a district system, each building will not need its own pipes and pump to the mine shaft. A district system may incur higher consultant and overhead costs due to the greater number of legal hurdles especially if the system is to become a utility.

The planning team can encourage the community to use this spreadsheet tool in conjunction with data displayed on Google Earth. Encourage all interested members to experiment with the tool by evaluating different buildings and pipe layouts. If there are people in your community interested in more detail or more accurate estimates, the calculator can be modified.

Community members can also use the more complex, but more accurate, calculator created by ClimateMaster, a manufacturer of heat pumps[33]. The community can then get together to discuss favorable configurations, considering the environmental, ownership structure, social, financial, and legal barriers and opportunities each option may present.

Furthermore, local HVAC contractors are likely to have their own calculators and may be willing to conduct feasibility studies at low costs in hopes of getting a large installation contract.

Water Quality – Avoiding Potential Problems

Research has found that the quality of some mine water can change for the worse once an open loop mine water geothermal system is installed. This is due to the introduction of oxygen to the mine water which can occur if an open loop system configuration allows returning water to freefall from the ground surface causing splashing.

This discovery was made from analyzing the mine water of two geothermal systems in Scotland. Fortunately, those systems were designed such that the water would not become exposed to oxygen and operational experience found no mineral precipitation to the heat pump systems [34].

Putting It All Together

This section helps community members begin to envision how a geothermal system can fit into their community. Looking at the information gathered on mine water, potential access points, and current energy and HVAC systems should help the community answer the following questions:

- What shaft(s) can be used? If no shafts are suitable, where are potential drill sites?
- What building(s) are most cost effective to retrofit? Which building(s) does the community want to retrofit?
- Are the desirable buildings close enough together to warrant a district system?
- What system designs (open or closed loop) are possible based on the water quality data?
- What social, cultural, and/or economic impacts are possible at each potential location?
- What kind of design is most likely to bring the greatest benefit to the community while balancing costs and potential problems?"

These decisions can be made through participatory planning. Community meetings can be held to share data about mine water and make decisions about if, where, and how a project should be designed and how the community would fund the project.



Ownership Structures

The ownership of a geothermal system can impact who benefits from the system and can present available funding opportunities. The simplest ownership structure would be an individually owned system installed in one building. This could be a private residence, a publicly owned building, a community building, or a privately owned business. The benefits of these types of setups would primarily be to the owners of the system (who may or may not be the users).

There would also be community benefits through lower carbon emissions and possible training on geothermal systems. If the project was part of a larger energy efficiency weatherization program, training on these aspects could also be provided. If the system was installed in a community building, it could serve as a focal point for energy efficiency education programs.

Systems installed in community owned buildings could also provide savings in tax dollars. Buildings that are owned by organizations providing social services could benefit from reduced energy bills which would increase budget allocations to their services. More about various system configurations and ownership structures are outlined below.

SINGLE BUILDING

The following examples are for situations where the system is installed in one building. In some of these situations, the owner of the building may not be the user of the building. This may be the case for rental properties or civic buildings.

Showcase building

This could be a community building (a sports arena, museum, library, etc.) that is used by a large section of the community and is frequently visited by out-of-towners. A side objective of this type of project would be to attract tourists to the area. This project could be a combined project between the municipality and the owner/manager of the building.

Some difficulties associated with this type of project include the coordination between the municipality and the owner/manager of the building. Benefits could include lower membership fees, energy savings for the building owner/manager, and political good will.

Municipal or community building

This could be a building such as a government office building, a school, library, recreational center, or community center. While it would also serve as a showcase of the technology, the installation and utilization of a geothermal system could provide savings for the municipality and taxpayers.

This system could also reinforce a community's commitment to the environment and celebrate local history. This system could also benefit the users of the building through reduced fees.

Private building

There are many private buildings including residential homes, apartments, industries, and businesses that could benefit from a geothermal system. Buildings with large numbers of computers or other intensive cooling needs stand to benefit the most.

Various manufacturing plants can also utilize geothermal heat pumps to do simultaneous heating and cooling of different areas and processes. Residents can benefit through energy savings. Private systems can benefit the community through direct or indirect job creation. These systems can be privately funded or supported by the municipality as part of a revitalization/economic development initiative.



Showcase Building Example



Municipal Building (Individual System, Single Owner/User) Park Hills, Missouri

Touted as the first building in the world to run on a geothermal system fueled by mine water, the Park Hills City Hall is an 8,100-square-foot building completed in 1995 that is heated and cooled by water from a flooded lead mine. The flooded mine contains an estimated 70 billion gallons of water and lies 35 to 435 feet below the surface of the city. While the water has high levels of iron, the lead does not leach into the water because it is not acidic (pH 6.0-6.5). The temperature of the water is a constant 57 °F. The system utilizes a 400-foot-deep supply well, a plate-and-frame heat exchanger, and a second return well.

The heat exchanger prevents the mine water from being contaminated (it is also used as a source of drinking water) and keeps the iron in the mine water from being deposited in the heat pumps. The internal loop is a closed loop water system that circulates throughout the building. There are nine water-to-air heat pumps that extract heat from the internal loop and transfer it to the building. For cooling, the process is reversed.

The building maintains nine different temperature zones and has successfully provided building comfort even when the outside temperature ranges from 108 °F to -10 °F. The building cost \$700,000 to construct with the heat pump system costing \$132,000.

Part of the costs (\$20,000 each organization) of the system were paid for by the Union Electric Company (the local utility) and the Electric Power Research Institute (EPRI). A comparable conventional system would have cost \$110,200. Estimated energy savings are in the range of \$4,800 a year giving the system a 4.6 year payback period even without the financial contributions from Union electric and EPRI [35].

DISTRICT HEATING SYSTEMS

There may also be cases where the system is designed to heat or cool a number of buildings. This is known as a district heating system. These systems have been used in various municipalities and locations throughout the world. District heating systems can benefit more people through the heating and cooling actions.

Members of the system would also benefit from more stable energy prices and utilities would benefit through more stable energy demands. Ownership structures of these systems could also be single party or multi-party. The

following examples are for district heating systems. These systems would be installed in a number of adjacent buildings.

District systems may be owned by a single entity (such as a municipality) or a group of owners (such as a business association).

Business district

In some communities, a downtown business district heating system may be feasible. This system could be owned by business owners that have come together to finance the system. Possible ownership structures will be discussed in the next section.

Alternatively, the system could also be financed, installed, and owned by a municipality or local community economic development corporation (CEDC). In this case, the municipality or CEDC could own the system as an economic development tool.

Educational district

In former mining communities, educational institutions could also benefit from mine water geothermal. The installation of these systems could incorporate training and development of new curriculum.

This system could be funded through incentives from the local utilities, local municipalities, energy-efficiency research organizations, and alumni among many other sources. In this scenario, the system could become an integral part of the institution's courses. Elementary and secondary schools could use the system to teach about geothermal, energy efficiency, and weatherization.

A vocational/technical school could teach courses about geothermal systems, heat pumps, radiant floor heating, energy efficiency retrofits, and other renewable energy sources. A community educational program could also host other outreach activities.

Industrial park

Industries are often located near one another due to zoning. Manufacturing plants are often large buildings with large cooling and/or heating needs. In many industrial and manufacturing facilities, there is a need for cooling at one process or part of the plant and heating in another at any given moment in time. The three factors combine to make industrial parks a good place for a district system.

Even if regulations restrict the development of a district system, the massive cost savings which can be realized by harnessing the near limitless thermal heat sink capacity of a flooded underground mine will sell itself. That is the case in Springhill, Nova Scotia, Canada home to Ropak Packaging, a manufacturer of plastic containers.

The mine water geothermal system saves the company \$160,000 annually. News about Ropak's success spread quickly leading to a dozen other businesses and institutions installing systems including Surette Battery Company Ltd. and the Dr. Carson and Marion Murray Community Center which uses geothermal energy to cool its indoor ice rink [36] [37].

Case Study — District Heating Systems Example Heerlen, the Netherlands

This multi-building project was co-sponsored by the European Union (EU) as a demonstration site for renewable energy technologies. This multistage project began in 2008 by conditioning two large buildings: the Central Bureau of Statistics office (237,000 sq. ft.) and the Heerlerheide Center (323,000 sq. ft.).

The Heerlerheide Center is a multi-use building which houses residential space, a supermarket, offices, a community center, and restaurants. Between 2012 and 2013, two additional large buildings and 350 single family homes (355,000 sq. ft. total) were added to the system.

An office building and datacenter added 344,000 sq. ft. to the system. A new college building also added 323,000 sq. ft. to the system. At present, Heerlen has already met its initial goal of conditioning a million square feet of buildings.

The capital cost and the first few years of operational costs of this system were awarded by grants from the EU. The lessons learned from this experience paved the way for the creation of a private mine water corporation. Discussion is still underway on the responsibilities of this corporation. At minimum, it will be responsible for connecting customers to the geothermal energy grid.

The charge for this service will be based on the capital and operational costs of connecting to and running the pumps on the grid which supplies warm (64°F to 72°F) and cool (61°F) water in two loops.

There are two potential future ownership structures for this system: 1) building owners will own and manage their own heat pumps and pay for the electricity associated with running it or 2) the corporation will own the heat pumps and pay for the electricity cost. Under this inclusive model, ratepayers will be billed for the BTUs of heating and cooling supplied.

The rate-tariff will be based on the avoided cost of operating gas boiler or electric chiller. The corporation will profit by being able to take advantage of cost savings from simultaneous heating and cooling, purchasing electricity and gas at bulk prices, as well as investing in renewable energies like wind and solar. [27] [38].

Residential district

A residential area may also be an appropriate area for a district heating system. This system could be installed and owned by a municipality, a local utility, a housing cooperative, or a homeowner's association.

BUSINESS/ORGANIZATIONAL MODELS

In the case of single owner systems, ownership structures are straightforward. In situations where there is a partnership formed to install and finance the system (such as a community building with several users), a new ownership/management structure may need to be formed. Communities that are looking at district systems may also need to develop innovative ownership structures for their systems.

This section will describe ownership structures some communities may find applicable for their situation. Many times, communities have resources to assist in business development. There may be a local community economic development corporation (CEDC), small-business association (SBA), or a university extension office that can provide assistance.

There is also a growing network of social entrepreneurs and social enterprises that can help. More information on these resources are included in Appendix B.

The purpose of establishing a corporate or business structure is to control liability and pool resources. Typical incorporated businesses have profit as their primary driving force. More and more, alternative business/organizational structures have been developed for businesses seeking to utilize triple bottom line reporting.

Triple Bottom Line Reporting

In typical business structures, the financial bottom line is the primary way the success of the business is evaluated. In triple bottom line reporting, businesses evaluate their success based on financial, environmental, and social impacts.

There are many different indicators that businesses can use to evaluate their triple bottom line. Some municipalities have developed their own "green business" certifications and there are also national and international standards.

BUSINESS PHILOSOPHIES

Social Enterprises

A social enterprise is not necessarily a business model so much as a business philosophy. The aim of a social enterprise is to achieve social goals through unique funding structures. Typically, social goals are addressed through the formation of a non-profit. While these structures are useful for tax purposes, they are limited by how they can raise funds for their budgets.

There are many different forms of social enterprises but they typically consist of a for-profit corporation that donates profits to a separate non-profit. Utilizing a LLC or cooperative structure is a potential way to combine both organizations under one structure.

B-Corporation

A B-Corporation is a third-party certifying and incubating organization for triple bottom line businesses. Information about the criteria can be found on the following website <http://www.bcorporation.net/become-a-b-corp/how-to-become-a-b-corp> [39].



Legal Considerations

Construction Impacts

Many previous mine sites have been left to their own devices for several years. Plant and animal life may have reclaimed the area. Hazardous materials may remain in the area leftover from former mining activity. Cultural resources and relics that tell the story of industrial activities or industrial communities may also be at risk. In planning the design and construction processes for a new system, it is necessary to consider aesthetics as well as ecological and human health, and cultural and recreational use of the site area and mitigate any potential negative impacts.

Environmental conditions should be researched and identified prior to finalizing a site location. For example, new habitats may have formed since mining activity ceased and these may be sensitive to mine water chemistry and inadvertent contamination. Some conditions to consider include flowing water in the mine, aggregate deposits, pre-existing groundwater or mine water contamination, and general layout of the mine shaft. Ensuring the mine water geothermal system does not negatively impact ecological habitats or sociocultural resources could alter many aspects of installation, design, and operation from the route of the pipe network to the building design and the type of construction equipment used.

Environmentally conscious construction and operational practices, along with care to preserve social and cultural resources should prevent sensitive habitats and valued resources from being greatly affected by geothermal operations.

WATER, LAND, HEAT, AND MINERAL REGULATIONS

While there are no specific legal regulations on mine water geothermal, regulations that may impact projects can be extrapolated from regulations that affect traditional geothermal systems. On the federal level, National Pollutant Discharge Elimination System (NPDES) permitting may be required for surface water discharge.

Most states have groundwater regulations, underground injection regulations, and mineral rights that may apply. Locally, building codes, zoning laws, and construction permits vary from one municipality to another. Site selection, system type, and size can also impact necessary permits.

In general, an open loop system is more likely to be subject to more water permitting rules than a closed loop system as shown in Figure 9. Regulations that may restrict system design options are primarily concerned with large releases of heat into the environment. Some states regulate how much groundwater can be extracted by one user while other states require permits for any injection into the subsurface. Both open and closed loop systems may need permits.

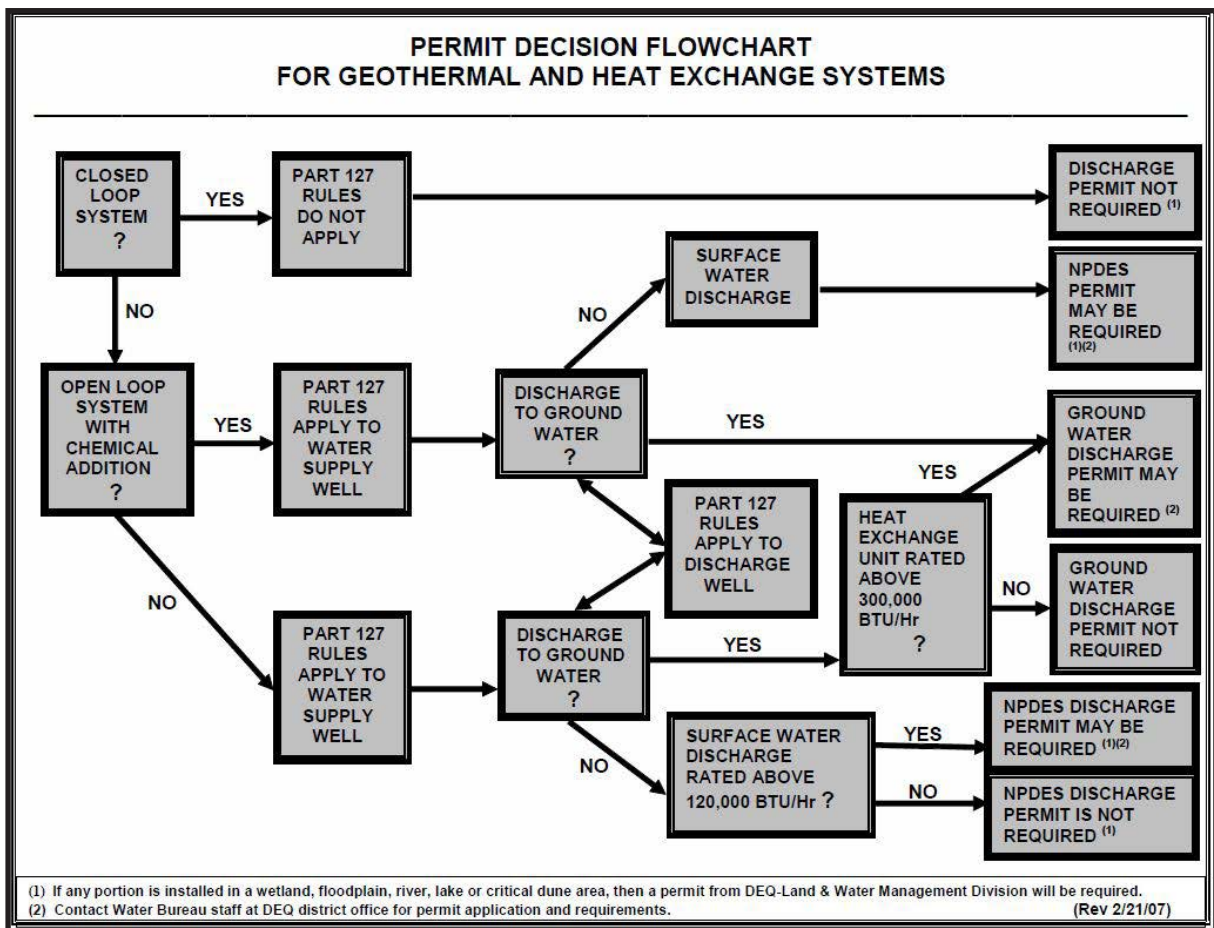


FIGURE 9. Permit decision flowchart: Michigan DEQ (individual states' policies will vary)[41].

Ground surface and subsurface ownership rules vary from state to state based on mineral rights. While mine water geothermal systems do not extract minerals from the subsurface, the thermal capacity of the mine water may be owned through mineral claims, thus making it important to understand your state's mineral rights [46].

In many ways, a mine water geothermal system does not fit into predefined categories from a regulatory perspective. As a result, it is important to work closely with the various regulatory agencies to learn about the proposed system in order to secure the proper permitting.

In the case of a district heating system, it will be important to know your state and local regulations on utilities. Most utilities across the U.S. are regulated monopoly franchises. In this system, the state gives a utility an exclusive right and obligation to serve a certain service territory. Inside this territory, no competition is allowed and, in exchange, the utility will be regulated by the state utility commission.

The utility is guaranteed a fair return on investments it makes to serve its customers. Customers that try to organize and supply energy service to each other, in this case heat and cooling, represent a loss of energy sales to the utilities.

No state utility commission has, to this date, looked into allowing or blocking non-utility generated heat energy. Multiple states have examined the sale of electricity to adjacent neighboring properties by a non-utility. For example, think of a residential or commercial electric customer wanting to sell power they generated to their neighbor.

States that allow retail choice have generally allowed service to neighboring properties while non-retail choice states have generally not allowed such transactions.

These policies apply only to electricity sales — at present, no state has examined whether they should also apply to heat energy sales. If states decide they do, then non-retail choice states will not be able to setup a traditional district heating system without becoming a utility.

Legal Designations

LIMITED LIABILITY CORPORATION (LLC)

LLCs differ from other forms of incorporation in how revenue and liability is distributed between the owners. In a typical corporation, revenue and assets are owned by the corporation while in an LLC, revenue and assets are owned by the owners of the LLC. LLCs do not have to be organized for profit.

NON-PROFIT

A non-profit (501(c)3) is an organization formed primarily to address social issues. A 501(c)3 is a legal, tax exempt status that allows activities undertaken by a non-profit to not be taxed. The registration of a 501(c)3 limits the fund raising and income generating activities a non-profit can undertake. As a result, non-profits must rely on donations and grants to achieve their budgeting requirements. This can sometimes result in a “non-profit treadmill” where more and more time of the staff is consumed by seeking funders rather than actually filling the organization’s mission.

COOPERATIVE

A cooperative (co-op) is a flexible business/organizational structure that seeks to pool resources to achieve a purpose. The co-op structure in America stems from rural electrification projects. Co-ops are funded by members and non-member users. In a co-op structure, profit goes back to the members.

Typical examples are rural electric co-ops, grocery co-ops, and agricultural co-ops. Increasingly, the co-op structure is also being used for biomass/biofuels projects.

There are four basic co-op models:

- Consumer co-ops: where members benefit from combined buying power
- Producer or Marketing co-ops: where members benefit through shared resources
- Worker co-ops: where workers own their business
- Housing co-op: where members share living spaces or community spaces

Co-ops are guided by seven principles (known as the Rochdale Principles):

- Open, voluntary membership
- Democratic governance
- Limited return on equity
- Surplus belongs to members
- Education of members and public in cooperative principles
- Cooperation between cooperatives
- Concern for community

There are many different organizations around the country that help interested parties in forming co-ops. A list of these organizations can be found in Appendix B.

COMMUNITY OWNED UTILITIES

In some situations, a municipality or private company may want to establish a geothermal heating/cooling utility. Regulations on district geothermal energy systems only take effect if the operator is considered to be a utility company as defined by the state utility commissions.

The regulations surrounding a district heating system are contingent on a number of factors:

- Whether the area/territory is already claimed by a utility
- Whether it will be for profit or non-profit

Regulations on these issues vary from state to state details of which can be found by contacting your state's Public Service Commission or Public Utility Commission.



Financing

Most community projects are funded through loans, grants, and/or public-private partnerships. Developing a working mine water geothermal system will require investment in consultants, installation, and maintenance and operations. These expenses and potential funding sources are discussed in more detail in this section.

Increasingly communities are looking for ways to leverage local resources to fund projects. One mechanism utilized to accomplish this goal is community-based financial institutions, such as community foundations, community-economic development corporations, and micro-funding organizations. Crowdfunding sites such as Kickstarter or GoFundMe are other options. These institutions can provide low-interest loans or other investments in community projects.

Local governments also have several funding mechanisms available to them to achieve social goals. Improvement districts and property assessed clean energy (PACE) financing districts can be set up to promote adoption of geothermal systems. Communities can also develop renewable zones and provide tax incentives for infrastructure improvements. Selling municipal bonds is another option. These bonds would guarantee investors a modest interest rate but could not be cashed out for a set period of years. They could be sized such that many local people can afford to purchase a piece. This model may require new regulations to be developed, however the result is a financial system that is not funded through taxes but rather through a sustainable and voluntary financial structure and one for which community members can be proud owners.

**Innovative Funding Structures:
A Innovative Funding Structures:
A.M.E. Zion Church Pittsburgh, Pennsylvania**

The A.M.E. Zion Church in downtown Pittsburgh struggled with acid mine drainage (AMD) seeping into its basement from the nearby Hill District coal mine. By joining with the larger community, the church found an innovative solution: The Herron Avenue Corridor Coalition.

As part of this larger local revitalization and mine water drainage mitigation project, the church applied for and received a Pennsylvania Energy Harvest Grant as well as funding from the Foundation for Pennsylvania Watersheds. These funds allowed the Herron Avenue Corridor Coalition to develop a low-grade mine water geothermal heating/cooling system for both the church and a nearby 40,000 sq. ft. addition. The project utilizes water from the mine through a drainage system installed through a Bureau of Abandoned Mine Reclamation project.

The Herron Avenue Corridor Coalition also received a grant from the Urban Land Institute to create a development plan for the site of the project. The Pittsburgh Urban Redevelopment Authority along with Carnegie Mellon University partnered to develop this site/project [40].

How Can We Afford This?

It is important for a community to fully understand how many different elements go into the development of a geothermal project so that they can begin to develop funding plans for the project. The following are various aspects that will need to be funded along with some potential funding sources.

CONSULTANTS

Throughout the design and implementation of a geothermal system, a number of technical consultants may be required. These include: engineers for the design of the system, lawyers to help navigate the permitting requirement and developing ownership structure, and accountants to set up individualized financing structures. While fees for these services will have to be covered by the operating budget of the system owner, there may be a possibility to develop partnerships with educational institutions or pro bono consultants.

CAPITAL COSTS

The capital costs of the system are the most expensive elements of the project. The drilling and installation of pumping and piping could be up to a third of the up-front cost or approximately \$8 per square foot for an average sized installation [10] [43] (2014 Seenti, Bruce and Ison, Barry from Mitsubishi Electric Personal Communications). These costs will change based on system configuration and the required number of wells.

Other capital costs of systems include the geothermal heat pumps and components as well as the piping to and the retrofitting of buildings. Many of the capital costs may be funded through state, local, or utility funds for energy efficiency projects.

Funding in the form of tax credits, property assessed clean energy (PACE) loans, on-bill financing, loans, community bonds, and grants could also cover the capital costs. A list of the available financial incentives is located in Appendix G.

One can also search for the most up-to-date listings from the Database of State Incentives for Renewables and Efficiency (DSIRE) website: <http://www.dsireusa.org/>, website.

OPERATION & MAINTENANCE

The main cost associated with the operation of a geothermal system is the electricity for the water pump and geothermal heat pump. While the efficiency of the system will reduce electricity usage, sourcing the electricity from renewable sources, such as wind or solar, could yield additional savings.

Depending on the size and the scale of the system, there may also be periodic maintenance costs. If the system utilizes an innovative ownership structure, there may be long-term accountant fees or other retainer fees. As operational costs should be minimum, for long-term sustainability, they should be completely covered by the operating budget of the system owner.

These guidelines are not meant to be an exhaustive list of all the costs of a system. Costs will vary from system to system but the basic categories of design, installation, and operation and operation will need to be considered

How the ownership of the system is structured and the overall goals of the project can open up different funding possibilities. For example, if the project is part of a larger revitalization effort, state funds for renovations of buildings may be available. If the project is part of a larger energy efficiency effort, federal energy efficiency funds may be available.

ENERGY EFFICIENCY FUNDING

Financial opportunities, incentives, and instruments change based on many factors including political climate, energy or environmental crises, energy prices, and evolving energy and/or environmental regulations. As of the writing of this guidebook, natural gas prices are at a historic low, yet concerns about climate change are at an all-time high.

Communities should evaluate national issues as well as local issues and how they affect the financial opportunities and favorability of installing a mine water geothermal system now or in the future. A national issue that will likely lead to direct and indirect effects that improve the financial outlook of mine water geothermal systems is the proposed EPA regulations on CO₂ emissions from power plants.

In 2014, the EPA released its Clean Power Plan which requires states to implement a carbon reduction plan. This plan requires a 30% decrease of carbon emissions below 2005 levels. States must have a plan submitted by mid-2016, be showing progress by 2020, and meet this target by 2030. States are allowed flexibility in how they will achieve this.

For many states, their strategy is to shut down the most polluting power plants and implement energy efficiency to reduce electricity demand. The Clean Power Plan's mandates have and will further stimulate states and utilities to offer financial incentives for energy efficiency upgrades. This makes mine water geothermal systems a very timely issue.

Mine Water Geothermal as a Sustainable Economic Development Tool

Introducing a project in phases is one way to begin a project at a smaller, more feasible, scale and eventually expand to improve the lives of the greatest number of community members. The impact of a system will be affected by the scope of the project.

Utilizing a multiphased project can yield the greatest economic benefits. This type of project would strive to improve the lives of the greatest number of community members. An idea for a multiphased project is outlined below.

Phase One: Low-income Energy Efficiency Education and Improvement

This would include teaching community members about weatherproofing and helping train them to install improvements in their homes. Younger community members could be given hands-on training by improving homes of the needy. This could be anything from caulking to insulation.

Funds for this could be raised as an energy efficiency/youth development project. This could also potentially develop into a company or organization that charges businesses for their services. This phase can leverage funds for energy efficiency projects from federal, state, local, and utility sources. Home weatherproofing teams could be supported through AmeriCorps programs or other funds available through the Corporation for Community and National Service.

Phase Two: Development of a Geothermal District

After a group of adjacent buildings/homes have been weatherized, a district system could be set up. This phase would include the retrofitting of the buildings. This activity could also provide training opportunities for youth in the community.

A geothermal co-op could be set up where members are users of the system. Members could buy into the co-op through membership fees or sweat equity. Lower-income members could be subsidized through higher fees for business users or funds for low-income heating assistance programs. Local businesses could support the co-op as members, or through corporate giving programs.



Conclusion

Moving from Talk to Action

Once the planning team and the public has come to a consensus on whether and how to move forward with an installation, those decisions should be written down in an action plan/report. The report should address topics such as: how the project will be funded, how ownership of the system works, scope and location of the system, the expected outcomes and reasoning behind recommending a system, and installation plans.

The planning team should become familiar with the The International Ground Source Heat Pump Association (IGSHPA) which is a trade association comprised of many geothermal heat pump installers, designers, and contractors. Their website contains a database of accredited installers and certified designers which can be searched by state [43]. This is a good place to start finding people with the expertise to do the detailed design and to install a system.

The planning team can refer to the IGSHPA Design and Installation Standards for background on the standards and become familiar with terminology a designer and/or installer would likely refer to when working with the planning team [44].

After construction, installation specs and an operation and maintenance manual should be developed and maintained. The planning team may shift into an oversight team to monitor and evaluate the performance and long-term effects of the mine water geothermal system. If the plan for the mine water geothermal system included a multistage expansion or implementation plan, a planning team should remain together to ensure design and decision continuity of these future developments.

Revising and revisiting the action plan/report every couple of years is recommended to stay up-to-date with new technology and funding opportunities and to recognize where further adjustments may be needed. Reviewing the established indicators will show where progress has been made, where more progress is needed, and whether the project is continuing to reflect the goals of the community.

The authors of this guidebook hope you have found this guidebook helpful. We hope communities will share the data and knowledge gained from exploring their mine water with the authors and the world. Information about water quality, data collection strategies, on-going monitoring, and evaluation will assist other communities interested in mine water geothermal.

The reuse of flooded mine shafts in geothermal energy systems remains largely untapped. As a result, the optimal means and methods to most effectively harness this unique opportunity are still being established. There is no doubt that as more communities learn about this opportunity and go through the process of evaluating the practicality of using flooded underground mines for geothermal heat pump systems, lessons learned from the process will reveal additional opportunities and challenges.

Evidence from existing systems around the world show that using low grade geothermal energy from flooded mine shafts can result in many benefits such as: cost savings, increased sustainability, innovation, community building, the stimulation of building improvements, and revenue sourcing.

Each example case began with proactive, visionary leadership which inspired commitment and investment from the community. Terry Ackman and George Watzlaf of the National Energy Technology Laboratory said U.S. mining regions are the “Saudi Arabia of Geothermal Energy” and regarded unused mine water as “a terrible thing to waste” (p. 1, 19).

Reusing the flooded mines can be the beginning to a series of cascading benefits that can contribute to renewed economic vigor, environmental leadership, and community empowerment while celebrating the mining legacy.

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Appendix

APPENDIX A - EXAMPLES OF MINE WATER GEOTHERMAL SYSTEMS

Globally there are about 30 documented mine water geothermal systems in place. The information available for many of these systems is limited and incomplete as shown in Table 1. The lack of detailed published data is to be expected since building operators typically have no incentive to document and publish performance results or conduct economic and environmental comparisons. Installation firms also lack an incentive to conduct and publish studies if the client does not demand one.

Table 1. Documented Mine Water Geothermal Systems To Date

Table 1. Documented Minewater Geothermal Systems To Date																
Date	Country	Site Name	System Purpose	Water Temp (F)	Depth (ft)	Pump Rate (GPM)	Mine Type	System Capacity	Loop Type	Number of Heat Pumps	Total Area Heated (ft ²)	Upfront Cost (\$)	Annual Savings (\$)	Payback period	Some Feasibility Analysis?	Literature
1979	USA	Radio Shack at Midway Shopping Center, Wilkes-Barre, PA	Heat & Cool	56 F	95 ft	89 gpm	Coal		Open, Single Well	1	3197 ft ²		1000		No	(Moran, 1981) & (Schubert and McDaniel, 1982) & (Korb, 2012)
1981	USA	Kingston Recreation Center, Wilkes-Barre, PA	Heat and Cool	61 F	30 ft	90 gpm	Coal		Open, Two Well	1	17000 ft ²		6000 vs Gas		Yes, Water Chemistry	(Schubert and McDaniel, 1982) & (Korb, 2012)
1980s	USA	First Hospital Wyoming Valley Nesbitt Memorial Health Center	Heat and Cool	54 F	275 ft to 380 ft	125 gpm	Coal		Open, Three Well						Yes, Water Chemistry	(Schubert and McDaniel, 1982) & (Korb, 2012)
1984	Germany	Nursing Homes in Essen-Heisingen, Germany	Heat				Coal	350 kW							No	(Wieber and Pohl, 2008), (Hall, 2011)
1980s	Canada	Ropak Can-Am Ltd. Springhill, Nova Scotia, CA	Heat & Cool	64 F	460 ft	63 gpm	Coal	45 kW	Open	11	16700	110,000	160,000	<1 year	Yes	(Jessop et al., 1995), (Jessop, 1995), (Mason, 2009), (CADDET, 1992), (Michel, 2007), (Michel, 2008), (Martin, 2009), (Watzlaf and Ackman, 2006)
1994	Germany	School in Ehrenfriedersdorf, Sachsen	Heat				Tin	1 School							No	(Wieber and Pohl, 2008), (Hall, 2011)
1995	USA	Municipal Buiding in Park Hills, MO	Heat & Cool	57 F	394 ft	75 gpm	Lead	112 kW	Open, Two well	9	8073 ft ²	132,400	4,800	4.6	No	(GeoExchange, 2002), (Ohio DNR, 2011), (Hall, 2011), (Watzlaf and Ackman, 2006)
1997	Germany	Mining Museum Visitor Center in Ehrenfriedersdorf, Sachsen, Germany	Heat				Tin	82 kW, Museum							No	(Wieber and Pohl, 2008)
1998	Norway	Wormshill Cavern, Concert and Banquet Hall in Hedmark County			1970 ft		Copper, Zinc, Sulfur		Closed	1					No	(Hall, 2011)
1999	Scotland	Housing Redevelopment Project in Shettleston	Heat	54-64F	328 ft		Coal	16 Houses, 65 kW		2			60% saving		No	(John Gilbert Architects, 1997)
2000	Scotland	Housing Redevelopment Project in Lumphmains	Heat	57 F	558 ft		Coal	18 Houses					75% saving		No	(John Gilbert Architects, 2004)
2004	Canada	Dr. Carson and Marion Murray Community Centre Springhill, Nova Scotia	Heat & Cool	68 F			Coal	96 Tons	Open Loop, Two Well	8	390,000 ft ²		60% Saving, 100,000 to 135,000	5	Yes	(Michel, 2007), (Michel, 2008), (Michel, 2009), (Mason, 2009), (McDiarmid, 2007), (Noble, 2012), (Kube Solutions, 2004)
2006	Germany	Zollverein Cube Building in Essen-Katernberg	Heat	96 F	3280 ft		Coal	School of Design Building, 790 kW	Open Loop						No	(Thien, 2015), (Zinger-Sned Architects, 2008)
2006	USA	John Wesley Church, Pennsylvania	Heat and Cool	56.6 F	0	75-100 gpm, free flowing	Coal	1 Church	Open Loop		2400 ft ² with an additional 40,000 ft ² of unused capacity	80,891	80% on Heating, 50% cooling		No	(Burtner, Cairns, and Cash, 2009), (Ohio DNR, 2011), (PA Environment Digest, 2009)
2006	Canada	36 Luxury Apartment Condos in Quebec	Heat & Cool					36 Apartments	Open		6039		50%		No	(Raymond, Therrien, and Hassani, 2008)
2007	Germany	Swimming Pool Heat and Supplemental District Heat in Shachsen	Heat	54 F	472 ft	528 gpm	Uranium	1 swimming pool + 690 kW supplement to district heating	Closed						No	(Matthias and Schreyer, 2007), (Hall, 2011)
2008	Netherlands	Heerleen, Netherlands	Heat & Cool	82 F Hot Well, 61 F Cold Well, 64-72 F Warm Well	2300 ft, 820 ft, 1150 ft	1057 gpm Hot, 2025 Cold	Coal	700 kW up until 2012	Open	Many	560,000 ft ² total in 2012, 5 million ft ² by 2015	5.7 Million Euro, Phase I	70% Energy Savings		Yes	(Op 't Veld and Demolin-Schneiders, 2007), (Op 't Veld, Cauberg-Huygens, and Maastricht, 2008), (Santer, 2008), (Verhoeven et al., 2013), (VITO, 2012)
2008	UK	Kensa Engineering Offices	Heat				Tin	20 kW	Closed Loop						No	(Preene and Younger, 2014), (Younger, 2013)
2009	USA	Marywood University	Cool	55 F	340 ft		Coal		Open Loop, Two Well			530,000			No	(Korb, 2012), (Hall, 2010), (Legere, 2014)
2009	Russia	District Heating System in Novoskhtinsk	Heat	55 F	164 to 500 ft		Coal	10.9 MW	Open Loop	3		11 Million Euro			No	(UNFCCC, 2007)
2009	Germany	Castle Freudenstein, Freiberg	Heat & Cool	50 F	200 ft	57 gpm	Coal	160-180 kW Heating, 120 kW Cooling	Open Loop, Single Well	1					No	(Kranz and Dillenardt, 2010)
2010	Spain	University of Oviedo	Heat and Cool	68-77 F	230 ft		Coal	3.7 MW	Open Loop				75% Energy Savings		No	(Loredo et al., 2011), (HUNOSA, 2015), (HUNOSA, 2014), (Op 't Veld, 2012)
2010	USA	Keveenaw Research Center in Calumet, MI	Heat & Cool	53 F	300 ft	75 gpm	Copper	129 kW	Open Loop, Single Well	14	10,000 ft ²				No	(Osborne, Green, and Meldrum, 2013, Personal Communications)
2010	Germany	4 Residential buildings in Auguste Victoria	Heat & Cool		560-2300 ft		Coal		Closed	4					No	(Bracke and Bussmann, 2015), (Thien, 2015)
2011	UK	Coal Authority Office Buildings	Heat	68 F		24 gpm	Coal	12 kW							Yes, Water Chemistry	(Banks, 2013), (Preene and Younger, 2014), (Younger, 2014)
2012	Germany	Small District Heating "Robert Muser" Project	Heat	68 F	1870 ft	419 gpm	Coal	4.5 MW	Open Loop	11					No	(BINE, 2013), (Thien, 2015)
2013	Germany	Freiberg University of Mining and Technology		64 F	750 ft	247 gpm	Coal	260 kW							No	(Bracke and Bussmann, 2015)
2014	Spain	Mieres Hospital	Heat & Cool										70% Energy Savings		Yes	(HUNOSA, 2015), (HUNOSA, 2014)

APPENDIX B — COMMUNITY PLANNING TOOLS

The following resources and websites may help your community through the participatory planning process.

A New Model: Participatory Planning for Sustainable Community Development

This website is maintained by the *Race, Poverty and the Environment* journal. The link brings you to a page that outlines what participatory planning is and the various steps involved in the process. The website also has other resources regarding race, poverty and the environment.

<http://reimaginerpe.org/node/920>

Community Tool Box

The community tool box is an online resource center for those interested in social change. Among the resources on the site is the following link, which provides information on strategic planning and developing a vision statement.

<http://ctb.ku.edu/en/table-of-contents/structure/strategic-planning/vision-mission-statements/main>

Community Planning.net

Another online clearinghouse of information related to community planning, this site has several guides and checklists available for download.

<http://www.communityplanning.net/useful/checklists.php>

Asset-based Development

Traditionally, community development projects were developed by conducting needs assessments. These assessments focused on what communities were lacking and took a problem solving approach to community development. Increasingly, asset-based development is being used as a tool to develop community projects. This approach focuses on building on the strengths of a community. Instead of asking the question “what do we need” it asks “what do we have”? The aim of this approach is to develop a collaborative environment within a community.

Some elements of asset-based development are community asset mapping, community institutions reviews, infrastructure assessments, and community skills survey.

Community Asset Mapping

This can be the development of a physical map that highlights important landmarks in a community. These landmarks can include schools, churches, hospitals, a popular restaurant, parks, etc. This tool can also be used to identify opportunities for growth.

The following are resources on community mapping:

Equitable Development Toolkit: Community Mapping
<http://www.policylink.info/EDTK/Mapping/>

Strengthening Community Education: The Basis for Sustainable Renewal
Mapping Community Assets Workbook
[http://www.abcdinstitute.org/docs/Diane%20Dorfman-Mapping-Community-Assets-WorkBook\(1\)-1.pdf](http://www.abcdinstitute.org/docs/Diane%20Dorfman-Mapping-Community-Assets-WorkBook(1)-1.pdf)

Center for Community Mapping
<http://www.centerforcommunitymapping.org/>

Community Resource Mapping: A Strategy for Promoting Successful Transition for Youth with Disabilities
<http://www.ncset.org/publications/viewdesc.asp?id=939>

Community Tool Box: Geographic Information Systems: Tools for Community Mapping
<http://ctb.ku.edu/en/table-of-contents/assessment/assessing-community-needs-and-resources/geographic-information-systems/main>

Community Institution Reviews

This is a process a community can undertake to better understand the institutions that exist in a community, the services and resources they provide, and important contact information. Community institutions may include schools, food banks, churches, non-profits, etc.

Infrastructure Assessment

This is a process a community would undertake to better understand their existing infrastructure. This would include looking at the conditions of sewage systems, roads and other transportation systems, parks, etc. This is also important to undertake as new development may impact existing infrastructure.

Community Skills Survey

This is an assessment tool that could be conducted at the neighborhood level. This process would develop a map of an area indicating the skill sets of residents of the area. Skills may include plumbing, sewing, childcare, etc.

Oral Histories

Oral history collects information about the past from observers and participants living during that time. It gathers data not available in written records about events, people, decisions, and processes. The following links offer suggestions on how to perform oral history interviews. Involving students and various community members in this process is highly recommended.

ORAL HISTORY TECHNIQUES: How to Organize and Conduct Oral History Interviews from Indiana University

http://www.indiana.edu/~cshm/oral_history_techniques.pdf

Step-by-Step Guide to Oral History by Judith Moyer

http://dohistory.org/on_your_own/toolkit/oralHistory.html

East Midlands Oral History Archive: Information Sheet #2; Conducting an oral history interview

<http://www.le.ac.uk/emoha/training/no2.pdf>

Grosse Pointe Historical Society: Sample Questions To Conduct An Oral History Interview

<http://www.gphistorical.org/pdf-files/oralhistory.pdf>

Guidelines for Oral History Interviews: The History Channel Student Workbook (adapted from Michael Gatto)

<http://www.history.com/images/media/interactives/oralhistguidelines.pdf>

Pennsylvania Historical and Museum Commission: Steps for Conducting An Oral History Interview

http://www.portal.state.pa.us/portal/server.pt/community/oral_history/4351/conducting_an_oral_history_interview/445230

Community Development Indicators

Although development indicators are unique to each community, it may be helpful to know that most indicators fall under four basic categories: sustainability, quality of life, performance evaluation and healthy communities. The links below offer examples of community development indicators as well as factors to consider while deciding which indicators are relevant for your community.

American Planning Association: Community Indicators

<http://www.seachangepop.org/sites/default/files/documents/2006%2009%20APA%20-%20Community%20Indicators.pdf>

Community Tool Box: Community-Level Indicators: Some Examples

<http://ctb.ku.edu/en/table-of-contents/evaluate/evaluate-communitarity-initiatives/examples-of-community-level-indicators/main>

Sustainable Measures: Sustainable community indicator checklist

<http://www.sustainablemeasures.com/node/94>

Ownership Structures/Funding Resources

As mentioned in the body of the guide book, there are a number of organizations that may exist that can help the planning team develop ownership models.

These include local community economic development corporation (CEDC), community development foundations (CDFs), small-business association (SBA), or a university extension office. You can learn more about these resources by following the links below.

Community-wealth.org: Overview: Community Development Corporations (CDCs)

This site includes a number of resources related to community-based economic development. This link will bring you to the site on Community Development Corporations. To find a CDC in your area, do an internet search on "Community Development Corporations" and your state/locality.

<http://community-wealth.org/strategies/panel/cdcs/index.html>

Charles Stewart Mott Foundation: Community Foundations

Good overview of the basics of a community foundation: a non-profit organization that uses local resources to meet local needs. Also includes resources on community philanthropy.

<http://www.mott.org/FundingInterests/Issues/Community%20Foundations>

The Community Foundations National Standards Board

Another site with overview information on Community Foundations. Includes a link to find local CFs.

<http://www.cfstandards.org/about-community-foundations>

US Small Business Administration: Local Assistance

The SBA assists small businesses through loans, loan guarantees, contracts, counseling session and more. To find a local office, use the following link:

<https://www.sba.gov/tools/local-assistance>

Cooperative Extension Offices

Your local cooperative extension office may provide economic development assistance.

Northwest Cooperative Development Center

A nonprofit organization located in Portland, Oregon that supports cooperatives in Oregon, Washington, Idaho and Hawaii. You can also learn about co-ops from their site.

<http://nwcdc.coop/>

The University of Wisconsin Center for Cooperatives

Comprehensive resource center on all aspect of co-ops, from planning to managing and everything inbetween.

<http://www.uwcc.wisc.edu/>

Cooperative Network

Information and resources on co-op in Wisconsin and Minnesota.

<http://www.cooperativenetwork.coop/>

USDA: Rural Business-Cooperative Service

Offering programs and services to support business development in rural areas.

<http://www.rd.usda.gov/about-rd/agencies/rural-business-cooperative-service>

Community Development Block Grant Program — CDBG

“The CDBG program works to ensure decent affordable housing, to provide services to the most vulnerable in our communities, and to create jobs through the expansion and retention of businesses. CDBG is an important tool for helping local governments tackle serious challenges facing their communities. The CDBG program has made a difference in the lives of millions of people and their communities across the Nation.”

http://portal.hud.gov/hudportal/HUD?src=/program_offices/comm_planning/communitydevelopment/programs

Socially Conscious Banking

As an alternative to the conventional model of banks working with big businesses to offer conventional products, a new idea is taking root that focuses on community-based businesses, responsible consumers and environmental commitment. Learn more about a model from the West Coast here:

Beneficial State Bank

<http://onepacificcoastbank.com/history.aspx>

Social Financing

There is a growing movement to address social issues through a business perspective. This approach is known as “social financing,” “social enterprises,” or “social entrepreneurship.” More information on this emerging financing model can be found below:

Center for Social Innovation: Community Bond

A Community Bond is an alternative funding mechanism for non-profits.

<http://communitybonds.ca/community-bond/>

AP Social Financing: Social Finance 101

A summary of the various terms and definitions found in the field of social financing.

<http://apsocialfinance.com/social-finance-101/>

AP Social Financing: Social Financing Resources

<http://apsocialfinance.com/>

APPENDIX C — EDUCATION OPPORTUNITIES

Adventures with Iggy

http://www.igshpa.okstate.edu/publication/edu_outreach.htm

United States Department of Energy

United States Department of Energy Office of Energy Efficiency and Renewable Energy has created a document outlining definitions and facts about geothermal energy and provide instructions for five different in-class activities for students in grade 5 through 8. This document also contains links for further educational resources.

http://www1.eere.energy.gov/education/pdfs/geothermal_energy.pdf

The Department of Energy (DOE) has an Energy Education and Workforce Development website designed to educate people of all ages about energy efficiency and renewable energy. It contains K-12 lesson plans and activities as well as clean energy jobs and career planning.

<http://www1.eere.energy.gov/education/lessonplans/>

Oral Histories

Oral history collects information about the past from observers and participants living during that time. It gathers data not available in written records about events, people, decisions, and processes. The following links offer suggestions on how to perform oral history interviews. Involving students and various community members in this process is highly recommended.

http://www.indiana.edu/~cshm/oral_history_techniques.pdf

http://dohistory.org/on_your_own/toolkit/oralHistory.html

<http://www.le.ac.uk/emoha/training/no2.pdf>

<http://www.gphistorical.org/pdf-files/oralhistory.pdf>

<http://www.history.com/images/media/interactives/oralhistguidelines.pdf>

http://www.portal.state.pa.us/portal/server.pt/community/oral_history/4351/conducting_an_oral_history_interview/445230

National Environmental Education Week

National Environmental Education Week (EE Week) is the nation's largest celebration of environmental education. It is held each spring around the same time as Earth Day and inspires environmental learning and stewardship among K-12 students. Although this website does not specifically address mine water geothermal, it does offer inspiring ideas for activities and educational opportunities that are generally informative and beneficial and can be adapted to fit your needs.

<http://www.eeweek.org/ee-week>

APPENDIX D: LOW-COST/DIY STRATEGIES FOR ASSESSING WATER QUALITY

Water quality data can be difficult to ascertain due to the depth and conditions of the shafts. In addition, on the shelf equipment designed to survey and sample such environments can be too expensive, complicated, or suboptimal for the task at hand. As a result the authors of this guidebook have devised some low-cost instruments for surveying and obtaining water samples from mine shafts using commonly accessible equipment. The following list of instruments and instructions on when and how to use each one has been developed as a starting point for you to modify for your situations. While this guidebook contains a number of creative solutions/strategies on how to obtain water quality data from depth, they are by no means the only or necessarily the best solutions. The planning team should make it a goal to brainstorm better ways to collect the desired water quality data and share success stories with the public at large.

Temperature At Depth

A fishing reel with a line counter can be used to measure the depth.



Submersible Thermometer

\$370



Dissolved Oxygen

\$20 Test kit



pH

\$4 Test Kit



Hydrogen Sulfide

\$45 Test Kit



Water Hardness

\$5 Test Kit



Angles



APPENDIX E — MINE SHAFT ASSESSMENT WORKSHEET

NAME OF MINESHAF	DESCRIPTION
Date and time of the survey	
Names of people on team	
Equipment check list	1. Phone <input type="checkbox"/> 2. Hiking boots <input type="checkbox"/> 3. Work gloves <input type="checkbox"/> 4. Hard Hat <input type="checkbox"/> 5. Shock cord and or rope <input type="checkbox"/> 6. Flashlight <input type="checkbox"/> 7. Note pad <input type="checkbox"/> 8. Camera <input type="checkbox"/> 9. Map or GPS <input type="checkbox"/> 10. Tape measure <input type="checkbox"/> 11. Inclinometer <input type="checkbox"/> 12. Fishing rod <input type="checkbox"/> 13. Towels <input type="checkbox"/> 14. Marks <input type="checkbox"/>
Date of the weather condition	
Incline of mineshaft	
Accessibility to the mineshaft	
Debris in the mineshaft	
Record measurements	
Miscellaneous	
Survey time ending	

ILL 4. Spreadsheet for taking field notes and data (a copy enhancement from the AEE team)

APPENDIX F — WATER CHEMISTRY

Water Chemistry

Analysis of the mine water chemistry is important if an open loop system is to be considered.

Some of the water quality data described in this section requires access to a local certified water lab. The closest water quality lab can be located via searching the Internet with your state and the term “certified water laboratory,” almost always your state’s department of public health or department of environmental protection/quality will have a list of certified water analysis laboratories to contact. The lab will or can provide two containers typically a 16 ounce plastic bottle and a 4 ounce sterile plastic container and a tablet that contains preservatives and a chlorine inhibitor for the 4 ounce bottle. The water in the larger container will be used to test for everything but bacteria. Samples must be brought to the lab within 24 hours if bacteria or nitrate/nitrite testing is to be conducted [1]. Thus it is also important to time the water sampling on a weekday during a time when the lab is open.

A complete batch of water quality tests from a certified lab can cost hundreds of dollars and the turnaround time for the results is usually a week’s time. Some water quality parameters that the lab will report can be determined quicker yourself. The pH is one such parameter, pH test strip can be found at pet stores (aquarium supplies) and the pool supply section of some department stores. They are inexpensive and give instant results. Simply dip the test strips in the water and watch the color change. Compare the color change to the chart that is provided from the pH testing kit. Additional ideas and resources on low cost water quality testing equipment can be found in Appendix D: Low-Cost/DIY Strategies for Assessing Water Quality.

Obtaining a surface sample of mine water is easy if it is visible and near the surface however more often than not, specialized equipment is needed to retrieve a sample. A Kemmerer sampler is likely the best tool for collecting a water sample at varying depths in a vertical mine shaft. Like a temperature logger, a Kemmerer sampler is quite expensive, usually in the hundreds of dollars.

However unlike a temperature logger, there may not be an easy to make homemade alternative to purchasing one. As a result, it is best to evaluate the condition of the mine shafts first to determine whether a Kemmerer sampler is a viable option for obtaining water samples since sliding the sampler down the side of a mineshaft will stir up debris and give a non-representative water sample.

The Kemmerer sampler is a cylinder with rubber stoppers at both ends that snap into place when triggered by a messenger, a sliding weight, as shown in Figure 1.



Figure 1. A Kemmerer sampler after it has been triggered by the messenger. [2]

To collect a sample, the Kemmerer is lowered into the shaft on a strong rope. Be sure to mark the string with measurements to know the depth at which the water sample is taken. Once lowered to the desired depth, drop the sliding weight down the line to close the cylinder. Then reel the Kemmerer back up to the surface and empty the water into the two containers wearing clean gloves to prevent contamination. The following video [3] by the California Environmental Protection Agency demonstrates how to use a Kemmerer device.

The feasibility of using the water in the mine shaft for an open loop geothermal setup can be assessed by analyzing the chemical characteristics of the water. These water chemistry analysis can determine characteristic such as the acidity and hardness of the water. Some of these characteristics can be measured directly while others are determined indirectly through proxy indicators.

Relevant water chemistry characteristics include measures of pH, salinity, hardness, dissolved gas, and suspended solids. Recommended maximums or range values will be provided. If the test results indicate values in excess or outside the range, corrosion resistant materials may be required to reliably operate an open loop geothermal setup. Alternatively a close loop system setup would be chosen.

In some communities the mine water is already being used in some way such as drinking water. In these cases, it is important to prevent changes to the mine water chemistry which would impact these other uses.

Obtaining a measure of the water conditions prior to installing a system is important for tracking any changes. More details about each of these water characteristics and its implications on costs and system configuration are described below.

PH

PH is a scale that measures the acidity or alkalinity of water. The scale runs from 0 to 14, where 7 is considered neutral (neither acidic nor alkaline). The pH of the water affects how corrosive the mine water is and whether an open loop system is possible. Water that is acidic (pH of 6 or less) will corrode metal surfaces and so will corrode the inside of a pump or heat exchanger more quickly than alkaline water. If the water is highly acidic (less than 4), the community needs to decide whether the extra capital cost for more corrosion-resistant materials for pumps and heat exchangers is worth the avoided costs of frequent maintenance or decide to install a closed loop system in order to protect lower-cost pumps and heat exchangers that are not equipped with corrosion resistant parts [4]. The rate corrosion is greatly multiplied when aggressive ions such as chloride and/or iron are present in the water in concert with a low pH [5].

Salinity

Salinity is a measure of the saltiness of a solution. The salt in mine water comes from water dissolving certain minerals in the bedrock of the shaft. Saltwater corrodes metals much faster than freshwater. Corrosion is a process that happens when dissolved salts — electrically charged atoms or groups of atoms — speed up electron transfers between themselves and metals. These electron transfers weaken metals however some metals are more resistant to these effects than others.

Careful selection of materials can go a long way to mitigating corrosion problems. Using elements made out of high grade stainless steel, bronze or titanium will increase corrosion resistance. Salinity can be measured in terms of parts per million (ppm), milligrams per liter (mg/l) or grams per liter (g/l) or by its electrical conductivity measured in millisiemens per centimeter ($\mu\text{S}/\text{cm}$). A salinity higher than $30 \mu\text{S}/\text{cm}$ (15 ppm or 15 mg/l) warrants parts designed to operate in saltwater conditions (seawater has a salinity of $50,000 \mu\text{S}/\text{cm}$) or a closed system with pipes that will last in saltwater conditions [6].

Titanium for example experiences almost no corrosion at even saturated levels of various chloride solutions [7]. The mine water in Heerlen, the Netherlands has a very high chloride concentration of 18,800 mg/l [8]. The titanium heat exchangers installed in 2008 are still operating problem free today [8].

Hardness

Hard water is water that has high mineral content. Some people may be familiar with the effects of hard water when it causes build-up on shower walls, faucets, and spots on the car after washing. Mine water can gain hardness as it contacts and dissolves calcium and magnesium contained in the bedrock of mine shaft. Hard water can form deposits called “scale” that can clog the pipes, pump, and heat exchanger of an open loop geothermal system. Water hardness is quantified in milligrams per liter (mg/l), parts per million (ppm), or grains per gallon (grains/gal). Table 1 is a chart for hardness classification. If the mine water is hard or very hard, a closed system is recommended to prevent costly recurring maintenance and breakdowns.

Table 1: Hardness scales [9]

Classification	Level (mg/l or ppm)	Level (grains/gal)
Soft	0-17.1	0-1
Slightly Hard	17.1-60	1-3.5
Moderately Hard	60-120	3.5-7.0
Hard	120-180	7.0-10.5
Very Hard	180 & over	10.5 & over

The amount of calcium and magnesium that can be dissolved in the water is also dependent on the pH and temperature. Warmer and more acidic waters can dissolve more minerals and therefore can have higher hardness [10]. The hardness of the water can be very different from location to location and at different depths thus it is necessary to take specific measurements [11].

Dissolved Gases

Dissolved gas is the combination of gas and water. The carbonation found in beverages like soda is an example of a dissolved gas. Dissolved gases are usually measured in either mg/l or ppm. The four dissolved gases frequently found in mine water are: carbon dioxide, methane, hydrogen sulphide, and oxygen. The most disconcerting dissolved gases are oxygen and hydrogen sulphide as they can contribute to corrosion. It is important to measure dissolved gas levels because sometimes the mine water has no dissolved oxygen to start, but the installation of an open mine water geothermal system could introduce dissolved oxygen into the mine water. In this scenario, problems like corrosion or the formation of biological growth of algae can occur.

Suspended Solids

Suspended solids are small solid particles that are mixed throughout the water and do not readily sink to the bottom. Most mine water contains a high degree of suspended solids. These suspended solids come from many sources, including dust and debris left over from mining, chemical reactions that cause mineral precipitation, and biological growth.

Suspended solids can clog pumps and coat heat exchangers with a film that can reduce performance. The amount of suspended solids in the water can be stated in two ways: turbidity and total suspended solids (TSS). Turbidity is a quick but less accurate measure of suspended solids. It estimates the amount of suspended solids by the amount of light scattered by suspended particles. Turbidity is measured in units of Nephelometric Turbidity Units (NTU) [12]. TSS measures all suspended solids in the water by mass with units of mg/l.

The composition of the suspended solids can also be analyzed. The characterization of the suspended solids is as important as the amount of suspended solids. Traditional well pumps can handle a small amount of suspended solids especially if they are not abrasive in nature.

Mine water often contains high levels of abrasive suspended solids. Suspended coal dust is highly abrasive and will quickly wear out a traditional submersible well pump. If this is found in high concentrations, an open loop system may still be viable if the pump is carefully selected. A submersible drainage or slurry pump designed for sewage or mining applications should be selected instead of a well water pump. The added cost of these pumps could warrant moving to a closed loop system configuration [13] [14].

A water quality lab will conduct tests which will measure the above water chemistry characteristics directly and indirectly. The water quality report from the lab may be difficult to interpret. Table 2 contains the parameters and terms frequently found in a typical report and explains the meaning and significance of different values that are relevant for developing a mine water geothermal system. Ranges or maximum recommended values are included for parameters that can impact the longevity of an open loop system.

The table also explains how the values contribute to pH, salinity, hardness, and suspended solids described above. For a direct example of how to interpret water quality test results, Appendix F includes a report for samples collected from mine shafts in Calumet, Michigan.

Table 2: Description of Common Parameters Found in a Water Quality Lab Test Result With Value Ranges Relevant to Mine Water Geothermal Heat Pump Setups

Parameters	Descriptions
Carbonate & Bicarbonate Alkalinity	Carbonate and bicarbonate anions contribute to alkalinity meaning they have the ability to neutralize acid. This would not have an effect on the system.
Chloride	Chloride is sometimes found in concert with sodium, the combination is commonly known as table salt. The presence of chloride in even low concentrations (10s of ppm) accelerates a condition called pitting corrosion to many metals including steels, stainless steels, aluminum, and aluminum alloys when in constant contact with the water. Bronze and titanium are metals that are highly resistant to saltwater corrosion.
Conductivity	Conductivity in water is due to the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Conductivity is measured in micromhos per centimeter ($\mu\text{mhos/cm}$) or microsiemens per centimeter ($\mu\text{s/cm}$). A closed system should be considered if the mine water has a conductivity of thousands of $\mu\text{s/cm}$ or more as this indicates very high levels of dissolved solids which can react with metals [15].
Hardness	<p>Hardness is very important because it indicates how much dissolved calcium and magnesium is in the water. The hardness of water is measured in three different types of units: grains per gallon (gpg), milligrams per liter (mg/L), or parts per million (ppm) [9]</p> <p>The hardness classification of the water from soft to very hard in different units of measure is shown in Table 1. If the hardness is above 120 mg/l a closed loop system is recommended to prevent clogging.</p>
pH	A closed system or materials which are especially corrosion resistant is recommended if the pH is less than 4 to ensure longevity of the system.

Sulfate	<p>The presence of sulfates alone should not have an effect on a mine water geothermal system however sulfates are often linked and found in concert with salts such as calcium and metals such as iron which have negative effects on equipment and the environment. At times these compounds can be at critical conditions inside mines such that if for example, a small amount of oxygen were to be introduced, undesirable chemical reactions could occur. Many ore deposits, especially gold and coal mines, contain high amounts of sulfate even after mining [16].</p> <p>Under the right conditions, especially if oxygen is available, oxidation and reduction chemical reactions that can result in sulfur gas releases, metal precipitation, and scaling deposits. These reactions can happen naturally as water fills the mine after closure resulting in environmental liabilities such as acid mine drainage [17].</p> <p>If a mine site is not experiencing such reactions, but the water is found to contain high levels of sulfate (1,000s of mg/l), great care should be taken to ensure that a mine water geothermal system does not introduce oxygen into the mine water which can trigger undesirable reactions [18]. Sulfates present in the water in even small concentrations can give off a rotten egg smell.</p>
Iron	<p>Iron is frequently sourced from iron sulfide (aka pyrite) which is the most common sulfide mineral and commonly found in coal and gold mines. As a result it is common to find iron in mine water. Pyrite forms oxidizing reactions in the presence of oxygen and water, these reactions have a tendency to lower the pH of the water and form iron solids called iron(III) hydroxide [19].</p> <p>Iron in low concentrations should not pose a problem however iron in concentrations of 1,000s of mg/l will likely be in concert with low pH and visible iron precipitates. These precipitate contribute to water hardness and can clog pipes, corrode heat exchangers and pumps [20] [21].</p>

<p>Manganese</p>	<p>The presence of manganese occurs in nature occasionally, and is usually accompanied by iron but in much lower concentrations. Manganese is typically found in higher concentrations with acidic water. It does not typically precipitate into a solid unless high amounts of dissolved oxygen is available nor does it cause reactions which affect pH. The presence of manganese should not affect a mine water geothermal system [22] [23].</p>
<p>Potassium</p>	<p>Potassium is commonly found in small concentrations in water, it is part of the standard batch of tests conducted at a water quality lab because occasionally it may be high enough to pose a problem for drinking water. In a mine water geothermal system, the level of potassium is not a problem. It does not affect the pH or precipitate into a solid because itself is not water soluble. [24] [25].</p>
<p>Sodium</p>	<p>Sodium is commonly found in all waters. In mine water, it is often accompanied by high levels of chloride however it can also be found in the form of sodium sulfite and sodium nitrate. High sodium alone will not cause problems with a mine water geothermal system, it is neither corrosive nor easily precipitated. [26]</p> <p>Note: Historical records may indicate other unique minerals/chemicals that may justify additional water quality tests at specific locations. A good resource for additional information about the above water quality parameters and water quality indicators can be found at the "National Ground Water Association [27]"</p>

CASE STUDY, Assessment of the Calumet No. 3 Mine Water

Two water samples were collected from a mine shaft named Calumet #3 in Calumet, Michigan for water quality tests to determine the feasibility of an open loop geothermal system. The results are shown below in Figure 2. Comparing the results with the information above, the water quality report shows that the mine water in Calumet No. 3 has a hardness scale in the “moderately” hard range, not high enough to be a cause of concern. The chloride, sulfate and conductivity results are low enough coupled with a neutral pH to suggest that no special materials will be needed. The trace metals concentrations are not high enough to pose a problem in a mine water geothermal system.

Note that the iron and manganese values in this report are in micrograms per liter (ug/l) rather than milligram per liter (mg/l). The iron concentration is 9.5 mg/l which is low and will not be a concern. Because the water will not be consumed for drinking the bacteria count in coliforms and E. coli are not a concern. These bacteria are not the ones which will cause any chemical reactions in the water. In summary, this water quality test report shows no barriers to the option of an open loop geothermal heat pump system.

Figure 2. Water Quality Report of Sample Collected From Calumet No. 3

APPENDIX F

ANALYTICAL REPORT



Client: MTU/KRC

WWA Job #: 54372

Project:

Date Received: 10/11/2014

Date Reported: 10/27/2014

Sample Results

Sample No. / ID / Description / Matrix	Result	Flags	Units	Date	Method	MDL	SQL
54372-001 / Calumet #3 / Drain Pipe / Water							
General Chemistry Parameters							
Alkalinity (t)	120		mg/L	10/15/2014	310.2	50	100
Chloride	10 J		mg/L	10/21/2014	4500-Cl- E	7	20
Conductivity	240		umho/cm	10/22/2014	2510B	1	2
Hardness	100		mg/L	10/23/2014	2340B	0.1	0.7
pH	7.1		pH Units	10/14/2014	4500H+ B	0.10	0.20
Sulfate	16		mg/L	10/17/2014	4500-SO4- E	3.0	6.0
Total Dissolved Solids	210		mg/L	10/15/2014	2540C	10	10
Trace Metals - Total							
Iron (t)	9500		ug/L	10/23/2014	200.7	10	20
Manganese (t)	96 Q		ug/L	10/23/2014	200.7	0.50	2.0
Potassium (t)	4.5		mg/L	10/23/2014	200.7	0.10	0.40
Sodium (t)	7.6		mg/L	10/23/2014	200.7	0.50	1.0
54372-002 / Calumet #3 / Water							
General Chemistry Parameters							
Coliforms	140		MPN/100 mL	10/11/2014	Modified Colitag	1	1
E. coli	ND		MPN/100 mL	10/11/2014	Modified Colitag	1	1

ND = Not Detected, MDL = Method Detection Limit, MQL = Method Quantitation Limit, ppm = mg/l (liquid) or mg/kg (solid), ppb = ug/l (liquid) or ug/kg (solid)

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APPENDIX G — FUNDING SOURCES

Federally the IRS, DOE, and USDA are the main branches which offer financial assistance for geothermal systems. In addition to the tax, grant, and loan incentives described in Appendix B1, one should check the DOE's Geothermal Technologies Office for updates on new incentives. Federal funding frequently waxes and wanes with the changing political climate. For example, in the 1970s and 1980s a series of Federal risk reduction policies were implemented through the Program Research and Development Announcement program (PRDA), User Coupled Confirmation Drilling Program (UCDP), and Program Opportunities Notice (PON). Additional grants are available for specific joint scenarios, for example the DOE's Technical Assistance Grant Program is available for projects which involve superfund site remediation.

Funding sources are often organization specific, for example a cooperative-run utility district heating system could apply for funding through the National Rural Utilities Finance Corporation and National Cooperative Services Corporations.

While federal funding experiences boom and bust cycles, state, local and utility level incentives are often much more stable albeit unevenly distributed. Due to proactive environmental and energy policy by many states have implemented Renewable Portfolio Standard (RPS), state tax incentives, loans and grants targeting specific and/or multiple organizational sectors. A matrix of which current state/local and utility incentives are applicable to each organizational sector can be found in Appendix B2. Most projects take advantage of government sponsored loans because it is often difficult to obtain a private loan or support from venture capital due to the perceived high risk and long payback periods of low-grade geothermal projects (Bloomquist, 2004).

In addition to financial incentives, policy can further enhance the incentive to promote clean energy. For example, two states, Maryland and New Hampshire, have made GHPs a qualifying technology for Renewable Energy Credits (REC's) under the State's Renewable Portfolio Standard (RPS) mandate. This provides utilities an additional incentive to promote the use of GHPs and receive environmental credits for the avoided thermal load (GEO-NII, 2013).

Many states have a policy setup where the utility's profits are not dependent on the amount of energy sales; this policy is formally called decoupled. Where this is the case, the utilities may offer or can be persuaded to offer on-bill financing implemented either in the form of a tariff-based system or an on-bill loan. On-bill financing uses energy utility bills as the vehicle or repayment of loans. Currently five states Oregon, California, New York, Massachusetts, and Hawaii have state requirements for utilities to offer on-bill financing (C2ES.com, 2014).

According to data compiled by the Center for Climate and Energy Solutions, nine additional states have on-bill financing offered by one or more utilities. In addition four other states are in the process of setting up on-bill financing policy. On-bill financing has gained rapid popularity with good reports of high utilization due to it being a zero or subsidized interest loan. On-bill financing if implemented in tariff-based is not considered a loan which allows organizations which are prohibited from assuming new debts to fund a system.

PACE financing is another innovative scalable and sustainable financing strategy which has been set up by many states. The capital is typically obtained by local or state governments issuing bonds to investors and then using the money to provide loans to consumers and businesses to fund energy efficiency retrofits. The loans are repaid over the assigned period (typically 15 or 20 years) via property taxes. The advantage of PACE financing is that the loan is attached to the property rather than the homeowner so if the property is sold before the loan is paid off, the new owner continues making payments.

In both on-bill and PACE financing, the loan terms are generally setup such that the financial savings from the energy efficiency retrofits is greater or equal to the monthly payment or increase in property tax, thus homeowners and businesses are not paying more than they would be prior to the upgrades.

Federal:

*Table 1. Federal Incentives for Geothermal Heat Pumps
The Rural Energy for America Program (REAP)*

Incentive Program/Description	Eligible Sectors															
	Residential	Multi-Family	Commercial	Industrial	Manufacturing	Agricultural	Native Corporation	Schools	Non-Profits	Utility	Municipal Utility	Rural Electric Cooperative	State Government	Local Government	Tribal Government	Non-Federal
Investment Tax Credit (ITC)			X	X		X				X						
Modified Accelerated Cost-Recovery System (MACRS)			X	X		X										
USDA - Rural Energy for America Program (REAP) Grants			X			X	X		X		X	X	X	X		
USDA - REAP Loan Guarantees			X			X										
Renewable Energy Production Incentive (REPI) (Certain)							X				X	X	X	X	X	

The Rural Energy for America Program (REAP) provides financial assistance to agricultural producers and rural small businesses in rural America to purchase, install, and construct renewable energy systems; make energy efficiency improvements to non-residential buildings and facilities; use renewable technologies that reduce energy consumption; and participate in energy audits and renewable energy development assistance.

The REAP program is comprised of the following components:

The Renewable Energy System and Energy Efficiency Improvement Guaranteed Loan and Grant Program provides financial assistance to agricultural producers and rural small businesses to purchase, install, and construct renewable energy systems; make energy efficiency improvements; use renewable technologies that reduce energy consumption; and participate in energy audits, renewable energy development assistance, and feasibility studies. Read more

The Energy Audit and Renewable Energy Development Assistance Grant Program provides grant assistance to entities that will assist agriculture producers and small rural businesses by conducting energy audits and providing information on renewable energy development assistance. Read more: http://www.rurdev.usda.gov/BCP_Reap.html

Table 2. State and Local Incentives for Geothermal Heat Pumps

State & Local Incentives	Incentive Program/Description	Residential	MHI/Family	Commercial	Industrial	Manufacturing	Agricultural	Native Corporation	Schools	Non-Profit	Utility	Municipal Utility	Rural Electric Cooperative	State Government	Local Government	Tribal Government	Non-Federal	Contractor	Installer Contractor	
		Eligible Sectors																		
Alabama	Local Government Energy Loan Program								X										X	
Alaska	Renewable Energy Grant Program			X							X				X	X				
Arizona	Energy Equipment Property Tax Exemption	X		X	X															
Arizona	Renewable Energy Business Tax Incentives			X	X															
Arizona	Town of Buckeye - Green Building Incentive	X																		
California	Burbank Water & Power - Green Building Incentive Program		X	X						X										
California	California Enterprise Development Authority (Figtree PACE) - Statewide PACE Program	X		X																
California	CaliforniaFIRST		X	X	X		X													
California	City of Santa Monica - Expedited Permitting for Green Buildings	X		X																
California	County of San Bernardino - Green Building Incentive	X		X														X	X	
California	Sonoma County - Energy Independence Program	X	X	X	X															
California	Western Riverside Council of Governments - Home Energy Renovation Opportunity (HERO)	X																		
California	Western Riverside Council of Governments - Large Commercial			X																

Table 3. Utility Incentives for Geothermal Heat Pumps

Utility Incentives	Incentive Program/Description	Residential	MHI/Family	Commercial	Industrial	Manufacturing	Agricultural	Native Corporation	Schools	Non-Profit	Utility	Installer Contractor	Municipal Utility	Rural Electric Cooperative	State Government	Local Government	Tribal Government	Non-Federal	Contractor	Installer Contractor	
		Eligible Sectors																			
Alabama	Central Alabama Electric Cooperative - Residential Energy Efficiency Rebate	X																			
Alabama	South Alabama Electric Cooperative - Residential Energy Efficiency Loan	X																			
Alabama	TVA Partner Utilities - Energy Right Heat Pump Program	X								X	X										
Arizona	UES - Renewable Energy Credit Purchase Program	X	X																		
Arkansas	JAEP SWEPCO - Commercial and Industrial Energy Efficiency Rebate Programs			X	X			X	X					X	X	X					
Arkansas	First Electric Cooperative - Home Improvement Loans	X																			
California	Lassen Municipal Utility District - Residential Energy Efficiency Rebate Program	X																			
California	Pacific Power - FinAnswer Express		X	X		X			X					X	X	X					
California	Phumas-Sierra REC - Residential Energy Efficiency Rebate Program	X																			
California	Redding Electric - Earth Advantage Rebate Program	X	X																		