As part of an ongoing series of articles, we present the Technical Papers associated with the best presentations made at the last GRC Annual Meeting. This paper is from the session on Regulatory and Business Development.

Geothermal Energy in Mining – A Renewable and Reliable Energy Solution

Kyle Boynton, Mark Berkley, Steven Perkins and Steven Albert-Green
Hatch Ltd, Mississauga, Canada

Keywords
• Geothermal
• Energy
• Mining
• Synergies
• Carbon Emissions
• Renewable Power

ABSTRACT
This paper presents the business case for utilizing geothermal potential to support mining operations with available and favorable geothermal conditions. Global factors are creating continuing energy and carbon challenges within the mining sector for which no single solution exists. Whether it is a remote or grid connected operation, the challenges facing mining companies include: high energy costs, volatile fossil fuel pricing, carbon pricing and energy security to name a few. The opportunity exists to develop new solutions to improve operations and economics, leading to more environmentally friendly, long-term solutions. Although the role geothermal plays in the utilities sector is well understood, the potential in mining has remained underdeveloped. Mining operations typically have large process heat and electrical demands, which are frequently supplied by isolated and expensive diesel/fuel oil systems involving their own cost, supply chain, and logistical challenges. In terms of risk and reward, it is well understood that the greatest risk involved with geothermal projects is in making capital investment and development time during exploration and drilling, with the reward of significant reductions in operating costs and carbon emissions. Those involved in the mining industry have a more analogous view of this risk profile than utility market players. It is proposed in this paper that there is opportunity to seek solutions to provide mining operations with geothermal heat and power where it may not yet have been considered. An overview of mining operations and favorable geologies, as well as geothermal technologies and applications, similarities within the mining industry requirements and processes, and specific case studies are presented.

1. Introduction
Geothermal power as of 2018 represents less than 1% of total installed global generating capacity. The earth’s natural heat reserves are estimated to store considerably greater thermal energy than the world’s total primary energy
consumption. Estimates of accessible electrical potential range from 35GW to 200GW, representing 16 times the current installed global generating capacity (Montague, 2016).

On a global scale, market conditions are constantly transforming as stalled global economics, reduced investment activity, weaker global trade and geopolitical turmoil drive significant change in industry. On top of this the realities of climate change are transforming the global energy mix. Emerging technologies and previously underdeveloped technologies are speeding the transition to a more harmonious mixture of traditional and greener energy sources. In terms of renewables, technologies like energy storage, hydro dams, wind turbines and solar arrays have dominated the emerging market. However, governments today are supporting new developments, research and development institutions, and industry leaders who are working toward solutions that expand upon traditional renewables. This is causing costs to inch down and come closer to attaining grid-parity with larger conventional sources. Many within the energy community believe geothermal is emerging as one of the technologies that will play a larger role in the energy mix as a base-loaded renewable energy source, which is being further substantiated year after year as exploration and developments continue to grow.

Apart from the better understood role geothermal plays in the utility sector, global factors are creating continuing energy and carbon related challenges within the mining sector for which there is not yet a clear solution. Whether their assets are remote (islanded) or grid connected, companies today are continuously searching for solutions to the following major energy challenges:

- Addressing high energy costs (especially in remote operations) and volatile fossil fuel pricing
- Impact of carbon pricing on energy choices and energy costs (both capital and operating)
- Searching for energy solutions that provide reliable power on a large scale that address the above two challenges
- Security of energy supply and logistical simplicity

The mining sector requires long-term power supply options that can address the challenges above. Energy mixes of renewables (traditionally being wind, solar or hydro), energy storage and conventional thermal systems are the focus of studies and research. Geothermal represents another renewable power supply that eliminates many of the complications currently present with wind and solar, such as reliability, adjustability of load, and predictability. Additionally, geothermal presents secondary applications and benefits such as direct heating and cooling applications and mineral recovery, to name a few. It is possible that geothermal could be a viable and competitive solution that will play a larger role in the mining industries future.

2. Current Geothermal Energy Outlook

It can be suggested that the most pressing issue on a global scale in terms of energy, to-date, is limiting carbon emissions through increasing system efficiencies and increasing the percentage of installed renewables in the global energy mix. This is being done at many levels, from public and corporate policy to research and development. A recent example of major policy on a global scale is the Paris Climate Accord which is an agreement within the United Nations Framework Convention on Climate Change dealing with greenhouse gas emission mitigation, adaption and finance. As of 2018, 194 members have reaffirmed their commitment to mobilize $100 billion a year in climate finance by 2020 and have agreed to continue mobilizing finance at the level of $100 billion a year until 2025 (United Nations Framework Convention on Climate Change, 2018). Although this number encompasses all types of energy, geothermal very much falls under the umbrella. This example represents the largest scale policy development, however there are more examples among various governments that are adapting policy specific to geothermal, which in turn can shape corporate policy for operations within a government’s jurisdictions.

Global geothermal power capacity is expected to grow 5GW (or 30% of 2015 global capacity) through 2021. Projected spending for this is estimated to be $25B in less than 10 years (Matek, 2016). This is shown in the figure below (figure 1).
Currently there are a few ‘active and attractive’ regions for geothermal potential, including Eastern Africa, Central and South America, Caribbean, Japan, China and the South Pacific (all within the Ring of Fire). Indonesia has reorganized their government’s policy on geothermal assets to promote development, with the United States, Turkey and Kenya doing the same. To provide a better picture, the graph below (figure 2) shows both the targeted and potential geothermal energy production for countries in 2030.

3. Geothermal and Mining

3.1 Global Geothermal Potential and Mining

3.1.1 Overview

The mining industry is one of the largest industries in the world with clients on every continent (except Antarctica). Whether the mine is interconnected with a local grid or produces off-grid power, the capital cost, operating cost and sustaining capital requirements associated with the energy supply represents a large percentage of the overall operation’s budget. Within the topic of energy, mines are under constantly increasing pressure to tackle modern challenges such as the high cost of power, carbon taxes, and more stringent emissions requirements. Many companies are constantly exploring ways to reduce the cost of power through increased efficiencies and incorporating renewables into their energy mix.

Mining operations tend to congregate around geological formations, the result of past or present geothermal activity. This is evident in the Figures below (figure 3 & 4). This conclusion suggests there is opportunity to investigate solutions to power mining operations with geothermal power. Geothermal is a well-established technology with more than 100 years of experience and an estimated 13.2GW of installed global capacity (Matek, 2016). The true implication is not proof of concept but determining where there is sufficient geothermal potential to support a mining operation’s power demand and how to de-risk the capital investment required.

Figure 1: International geothermal power nameplate capacity (MW) (Matek, 2016).

Figure 2: Potential role of geothermal energy in electricity demand (Oliver, 2015).

Figure 3: Global mining operations (INFOGRAPHIC: locating the world’s minerals and mines, 2013).
3.1.2 Business Case

The mining industry today requires long-term reliable power supply, sometimes for more than 50 years mine-life. Uncertainty in fossil fuel pricing threatens a mine’s value proposition due to resulting high-power costs. Geothermal represents a potentially co-located, renewable power supply that can provide base load power as well as direct use applications (such as heating, ventilation and air conditioning, process heating, etc.) (Jensen, 1983). Additionally, the long-term low cost of power (average levelized cost of electricity quoted by the US Department of Energy for resources entering service in 2022 of 3 to 6 cents/kWh) is very competitive compared to the alternative conventional thermal power supplies (U.S. Energy Information Administration, 2018).

Geothermal provides to a mining operation the following:
- Reduction in fuel supply logistics (most beneficial in remote locations)
- Elimination or limiting of future greenhouse gas and carbon tax risks
- Opportunity to improve overall project economics
- Physically secure relative to fossil fuels (collocated, only applies to mines with remote generation or power supply)

3.1.3 Business Compliment

Geothermal and mineral exploration risk have similar risk profiles. Mining companies understand this risk profile. At the risk of losing capital investment and development time for exploration and drilling, significant reductions in operating costs as well as reduced environmental impact are realized. This is not to say the concept applies to all mining operations globally (just as for wind, solar and hydro), but where geothermal potential can be proven and realized. The question now becomes how can mining companies use information they have available to de-risk geothermal exploration.

To identify geothermal potential, various methods have been implemented. Organizations have extensively mapped various regions to provide quick reference heat maps, such as the Oregon Department of Geology and Mineral Industries and Southern Methodist University have done in the United States (State of Oregon, n.d.) (SMU, n.d.). However, in the past drilling has always been the most effective means of providing initial justification for a comprehensive resource review. This allows mining exploration activities to be used as a “leg up” to quickly evaluate geothermal potential at mine sites with a degree of accuracy. In fact, many of the heat maps produced (including those developed by the above parties) use bottom hole temperature measurements from mining exploration sites to estimate thermal gradients. Exploration drill core data offers a determination if any geothermal potential exists at a site for a minimal, incremental investment. Stage-gated approaches implementing available mine data can mitigate potential risks, reducing the risk of exploration and technology to companies using existing mineral exploration data. If a viable opportunity is found, available mine data can be further leveraged to minimize the effort that is required for determining delineation wells and field development.

Secondly, companies can leverage geothermal power during the exploration phase of a geothermal field (if exploration is conducted). Companies can use successful wells, once drilled, to generate power for forward construction and exploration camps (likely in the range of 5 to 15 MW). Special purpose temporary geothermal turbine/generator sets are available that make use of standard test (“slim hole”) wells to take advantage of this resource, prior to full field development.

Thirdly, a benefit many mining operations in the preliminary stage present is the ability to manage and understand the drilling aspect of geothermal. In the past, a major hurdle that has
halted many geothermal projects from moving forward is the costs required for drilling the wells, especially deep wells. However, in the past decade the cost of drilling deep wells has declined significantly as a result in advances from the shale oil and gas industry. These reduced drilling costs are greatly helping to reduce the upfront cost of geothermal developments. To further reduce these costs, many mining operations will already have drilling rigs on-site with planned drilling programs. This offers the ability to drill slim holes (or if plausible production holes) quickly for testing and further resource verification at lower cost. For reference, the EIA has made the tables above showing the cost of drilling over the past decade (figure 5).

Lastly, there is benefit aside from electricity production that geothermal may offer a mining operation. Given a geothermal heat source, some direct uses can include heating and cooling for HVAC systems, process heating (for example ore pre-heating and product drying), mineral production from brines, greenhouse heating, remote food production and agricultural drying (E. Patsa, 2015). To gain a broader idea of possible direct uses for geothermal, refer to the Figure below (figure 6).

Based on these benefits, one can derive that the critical factors for determining the suitability of geothermal energy in a mine include: quantity and flowrate of fluids available, fluid temperature, fluid quality and composition, mine infrastructure, proximity to energy user, specific energy needs, remoteness of location and price of energy, and the climate (E. Patsa, 2015).

3.2 Geothermal Use in Active Mining Operations

Geothermal energy has significant potential for integration within the mining industry on a global scale; however as of 2013, it was estimated that less than 20 mining sites were using geothermal energy (Younger, 2014). Most of these sites were inactive mines that were flooded in order to capture low-grade geothermal fluids for distribution to local communities as district heating. The potential to increase the use geothermal heat for this application, at a minimum, is substantial with the already substantial and continuously growing number of inactive mines worldwide, many of which could benefit from a district heating and
cooling system (because of demand at the mine or at nearby communities).

Within Canada alone there are over 200 active mining installations, 55 of which are deemed to have usable geothermal energy sources for low grade use at a minimum. It has been estimated that typical Canadian mining operations utilize 20MW of heat which can correspond to an annual savings of approximately $3.5 million CAD if replacing natural gas or about three times that amount if replacing electricity (from a local grid) (Koufos, 2011). A separate study estimated that Canadian mines could potentially save $1.5 million CAD per year using 21MW of geothermal energy (in combination with heat pumps), saving 19,000 tons of carbon dioxide per year. This would only require underground fluid temperatures around 22°C (Koufos, 2011). However, the larger picture is for active mining sites to take advantage of geothermal resources to provide low cost energy and enhance operational sustainability.

Given geothermal energy’s proven reliability, it is recommended that it be used to provide a baseload energy supply to mining operations with other systems in place for peaking requirements. These other systems may rely on grid connections, energy storage or small conventional power installations. Experience has demonstrated that due to high energy demands at most active mining sites, geothermal sources alone would, in many cases, not meet on-site demands, but still significantly reduce conventional fuel requirements and the mine’s carbon footprint. Furthermore, following the mine’s closure, existing geothermal energy infrastructure can be used to supply energy or heat to nearby communities as an additional post-mine cash flow.

The explanation for the lack of geothermal use within the mining industry on active sites is not abundantly clear. The largest cost associated with this form of energy is well understood to be upfront capital investment required for the combination of drilling and above ground infrastructure. One benefit of mining operations is that drilling related work (a prerequisite for any mining operation) are already being undertaken, and site infrastructure already envisioned for conventional power generation. Operationally, once the initial investment is made, the cost of power is lower with regards to geothermal energy than conventional fossil fuels, especially in remote locations where fuel supply logistics are perpetually complicated and expensive.

4.3 Outlook on Electrification of Mines

Driven by environment, regulatory and economic pressures, one of the current goals that many mining companies would like to achieve is the electrification of as much of their operations as possible. In combination with a base loaded renewable power supply, this would represent a “greener mine”. While the use of energy storage technologies in battery-operated vehicles and mining equipment, as well as grid scale storage are becoming more prominent, the levelized price of electricity and reliability of its supply are still the main drivers. As a result, global operations remain highly dependent on fossil fuels.

The electrification of mines is the trend of using an increasing quantity of direct electrical energy instead of fossil fuels converted to create energy on-site to run a mine’s operations, much like the trend of vehicle electrification towards battery powered cars. Unless a grid connection is readily available, mines that are remotely located have traditionally relied on diesel as a multi-purposed fuel. An electrification strategy for companies serious about the idea comprises of several stages which complement the mine’s needs and lead to increased energy efficiency and decreased emissions. For example, being able to support a fleet of electrical mining vehicles can lower the need for energy-intensive ventilation in underground mines.

A general pathway for electrification could involve the following:

1. A base case is representative of conventional power generation and fossil fuels acting as the primary source of energy delivered to the mine. Mine electrical drives (such as vehicles, crushing and processing equipment) are running primarily on diesel. This requires a fuel supply network inclusive of transportation and storage.

2. Renewable energy is added according to the asset’s assessments (geothermal, wind, solar, hydroelectric) to provide part of the load. Conventional power generation operation
is reduced, and in the case of multiple generators, some may be taken offline (potentially kept as emergency back-up). Energy storage can be added to ensure higher penetration of renewables and optimize the energy system; such as maximizing the runtime of generators at their peak efficiency. This can also include considerations of diesel-hybrid or fully electric drives. At this point a mine may employ microgrid protocols and controllers to optimize the system, and can be programmed for either lowest cost, lowest emissions, or highest energy efficiency.

3. The share of renewable generation has increased in the mine’s energy mix, while conventional power generation has been minimized. At times, the mine can run on 100% renewable power, and only run on conventional generation for back-up power, much like grid connected mines. The share of electrified mine equipment can now grow to make use of the renewable energy available and minimize curtailment through smart charging of batteries.

4. Mine drives are now fully electrified and can run on renewable energy and energy storage batteries, and are managed by the mine’s central (microgrid) controller and renewable power supply. Here other aspects of the mine (such as ventilation needs) can be minimized, and further optimization with added energy storage can allow the mine to operate on 100% renewable electricity, if not most of the time. In cases where the mine’s consumption cannot be reliably met by renewable energy alone, there are options that will allow for load following capabilities to become a “set-and-forget” form of emissions limiting generation. Currently these technologies are limited in practice to conventional generators, however in the future may include small modular nuclear reactors.

3.4 Mineral Extraction

There exists an untapped secondary market in the geothermal industry, that being mineral extraction from geothermal brines. Depending on the location and depth of a geothermal brine, there is a possibility that dissolved minerals exist at large enough concentrations they become economically viable to extract and sell as a by-product. Among the various minerals that have been found in brines, such as manganese, boron, and zinc (to name a few), the most sought after in the current market is lithium. This additional opportunity can be very attractive to mining operations that better understand the mineral market, as this is in essence “mining of geothermal brines” and can transform a plant into a “mineral processing plant with thermal power”. The resale of these minerals will help to bring down the cost of geothermal power, making it more competitive to conventional generation and, in select cases, drastically improving the net present value of a project.

To-date the focus for mineral extraction from a geothermal brine has been within the Salton Sea area of California. It is believed this region, on top of being one of the most attractive geothermal resources within the United States, has high concentrations of lithium within its brines from which geothermal plants are already producing electricity. It is estimated that millions of tonnes of lithium could be produced from the reservoirs, enough to produce a significant number of the world’s electric cars. More specifically, Neupane and Wendt stated the majority of geothermal brines (from a sample of more than 900) have a lithium concentration of 20 mg/kg of brine, however within the Salton Sea area they have been found to be as high as 400 mg/kg (Wendt, 2017). To put this into perspective, current technologies are claiming extraction efficiencies of up to 99% are achievable from geothermal brines, which at a current market price of 16,500 USD/tonne presents a significant revenue stream (Lithium Price, 2018). However, although much research and development has gone into this geothermal field (including pilot projects), there has yet to be a technology commercialized and brought to market.

4. Risks and Opportunities

When it comes to evaluating the risks associated with geothermal developments, there is one challenge that is unique from both the renewable and conventional energy industry. That being every geothermal field is unique; sections within a geothermal field may exhibit different characteristics or development challenges (even
throughout a single geothermal field). As a result, investment in geothermal projects has significant upfront costs that must be spent prior to validating the performance (or lack thereof) of an exploitable resource. This investment is used to drill test wells to generate brine flow and test performance of the well. Additional to this, what are called delineation wells are drilled at the boundary of the field to test how the performance may vary across the field. This large upfront investment raises the risk for investors as they must commit capital without complete reassurance on the return profile for the project. This reassurance and risk reduction is only truly provided upon completion of test wells and delineation wells, as they can outline the performance of the project with real time data.

The risk profile in geothermal projects is demonstrated graphically in the figure below (figure 7). It’s worth noting that, although this profile is being explained in the context of the geothermal industry, it is applicable and well understood within the mining industry.

It can be inferred that the risk versus the opportunity geothermal presents in mining applications is relatively polarizing. That is the higher risk comes at a higher reward. However, this statement is also subject to a case by case basis and much of the risk can be reduced due to favorable project conditions (readily available and proven resource). The major risks and opportunities with geothermal power developments that would be of greatest concern to mines are outlined below.

4.1 Risks

High Risk – There is risk in the capital investment and development time (exploration and drilling) if an adequate resource is not identified. This is a risk related to any resource development and would have to be considered along with the development time of the mine.

Medium Risk – Depending on the location and requirements of the project, permitting the production wells, transmission, power interconnection and land ownership (surface and mineral rights) would have to be considered in the context of supporting the project and timelines. The capital cost and margins may be impacted by this.

Low Risk – There is a risk that fossil fuel prices trend downward with time over the development period of a project impacting the geothermal cost margin as opposed to the alternative. In terms of operational costs this is considered low risk impact as operating cost margins for geothermal power versus fossil fuel power are often large, however there may be considerable impact on the initial capital cost/benefit trade-off to the alternative.

4.2 Opportunities

Significant Cost Impact – The operating cost margins between geothermal power and conventional power are large and often imply good payback on capital investment as well as operating costs and project free cashflow after payback. Additional to this, depending on the local jurisdiction there is a possibility for environmental credits or other government subsidies to decrease either the initial capital or operating costs for a project.

Environmental Impact – The usage of geothermal power has a positive impact on project’s CO₂ footprint and will lower other emissions such as NOx. This drives the opportunity for projects to acquire carbon credits and other subsidies, depending on the jurisdiction they operate within.
Implementation Flexibility – Given the long development schedule for geothermal power, it can be considered a “bolt-on” option in the later years of a project, including existing projects, if another power supply option is initially carried forward or in place, respectively. The large operating cost margin will allow it to be considered for fossil fuel replacement in support of operating cost reductions. This type of implementation would fit well with a project that can generate free cash flow quickly after capital payback or if fossil fuel pricing spikes in the future.

5. Case Studies

5.1 Geothermal Electricity on Active Mining Sites

Mines in tectonically active regions of the globe may have access to high energy geothermal systems that can be used directly for electricity production. Possibly the only existing mining facility generating on-site geothermal electricity has been in Papua New Guinea. The Lihir Mine is currently one of the largest open pit gold mines in the world using conventional leaching processes for gold recovery. The gold deposit is within the Luise Caldera, an extinct volcanic crater that is geothermally active. Currently the mine’s installed electrical capacity sits at a combined output of 172MW, made up of 22 Wartsila engines. Originally geothermal development played the role of dewatering and depressurization of the mine (for use in processes), however as drilling activities increased and to offset fossil fuel requirements, geothermal exploration began in 2001 with a 6MW pilot plant being brought online in 2003 using 240 - 300°C brine (M. Melaku, 2010). A full scale 50MW facility was commissioned in 2007 and further exploration drilling has proceeded since. All units have operated with high availability of greater than 95%. This has resulted in an estimated CO₂ emissions reduction of roughly 250,000 tons per annum (Newcrest Mining Limited, 2012). This provides recognition that geothermal energy can be delivered to support mining operations and reduce dependency on conventional power plants given the right location.

A geothermal power generation plant was also considered at the Veladero Goldmine in Argentina in 2013 with a proposed capacity of 8 – 14MW using a binary power plant design (low temperature application). This plant would have provided 66 – 100% of the active site’s operational requirements, but a lack of current information leads one to speculate the project never came to fruition, likely due to external economic influences (Richter, 2013).

5.2 Geothermal Ancillary Applications on Active Mining Sites

One example of an older active mine utilizing low-grade geothermal energy for heating was the Henderson Molybdenum Mine in Colorado. Water at about 30°C was used to heat mine air to control working temperatures and prevent equipment from icing in the cold Colorado climate. Geothermal heating allowed for an increase in air temperature of 9.4°C, providing 5.9MW of energy (Jensen, 1983). This provided a very inexpensive source of heat energy. If additional heating was required above the geothermal capabilities, an on-site boiler was available.

Mining activities can also use geothermal brines for direct mineral extraction if they are in the form of concentrated brines. This extraction method has the potential to be more lucrative for certain precious metals, such as lithium, than conventional rock mining. Additionally, geothermal fluids can be used to run desalination plants which will become more important as water shortages become increasingly commonplace world-wide. Given that most mining operations require large volumes of water, desalination facilities could be necessary or even mandated by some governments in the near future. Geothermal desalination processes often use 55 - 99°C fluids to thermally distill seawater (E. Patsa, 2015).
ORMAT offers geothermal clients more of everything that matters when it comes to developing geothermal resources.

We’ve built more than 2,900 MW of capacity in approximately 180 power plants worldwide. We’re experts at using more technologies, including conventional steam, binary, combined cycle and integrated two-level unit technologies. We’ve developed more facilities, in more sizes, from a few kilowatts to hundreds of megawatts. We’re involved in more of the essential steps needed to take a facility from concept to reality; whether it is exploring, developing, designing, engineering, manufacturing, constructing or operating geothermal power plants.

Doing more also means we offer clients more of our in-depth experience as an operator. We’ve learned more about geothermal by operating a global network of geothermal facilities efficiently and profitably; and it is that deeper knowledge we share with our clients. We do more to add value to existing facilities, year after year, by expanding and integrating new technologies to boost efficiency and power output.

More is what ORMAT is all about. Give us a call, we’ve got more to share to make your project excel.

Learn more at www.ormat.com and contact us at +1-775-356-9029 or info@ormat.com
Finally, mineral processing methodologies themselves can be improved with the use of energy from geothermal fluids. One such process is enhanced heap-leaching which recovers minerals from low-grade metal ores that contain uranium, gold, silver or copper. The use of heated fluids can speed up and improve the yields from this process. In Nevada alone, 10 such heap-leaching mining sites exist with near-by geothermal resource capabilities. Two highlighted facilities that have used geofluids are the Round Mountain Goldmine using 82°C fluids with a capacity of 14.1MW and the Florida Canyon Mine using 99°C fluids at 1.4MW (E. Patsa, 2015). Previously, the Freeport Jerritt Canyon Mine and the Gooseberry Mine also utilized similar geofluid-enhanced mineral extraction processes.

5.3 Geothermal Use in Northern Mining Operation

An assessment was recently done by a Canadian engineering firm of the geothermal potential at a northern mining site located within North America with an anticipated mine life in excess of 40 years. The remoteness of the mine resulted in studies for more than 300 km of transmission lines as well as remote site power generation and fuel storage. The potential for geothermal power was identified previously by the Southern Methodist University (SMU) utilizing bottom hole temperatures from existing exploration drill core data, offering a fast and cost-effective method of determining site suitability. Using the available data, an analysis of the site and surrounding area was undertaken to compare the possible costs of geothermal versus on-site diesel or natural gas generation. From the drill core data, it could be inferred that 120 - 150°C could be achieved at depths of roughly 5 km. The conditions at this site were determined to be unfavorable compared to others on a basis of initial capital investment. It was estimated that a geothermal facility would cost more than double that of a diesel power plant, however the benefit in the reduced operating costs would represent a reduction of more than 90% compared to a diesel power plant.

5.4 Geothermal Assisted Power Generation

Another promising application of geothermal is the integration with conventional steam power plants through geothermal pre-heating, more specifically those supplying mining operations. Existing coal fired power plants can increase their overall plant efficiency by installing geothermal pre-heaters for the boiler feedwater (thus increasing overall system efficiency). Conventional feedwater heaters, which use steam extractions from the various steam turbine stages to preheat the boiler feedwater for higher plant efficiency, could be replaced by geothermal feedwater heaters. Geothermal preheaters function similarly to conventional preheaters, except geothermal fluid would circulate through the heat exchangers instead of extracted steam. By reducing the steam extracted, more steam passes through the turbine resulting in a lower fuel demand from the boiler. The number of feedwater heaters that could be replaced depends on the temperature and flow rate of the geothermal source and the plant’s design. Although not all feedwater heaters can be feasibly replaced with geothermal, significant benefits could be realized by the replacement of even one or two.

A model was developed to assess the potential of geothermal pre-heating. An existing 300MW coal fired power plant with a circulating fluidized bed boiler was modelled. The two lowest temperature feedwater heaters were replaced with geothermal pre-heating and the third lowest feedwater preheater benefitted from partial pre-heating using the geothermal source. A representative geothermal source of 175°C was used. A potential increase in gross power of 2% to 3% (9MW) was realized for the same fuel consumption with one-third of the capacity of one geothermal well (approximately 30 kg/s of brine flow).

Geothermal pre-heating is not a new concept. It has been considered since the 1970s, but the high capital cost has been off-putting to investors and owners. However, it is proposed to employ geothermal pre-heating as the first step in a phased implementation approach to a full geothermal power conversion. This approach is attractive to investors as it offers mitigation of major risk, deferred capital expenditure, a more inviting cash-flow and a test period for geothermal technology in operation.
The main benefit of this proposal lies in risk mitigation and evaluation of the technology in operation. By developing only a few wells and subsequently implementing geothermal pre-heating, the quality and availability of the geothermal resource will be confirmed prior to investing the larger upfront cost required for the geothermal power plant. The returns on investment for these wells will not appear attractive when looked at separately from the downstream benefit. The phased approach also allows the owners and operators to evaluate the technology in operation before converting to a geothermal power plant.

6. Conclusion
It is clear geothermal and mining have historically had little engagement between industries due to a lack of economical and practical applications. Recently, the geothermal industry has been working towards reducing costs and expanding exploration and opportunities where previously believed to not be plausible. In conclusion, there are now evident synergies between the geothermal and mining industries which could benefit one-another given the right opportunity. Although it may not be realized the mining industry already plays a large role in front end identification of geothermal resources. As inevitable trends such as climate change and renewable energy continue to drastically change the markets, mines will be looking for solutions that offer the most benefit. It is possible that within the future energy mix, geothermal can play a much larger role.

REFERENCES