# The potential use of ground energy in the mining industry – exploration to closure

Gareth Digges La Touche[1], Martin Preene[2]

[1]*Golder Associates (UK) Ltd, Attenborough House, Browns Lane Business Park, Stanton-on-the-Wolds, Nottinghamshire, NG12 5BL, United Kingdom, gdiggeslatouche@golder.com*
[2]*Golder Associates (UK) Ltd, Golder House, Tadcaster Enterprise Park, Station Road, Tadcaster, LS24 9JF, United Kingdom, mpreene@golder.com*

**Abstract** The mining industry is subject to significant drivers, both economic and environmental, for reducing traditional energy use, which has resulted in a corresponding interest in renewable and alternative sources of energy. Ground energy systems make use of the heat energy in 'ambient' temperature soil, rock and groundwater beneath a mine site and are an established low and zero carbon (LZC) technology widely used to reduce energy consumption and carbon emissions associated with the heating and cooling of buildings. Currently few ground energy applications have been applied on mining projects. It is postulated that there may be a missed opportunity because many mine sites already have features, such as groundwater from dewatering systems, borehole networks, pit lakes and settlement ponds which can be used as part of the ground collector elements of these systems. This paper identifies potential ground energy heating and cooling sources on mine sites, including natural ground, static water bodies, backfilled workings and dewatering systems. If these potential heating/cooling sources can be exploited by matching with on-site or off-site heat demands (such as heating of mine camps and following closure residential properties or agricultural greenhouses) and cooling demands (mine camps in many parts of the world and the working environment in many "deep" hard rock mines), there may be opportunities to reduce energy costs, improve environmental performance and potentially provide additional revenue streams to mine operators.

**Key Words** geothermal, ground energy, ground source heat, heating, cooling

## Introduction

The mining industry is subject to economic, environmental and legislative drivers to reduce energy usage. Incremental improvements in energy efficiency and transfer of technologies from other industrial sectors are likely to deliver the easiest and most sustainable gains in energy performance and emissions rather than radical innovation.

## Energy issues in the mining industry

The mining industry, as with the rest of the industrial economy, is under pressure to reduce energy use and carbon emissions. This is driven by the industry's desire to be more sustainable and to meet internal targets and also from Government and regulatory pressure. In the UK, for example, depending on the scale of the operations, operators may be subject to the requirements of Climate Change Agreements or the Carbon Reduction Commitment (CRC) Energy Efficiency Scheme which require energy use and carbon emissions to be quantified, and reduced on an ongoing basis. In many countries financial incentive schemes exist or are planned to promote the use of renewable energy. For example, in the UK a subsidy scheme called the Renewable Heat Incentive (RHI) is currently in the early stages of implementation by the UK Government, with the aim of providing long term (up to 20 years) subsidy to the users of heat energy from renewable sources. Such schemes make renewable heat sources (including ground energy systems) financially attractive compared to fossil fuel derived heat sources.

Fossil fuel and carbon emissions may be reduced in two principal ways:

1. by reducing energy usage – for example through energy efficiency measures; and
2. by displacing fossil fuels with lower carbon alternatives such as renewable energy sources or low and zero carbon (LZC) technologies which produce energy more efficiently from moderate inputs of traditional energy sources.

This paper presents a brief background to ground energy systems which are a type of LZC technology. Potential ground energy applications for mine sites, exploiting a range of thermal sources are reviewed, and potential benefits and constraints are discussed.

## Ground energy systems

Ground energy systems (also referred to as ground source heat pumps (GSHPs) or low temperature geothermal systems) are an established LZC technology which can produce heat energy very efficiently by exchanging heat energy with the ground. These systems are increasingly being considered as part of space heating and cooling systems for buildings throughout the world.

Since the 1970s ground energy technology has been applied on a commercial basis in the United States and Scandinavia. In other countries the use of such systems has been limited typically due to the availability of other sources of relatively cheap energy. It is however widely predicted that there will be significant growth in the number of ground energy installations worldwide driven by the rise in price of conventional fuels (principally natural gas), making ground energy more attractive financially, and in some countries changes in regulation, requiring building services engineers to consider the heating and cooling efficiencies and carbon emissions of buildings.

Mines often have features such as pit lakes or groundwater pumped from dewatering systems which have the potential to be used as part of ground energy systems. To date there has been little application of ground energy systems on mines although a recent UK report (Ellis *et al.*, 2008) identified the potential and the exploitation of closed mines as heat sources is often considered (e.g. PB Power 2004, Rodrıguez and Diaz 2009, Kynoch 2010). In reality, there are various potential barriers to the successful and economic implementation of ground energy systems on mining projects, not least the need to match the availability of energy sources with nearby energy demands.

## Principle of operation

Ground energy systems exploit underground thermal sources such as the ground, groundwater, or bodies of water in intimate contact with the ground. An artificial system known as a ground collector (typically a sub-surface array of boreholes or pipework loops or other structures) is used to extract heat energy from, or inject heat energy into, the source. The ground collector is linked to a heat transfer system (typically using heat pumps) which passes heat energy from the source to the thermal load, most commonly derived from the space heating and cooling demand for a building.

There are two types of ground energy systems: open loop and closed loop. Open-loop systems abstract water from a water source (an aquifer or a shallow pond), and pump it to the surface (Figure 1). The water is passed through a heat transfer system, before disposal (at a different temperature) either to waste or by re-injection into the original source. Closed loop systems do not abstract water, instead a fluid is circulated through a ground collector comprising a loop of pipes (the ground loop) buried in the ground (Figure 2). The circulating fluid passes through a heat transfer system at the surface, and is then recirculated back through the buried ground collector, to exchange heat with the surrounding soil or rock.

In principle the ground and groundwater at a site may be used as a heat sink or source, because in the absence of external influences, and below the relatively shallow zone of annual temperature variation, the ground acts as a large thermally stable mass, where the temperature varies little during the year. Ground temperatures within 100 m of the surface typically reflect the mean annual air temperature at a site (i.e. in many parts of Central Asia and Europe, 10 °C to 14 °C). In the summer months the ground will be cooler than the surface air temperature, so heat may be rejected to the ground to cool a building, and in winter the ground will be warmer than surface air temperature, and may be used as a heat source (Figure 3). As an example groundwater temperatures recorded at a mine site in Russia and in January/February 2011 were approximately 7 °C whilst air temperatures rangied from -38 °C to 0 °C during the same period.

## Heat pumps

A ground energy system needs a heat transfer system to pass the thermal load from the load side

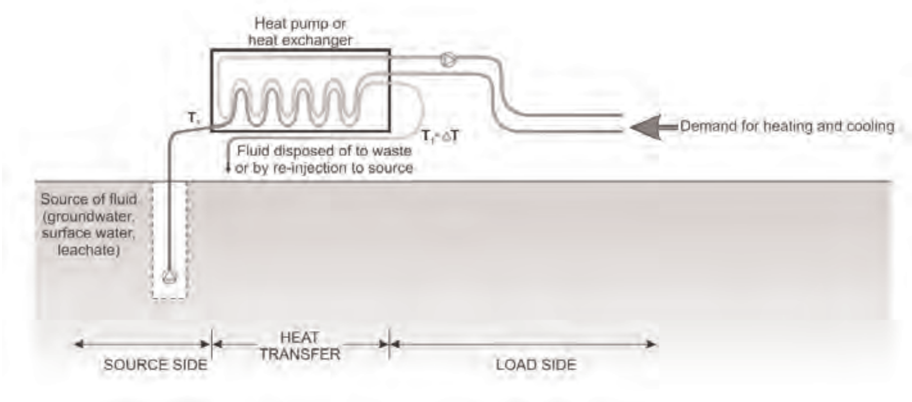


***Figure 1*** *Open loop ground energy system.*

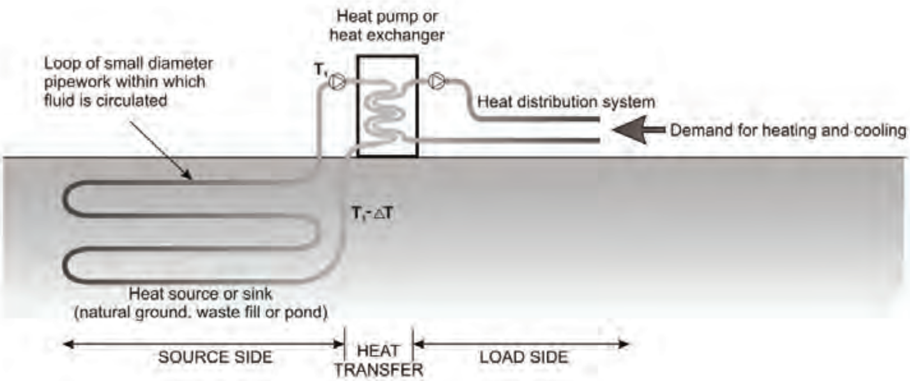


***Figure 2*** *Closed loop ground energy system.*

(e.g. a building) to the source side (e.g. the ground collector and the surrounding ground). The most common form of heat transfer system is a heat pump, which is a mechanical device which, typically, uses an electrically driven refrigerant vapour compression cycle to upgrade heat from one reservoir to another. For example, a heat pump can use the ground beneath a site (at say 12 °C) to produce warm water at say 35–45 °C to heat a building.

Although heat pumps based on the vapour compression cycle use electricity to operate a compressor they do this very efficiently. One approximate measure of the efficiency is the seasonal performance factor (SPF), which describes the ratio of the total heat output to the quantity of electrical energy used to drive the heat pump, measured over an annual cycle.

The external energy, E, used to drive a heat pump to produce heat energy, H, is related to SPF by:

$$E = {}^{H}\!/_{SPF} \tag{1}$$

SPF is influenced by the source temperature and the output temperature of the heat pump, but SPF values of 3 to 5 are not unusual for well-designed systems. This means that for every kW of electrical energy used, 3 kW to 5 kW of heat energy may be obtained. As a result the energy usage (hence the energy bill) will be typically 20 to 30% of that for a conventional fossil fuel system. Based on current UK energy costs at SPFs of 3 to 5, ground energy systems can produce heat at unit costs per kWh comparable to the cost of nat-

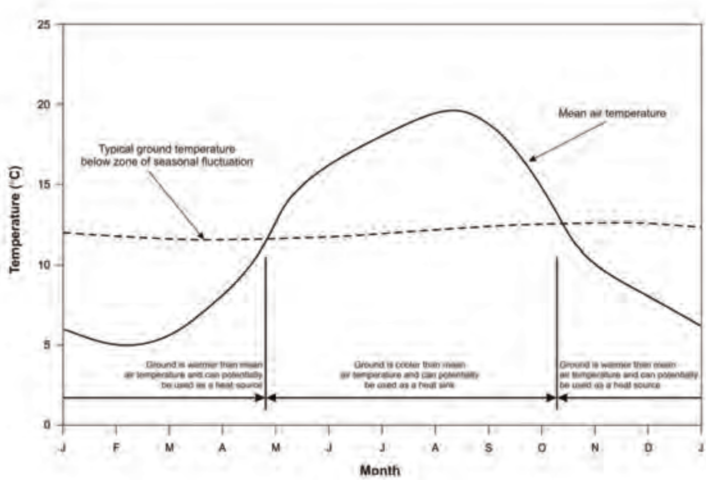


***Figure 3*** *Typical relationship between surface air temperature and ground temperature (temperatures based on UK conditions).*

ural gas from grid supplies. For sites not connected to the gas grid, ground energy systems can provide heat at significantly lower cost than heat from electrical or oil-fired heating systems.

Ground energy systems may in some cases be operated without a heat pump, for example where the difference between the source temperature and the required output temperature is relatively small, it may be possible to use a simple heat exchanger. This approach is known as 'direct heating' or 'direct cooling' since there is no requirement to use electricity to drive a heat pump (there will however be a small power requirement for a circulation pump). 'Direct' systems are very energy efficient and may have SPFs in excess of 20; and unit heating/cooling costs are correspondingly low.

## Identifying potential sources of ground energy on mine sites

Mine sites may contain various possible sources of ground energy on a given site. Each type of source will have different positive and negative features. Understanding the characteristics of the source is vital if ground energy systems are to be successfully implemented. The principal ground energy sources relevant to mine sites are briefly summarized below.

### *Natural ground*

The most common source of energy exploited by ground energy systems is the natural ground and groundwater and is the source/sink typically used for systems that heat and cool buildings. Where water bearing strata are present, open loop systems can be used, alternatively closed loop systems may be used in a wider range of ground conditions, whether water bearing or not.

### *Static water bodies*

Where mines are restored as water bodies or pit lakes are present, both open loop and closed loop systems may be used. Open loop systems involve pumping (or allowing gravity flow) of water from the water body, and passing the water through a heat pump or a heat exchanger. Closed loop systems involve placing a heat exchanger system (either a proprietary unit or one fashioned from coils of pipe) within the water body. The heat exchanger can be placed in the base of the pit lake prior to flooding, or can be floated out and sunk after the works are flooded.

### *Backfilled workings*

Another potential source of ground energy on mine sites is backfilled workings. In low permeability materials it may be appropriate to install a closed loop ground collector during the backfilling of the works. Where mines were dewatered in operation, it may be possible to install wells or sumps during backfilling, to allow water to be abstracted and used in an open loop system once mine backfilling is complete.

### *Dewatered mine workings*

One of the most obvious source of ground energy is water pumped from dewatering systems. The mine operator is already pumping this water, which contains a lot of heat energy, hence it makes sense to try and exploit this energy by diverting some or all of the water flow though a heat pump or a heat exchanger, to allow heat to be extracted for use via an open loop system.

## Potential heat demands associated with mine sites

The potential demand for the heat energy available from mine sites can be divided into two categories: on-site demand and off-site demand.

The most obvious use for the energy from mine sites is on the site itself. This is because the on-site heat demand will be nearby, and will typically be under the control of the operator. As a result the practicalities and commercial relationships will be straightforward. Many mine sites will contain site offices, accommodation and workshops which may require heating at various stages in the mine lifecycle from exploration through to closure. Other applications can include heating of portals (e.g. Toth, 2011), and other areas and systems prone to icing. Conversely, ground energy can be used to provide cooling of air for ventilation through the mine. Ground energy systems can be used to replace gas heaters or electric chillers in these applications.

The potential for off-site heat demand will vary significantly from site to site. It is relatively unusual in mine sites to be located in densely populated areas. However, it is likely that, as a result of ongoing development, particularly in Europe, an increasing number of mine sites will be near development areas. As a result there may be opportunities to provide heat to properties via, for example, district heating systems. These allow a relatively small number of heat sources to feed into a heat network (typically comprising buried pipes used to circulate warm water). Other potential heat users are agricultural such as for glasshouse heating, produce drying, fish farm heating and other large scale uses of low temperature heat. In rural areas mines may have a significant potential as a low grade heat source.

## How can ground energy be used on mine sites?

It is clear that mines contain potential sources of ground energy, however this energy is not exploitable unless three conditions are met:

1 There is a demand for the heat energy;
2 The temperatures of the heat demand are compatible with ground energy systems; and
3 The heat demand is located close to the source.

These factors are explored in more detail below:

### *Demand for the heat*

Without a demand and viable end use, the heat energy is of no value. The first stage in developing a ground energy scheme is the identification of end uses for the heat that can be harvested from a mine. Potential heat uses are identified in the previous section.

### *Temperatures of heat demand*

Ground energy systems cannot generate heat efficiently at very high temperatures. They operate most efficiently when providing warm water up to around 35ºC, and to a maximum temperature of up to 60 ºC, albeit at lower efficiencies. Systems are will generally only be viable when heat demands are in this temperature range. Where higher temperatures are required ground energy systems may be appropriate for pre-heating, thus reducing fossil fuel use in a heating system.

### *Location of heat demand*

Ground energy systems typically produce heat in the form of warm water, which must be transmitted through insulated pipes from the source to the point of demand. This form of transmission is relatively inefficient and successful ground energy examples are rare where the source of energy and the heat demand are separated by more than a few hundred metres.

## Sustainability of ground energy use

The shallow ground is not an infinite heat source. Previous studies have shown that shallow ground energy systems tap into heat energy stored in the ground that is predominantly solar in origin, rather than from geothermal heat flux from depth. Ground and groundwater temperatures are relatively stable during an annual cycle as natural heat inputs and outputs are approximately in balance. The introduction of a ground energy system extracting heat (or rejecting it in the case of cooling systems) will change that balance. To be considered sustainable, the rate of extraction of heat by ground energy systems should be limited to rates that do not result in large temperature changes in the heat source (i.e. the ground, groundwater or surface water). In the example of systems used for heating, excessive rates of heat extraction will result in the temperature of the source reducing with time, causing practical difficulties and reducing the efficiency of the system, as well as the detrimental environmental impact.

The design of a ground energy system should assess the sustainable rate of heat extraction, considering the characteristics of the source and the proposed ground collector. Guidelines for the sizing of ground collectors can be found in design guides such as Banks (2008).

## Commercial aspects

Where mine operators use heat from ground energy systems to meet on-site demand, the commercial situation is straightforward as the heat energy from the ground energy system will replace heat from conventional sources (e.g. gas, oil, electrical heating).

However, where the operator intends to harness heat energy and export it to supply off-site demand the commercial situation may be more complex. The sale of heat would potentially provide a new income stream, the downside is that there would be a need for commercial arrangements with those buying the heat, and systems for metering and billing are likely to be necessary. In practice, it may be appropriate for the mine operator to become part of, or develop a relationship with, an 'energy supply company' (EsCo) to manage the sale and distribution of heat energy.

## Conclusion

Ground energy systems are a proven and reliable low and zero carbon (LZC) technology, which are increasingly being used to provide heating and cooling to buildings. Current and future regulatory and economic drivers to reduce energy costs and carbon emissions are likely to make ground energy systems increasing attractive in the future.

It is identified that mine sites contain several potential ground energy heat sources, including natural ground, water bodies in flooded or restored workings, backfilled workings and water from dewatering systems. If the potential heat sources can be matched with on-site or off-site heat demands there is the potential for considerable opportunities to reduce energy costs, improve environmental performance and potentially provide additional revenue streams to mine operators.

## References

Banks D, (2008). An Introduction to Thermogeology: Ground Source Heating and Cooling. Blackwell, Oxford.

Ellis P, Healy N, Leake C, Smithyman R, Ward A, Moore S & Mann D, (2008). Water-based quarry restoration: opportunities for sustainable rural regeneration and nature conservation. Report MA/6/2/013, Minerals Industry Sustainable Technology Programme, Minerals Industry Research Organisation.

Kynoch, B, (2010). Mining Heat. Canadian Consulting Engineer. May 2010, pp.18—23.

PB Power, (2004). Scottish National Minewater Potential Study: Shawfair Mining Project. Report to Midlothian Council.

Rodriguez, R and Diaz, M, (2009). Analysis of the utilization of mine galleries as geothermal heat exchangers by means of a semi-empirical prediction method. Renewable Energy 34, pp.1716—1725.

Toth A, (2011) Geothermal deicing in a mine tunnel. Proceedings, Thirty-Sixth Workshop on Geothermal Reservoir Engineering. Stanford University, Stanford, California. January 31 – February 2 2011. SGP-TR-191.