Proyecto Fin de Carrera
Ingeniería Industrial

Renewable Energies in the Mining Industry. Estudio de integración de tecnologías de economía baja en carbono (LCE) en planta minera

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El tribunal nombrado para juzgar el Proyecto arriba indicado, compuesto por los siguientes miembros:

Presidente:

Vocales:

Secretario:

Acuerdan otorgarle la calificación de:

Sevilla, 2017

El Secretario del Tribunal

A mi familia, por todo su apoyo a lo largo de estos años.

Al profesor Ricardo Chacartegui, por su guía e infinita paciencia durante el desarrollo de este proyecto

Resumen

La industria minera, como sector primario, se encarga de proveer a otras industrias de los elementos necesarios para realizar todo tipo de productos. Para ello, se le debe suministrar una gran cantidad de energía para poder realizar todas las actividades que componen esta cadena, desde la apertura inicial de la mina hasta el refinamiento y transporte final de los materiales hasta los diferentes solicitantes.

En este proyecto nos centraremos en las posibles aplicaciones de la energía geotérmica en diferentes lugares del mundo y sus condiciones ambientales.

En primer lugar, el proyecto comienza con una revisión de las leyes actuales y la situación de las energías renovables, especialmente en la Unión Europea, y sus expectativas futuras.

El siguiente capítulo analiza las muchas sinergias entre la industria minera y otras industrias, así como la sociedad. Dado que pertenece al sector primario, la principal sinergia estará relacionada con el producto final, cuya disponibilidad y precio tienen una enorme influencia en el siguiente paso de la cadena productiva. Pero también es relevante comentar los usos posibles de los residuos mineros en otras industrias.

Posteriormente, se hace obligatorio describir tecnologías bajas en carbono potencialmente aplicables en lugar de las energías convencionales de combustible. Las tecnologías estudiadas fueron la extracción de energía geotérmica a través del ciclo orgánico de Rankine (ORC), la energía fotovoltaica y, finalmente, una breve descripción de los sistemas híbridos. Además, cada paso del proceso de minería se explicará para obtener la demanda total de energía en los diferentes casos estudiados.

Finalmente, el propósito de este proyecto se muestra en el análisis completo de casos de estudio de diferentes minas en lugares como Arizona, en los EE.UU., Sumatra en Indonesia y Kurgan en Siberia, Rusia. Todos estos lugares tienen condiciones ambientales muy diferentes y potencial para el uso de la energía geotérmica, que nos permite analizar los diversos comportamientos entre estas condiciones.

Abstract

The mining industry, as primary sector, is in charge of providing other industries the needed raw elements in order to perform all kind of products. For that purpose, a high amount of energy must be spent to able every activity that compounds the whole chain,from the initial mine opening to the final material milling and transport to the different petitioners.

In this project we will focus on the possible uses of geothermal energy in different world places and environment conditions.

First of all, the project starts with a review of the current laws and situation of the renewable energies,especially in the European Union, and their future expectations.

The next chapter analiyzes the many sinergies between the mining industry and other industries, as well as the society. Since it belongs to the primary sector, the main sinergy will be related to the final product, whose disponibility and price has a huge influence in the next step of the production chain. But also it is relevant to comment the possible uses of the mining waste in other industries.

Afterwards, it becomes compulsory to describe potentially low carbon technologies instead of conventionally fuel energies. The studied technologies were geothermal energy extraction through the Organic Rankine Cycle (ORC), photovoltaic energy and finally a brief description of hybrid systems. In addition, every step of the mining process will be explaint to obtain the total energy demand in the following case studies.

Finally, the purpose of this project is shown in the complete analysis of case studies of different mines from places such as Arizona, in U.S.A., Sumatra in Indonesia and Kurgan in Siberia, Russia. All of these places have extremely different environment conditions and potential for the use of geothermal energy, that allows us to analyze the diverse behaviors between these conditions.

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Notación

A^*	Conjugado
c.t.p.	En casi todos los puntos
c.q.d.	Como queríamos demostrar
■	Como queríamos demostrar
e.o.c.	En cualquier otro caso
e	número e
IRe	Parte real
IIm	Parte imaginaria
sen	Función seno
tg	Función tangente
arctg	Función arco tangente
sen	Función seno
$\sin^x y$	Función seno de *x* elevado a *y*
$\cos^x y$	Función coseno de *x* elevado a *y*
Sa	Función sampling
sgn	Función signo
rect	Función rectángulo
Sinc	Función sinc
$\partial y\ \partial x$	Derivada parcial de *y* respecto
$x_\circ$	Notación de grado, *x* grados.
$\Pr(A)$	Probabilidad del suceso *A*
SNR	Signal-to-noise ratio
MSE	Minimum square error
:	Tal que
<	Menor o igual
>	Mayor o igual
\	Backslash
⇔	Si y sólo si

1 IDENTIFICATION OF EUROPEAN, REGIONAL AND LOCAL ENERGETIC STRATEGIES AND APPLICATION AT THE MINING INDUSTRY

There is nothing permanent except change

- Heraclitus -

The main topic of this chapter is going to be the description and analysis of the different energetic politics at European and regional level, as well as its future targets, focusing after on the mining industry. In addition, the need of a soon substitution of the energy produced by fossil fuels, whose scarcity in Europe means a huge waste continuously increasing, in favor of renewable ones in order to reduce the greenhouse effect will be profoundly discussed, defending this point of view by the use of examples of techniques already used by important mining companies, as well as the advantages coming from this kind of energy in the whole sector.

Introduction

Lighting, heating, transport, industrial output: without energy we would have none of these essential services without which we and our businesses cannot function. Our stocks of fossil fuels (oil, gas and coal) will not, however, last forever. They need to be judiciously managed while we look into new sources of energy. Europe is consuming, and importing, increasing quantities of energy. Europe's countries are well aware of the advantages of coordinated action in such a strategic field. That has led to common rules throughout Europe and a pooling of Europe's efforts to secure the energy that it needs at an affordable price, while generating the least possible pollution.

Focusing on mining, this is a massive industry involving a diverse range of energy intensive processes such as excavation, mine operation, material transfer, mineral preparation and separation. The local environmental impact of mines, many of which are located in remote areas, has been a topic of concern to environmentalists for many years – and mining companies have worked to address issues such as water quality. The sustainability reports of the major mining companies frequently address the issue of water.

The high energy consumption of the mining industry means that the potential for generationg electricity as a byproduct of the process of mining is an attractive proposition.

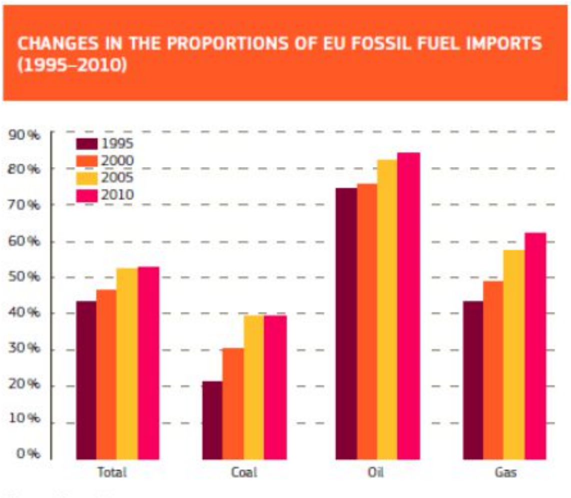


Table 1-1

ENERGY STRATEGY OF THE EUROPEAN COMISSION

Europe depends on the rest of the world for its energy. The European Union, the world's second largest economy, consumes one fifth of the world's energy but has very few reserves of its own. Fortunately, here in Europe, our portfolio — known as the 'energy mix' — is very diverse: from Austria's many dams, Poland's coal mines or France's nuclear power stations to the oil rigs of the North Sea and the gas fields of the Netherlands and Denmark, none of Europe's countries are alike. These countries are able to work together to make the most of their diversity.

Europe's energy dependence has an impact on our economy. We buy our oil from OPEC (Organization of the Petroleum Exporting Countries) and Russia, and our gas from Russia, Norway and Algeria. Europe's coffers are depleted to the tune of over €350 billion every year to pay for it. Energy costs are also continuing to rise. That leaves us with no other option: Europe has to be effective, set ambitious goals and work together if we are to diversify our energy sources and their channels of supply.

Because of Europe's few energy reserves, currently over half of its energy has to be imported. As the price to be paid is decided by world markets, Europe has no choice but to pay up. The only way of cutting our energy bill is therefore to reduce the amount of consumed energy. That may seem obvious. Can we consume less, however, while maintaining our standard of living and our modern conveniences?

Saving energy

Although it is no easy matter, the answer is yes: by using energy in better and more efficient ways. A win-win solution: CO2 emissions can be prevented, we become less dependent on energy imports and it may well be possible to create local jobs and export our expertise. Energy efficiency is therefore one of the European Union's main objectives for 2020. European leaders decided that forecast energy consumption in 2020 needed to be cut by one fifth. Such a substantial cut would be tantamount to turning off the output from over 400 power stations. If it is to achieve its objective, the European Union has to encourage its member countries to stop energy from being wasted by electrical appliances, industry, transport and buildings. Buildings are a key area, as we consume 40 % of our energy in them, 80 % in the form of heat. EU countries are all having to draw up plans to achieve the European energy efficiency objectives. In a climate of economic recession, the European Union has to be imaginative if it is to encourage investment in energy efficiency. Even if that investment is profitable and is soon recouped, the money has to be made available in the first place. The European Union, through its budget and its financial institutions, can help its member countries finance their energy efficiency plans.

A genuine European energy market

In principle, electricity and gas can flow freely though the grids which cross Europe. In a single European energy market, all producers and suppliers are competing with one another. In theory, it is therefore possible to buy and sell electricity and gas wherever you want, the aim being to obtain high-quality energy at the most competitive price. However, this market of 500 million consumers has yet to become a reality, as the development of cross-border energy businesses is still being hampered by a raft of national rules. The prices of gas and electricity for businesses, set by governments, are just one example. Some players even have an unfair privileged access to energy grids. Investors are therefore being put off because the outlook is not very promising. The knock-on effect of that could well be to delay the renewal of power plants that have become too old. Competition therefore needs to be managed in a better way and common rules on the equitable use of grids introduced. The European Union has a paramount role to play here as, if it sets the rules, it also has extensive powers to supervise markets to prevent certain players from unjustly exploiting any kind of monopoly.

Up-to-date energy grids

Energy grids also need to be modernized and developed to cope with the growing demand for energy and to diversify existing resources and make the market more fluid. Over the next 10 years, a massive investment of around €1 000 billion will have to be made in energy grids. The EU can give its Member States a real helping hand here, as it is in all their interests to develop high-voltage lines and gas pipelines connecting them to one another, and to store energy. Not only does that promote trade, it also promotes solidarity were demand to outstrip supply within Europe's borders.

High-voltage electricity grids, built originally to connect the large electricity power stations to their neighboring consumer areas, must also be connected up to further-flung power stations intermittently generating electricity from renewable sources. Lastly, distribution grids must make it possible to use electricity in a more flexible way so that peaks in demand can be better managed and must allow for individual micro-generation (solar panels for instance).

It still takes too long, however, to obtain the permits needed for grid projects. The European Union should therefore encourage the development of energy grids by laying down priorities at European level, speeding up the construction of any 'missing links' and modernizing grids, especially in eastern Europe. The role of the European Union should not just be one of overall coordination, as it should, in some cases, help out with certain projects that are essential but involve too many economic risks.

Consumers are central to concerns

All that has one ultimate aim: to benefit consumers, whether they are individuals or small or large businesses. Consumers have rights and must be better informed about them if they are to make the most of the opportunities offered by the internal energy market. For instance, they should be able readily to switch supplier, they should receive straightforward bills and offers that can be compared, they should be able to find out where their electricity has come from and they should be able to find out about their consumption at any moment. Information technology and telecommunications are set to occupy an increasingly important place in the energy sector as a way of involving consumers more proactively in the energy market. Only Europe-wide regulation will place all consumers on an equal footing and enable them to benefit from the economies of scale achieved by the sector. Europe must therefore introduce the necessary regulations, especially as regards the protection of data from meters. Consumers must also be able to buy energy-saving appliances and be informed about their actual consumption so that they have all the information at their fingertips before making a purchase. Businesses must also be able to buy their energy in as secure a way as possible from the place in which it is cheapest. Only real competition can pave the way for fair prices that are not artificially high or too low to encourage investment in energy generation.

Safety: an issue for Europeans

Europeans need to know that European energy policy is ensuring safe energy generation and transport. EU governments are aware of the advantages of Europe-wide coordination or even harmonization of the safety standards for critical power plants. The Fukushima accident in Japan has shown how important nuclear safety is. The European Union must therefore set the highest possible safety standards for European nuclear power stations and the management of nuclear waste. Set at European level, European standards to protect the population and nuclear-sector workers against radioactive radiation now apply throughout Europe. Lastly, Europe must be able to continue to guarantee that trade in uranium within its borders fuels neither trafficking nor the proliferation of nuclear weapons. All these rules may provide a template for the world as a whole. In the case of other power plants, such as offshore gas and oil plants, steps have to be taken to prevent any repeat off Europe's coasts of the disastrous oil slick in the Gulf of Mexico in 2010.

Leaders in low-carbon technology

There will have to be a technological revolution in Europe if its energy is to be generated without emitting CO2. In March 2008, the European Union therefore approved a strategic plan for low-carbon energy technologies. The aim is to rally industrialists in the sectors concerned to work together while benefitting from the support of the European Union. Some industrial initiatives are focusing on energy generation and sources such as biofuels, wind, solar and nuclear power, as well as fuel cells and the use of hydrogen. Others are geared towards better energy management in 'smart cities', underground CO2 capture and storage and the electricity grids of the future. The aim is to make these new technologies affordable and profitable so that current technologies can ultimately be replaced and CO2 emissions reduced in the European energy sector. The huge finances involved mean that this goal can be achieved only by a Europe-wide coordinated effort: it is estimated that €50 billion will have been channeled into the European plan by 2020.

Energy diplomacy

Europe, the world's largest regional market, has to assert its interests in the international arena in order to ensure that its supplies of energy are secure. When you are so big but so dependent on the outside world, you cannot just leave matters to take their own course — especially at a time when the world race for energy resources is speeding up. The problem is that the European Union has always found it difficult to speak with a single voice when it should be presenting a united front and bringing all its weight to bear on the leading energy producing and consuming countries. Europe must first make sure that its neighbors serve its energy interests, not just for the purposes of secure transport of energy from its gas and oil suppliers, but also as a way of extending its energy market. Energy also has to be part of European external policies: development aid, trade and bilateral cooperation agreements. That is also a way of supporting exports of cutting-edge European technologies.

Democratic decision-making

European energy policy matters to all Europeans. European legislation has a major impact on national legislation, especially in the energy field. The European Parliament (elected every 5 years by Europeans) and the Council of Ministers of the European Union (representing member governments) jointly adopt European energy legislation, except for legislation on nuclear power and energy taxation which the Council of Ministers adopts on its own. National governments are involved at an early stage in drawing up European law, via committees of national experts. Professional organizations and civil society take part in this transparent process, as their opinion is sought during various consultation stages — that is, if they haven't already made their views clear!

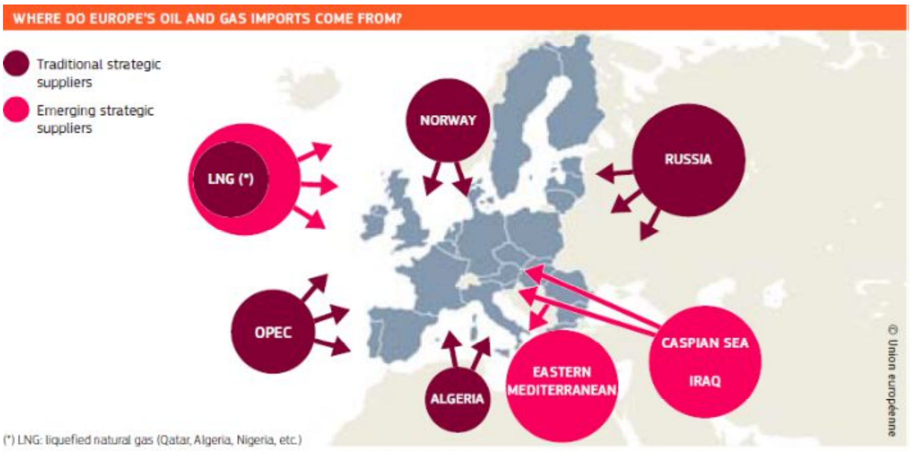


Figure 1-1

Empowering consumers and stimulating the energy sector

The EU is providing European consumers with an unprecedented level of protection: protecting vulnerable consumers, stepping up the regulatory powers of supervisory authorities and their ability to impose sanctions and making bills clearer. The real revolution lies, however, in the ‘smart’ meters and grids that the European Union hopes will make consumers more proactive. Not only will bills be based on actual consumption, but consumers will also be able to find out about their consumption at any moment and take steps to improve it. The European Union is introducing the necessary safeguards to ensure respect for privacy and for the information gathered from smart meters.

From the point of view of information, energy performance labeling, brought in by the European Union, means that purchasers of electrical appliances now have all the information they need at their fingertips. This kind of labeling is now being extended to many domestic electrical, office and other products. It has encouraged manufacturers to offer more energy saving products, helping to reduce bills, as the real retail price of a product does not just include its purchase price but also the cost of using it.

Cutting energy bills

The end of the monopolies in the electricity and gas markets means that all consumers are free to choose their energy suppliers. A recent study has estimated that over €13 billion, i.e. €100 per household per year, could be saved by switching electricity and gas supplier. Businesses were the first to be able to choose their electricity and gas suppliers. Energy accounts for a substantial proportion of the production costs of both large and small businesses in Europe’s main industries. Competition between energy suppliers has extended what is on offer, improved the overall quality of the service and kept prices as competitive as possible.

To back this up, national authorities, commonly known as energy ‘regulators’, have been established by the European Union. Their task is to police the system and represent the interests of the public and therefore consumers. They have extensive powers to punish anti-competitive practices and help consumers to make the best possible choices. The regulators set energy transport tariffs as fairly as possible so that grid operators receive a proper income and are encouraged to invest, without any major increases in final consumers’ bills. Energy prices will not necessarily go down, however, as they depend to some extent on world oil prices which are impossible to control. The only real way of reducing your energy bill is therefore to reduce what you consume. If European energy-saving goals are achieved in 2020, that will mean a yearly saving of €1 000 for every European household.

Securing Europe’s energy supplies

Although major electricity cuts are now rare in Europe, that is to some extent due to the cooperation between grid operators set in motion by the European Union. However, 50 % of Europe's gas is imported, in some cases from very far away. A breakdown in supply for reasons over which it has no control may have serious consequences. In the event of shortages, the European Union has a very comprehensive solidarity mechanism through which oil and gas stocks can be accessed. Prevention is nevertheless better than a cure: it has set up its own energy market observatory and even introduced an early warning mechanism with Russia.

Stimulating the energy sector

Competition between electricity and gas operators has shaken up the energy sector. New trades have emerged (traders, consultants, auditors) and the sector is increasingly drawing on information and communications technologies. New operators have broken into national markets and many now have a European dimension. Winning over new customers requires innovation to create new products, at a competitive price, and therefore greater efficiency. The European Union has introduced incentive and priority measures to promote new sources of energy in electricity generation, in biofuel and heat production and even in combined electricity and heat generation.

The boom in renewables

Europe has set itself an objective: one fifth of the energy consumed in the European Union in 2020 should come from renewable sources. Promotion throughout Europe has led to a spectacular increase in the production capacity of renewable sources, with conventional power stations lagging some way behind. The cost of solar panels has fallen by 50 % over the last 5 years. In 2009, the industrial renewables sector was already worth €70 billion and employed over half a million people in Europe. And that is set to continue, as renewable sources are at the core of Europe's long-term energy strategy because they make it possible to cut greenhouse gas emissions and reduce energy imports. This booming economic sector leaves no doubt that Europe is leading the way in the new energy technologies, providing Europe with 'green' jobs and high added-value exports.

Energy efficiency: a promising market

Research into greater energy efficiency is stimulating growth. Insulating homes, installing new energy-saving equipment, refurbishing buildings, carrying out audits: they all create economic activity. Two million jobs could be created by 2020 if Europe's energy-saving objectives are achieved. With a return as well! With a yearly investment of €24 billion in insulation and energy management and control systems, for instance, the European energy bill could be cut by some €38 billion between 2011 and 2020.

From now on, energy suppliers will also have to deliver energy savings for their customers. The energy service company business model will need to be rolled out throughout Europe. Companies like this are tasked with supplying energy services (lighting, heating, air conditioning, electricity supply) on condition that they invest in high-performance equipment and reap their rewards from the energy savings that they achieve.

In the case of appliances, Europe is giving consumers the option to replace their current appliances. It is lowering energy consumption standards for a whole range of appliances, from their design to the end of their life: televisions, refrigerators, dishwashers, washing machines, fans, freezers, lamps, etc. The most radical change, which will not have escaped anyone in Europe, has been to put a stop to the production of conventional light bulbs, which have been replaced by energy-saving light bulbs. These bulbs may use up to five times less energy. Overall, between €5 billion and €10 billion will be saved and channeled back into the economy.

The Energy Star logo that you see on your office equipment is visible proof that the European Union is encouraging the sale of energy-efficient products. Since 2001, under this agreement with the US, it has been possible to showcase the good energy efficiency of products (computers, photocopiers, printers, monitors). This information offers the public authorities a valuable guideline when making bulk purchases.

Combating climate change

Europe has undertaken, in international climate talks, to reduce its greenhouse gas emissions by 20 % of 1990 levels by 2020 and to increase that figure to 85 % or even 95 % by 2050. Most of that reduction will have to come from the energy sector, as it accounts for 80 % of the European Union's greenhouse gas emissions. If Europe manages to achieve its renewable energy and energy efficiency objectives by 2020, it would then be able to exceed its current goal of a 20 % reduction of greenhouse gas emissions from 1990 levels and achieve a 25 % reduction in 2020.

All decision-making levels are involved in implementing European energy and climate policies, be they local, regional, national or European. For instance, the European Union launched the Covenant of Mayors initiative in 2009. Signatory towns and cities undertake to exceed the European objectives. There are currently 4 000 signatories, representing over 160 million inhabitants and offering a potential CO2 reduction of 164 million tones, the equivalent of total emissions from Hungary, Sweden and Portugal.

Europe's place on the world stage

The European Union has set up a permanent dialogue on energy issues with its main suppliers — Russia, OPEC, Norway and the Gulf States — and with other countries or regions playing a part on the world energy stage — the United States, Africa, Brazil, India, China and the Mediterranean. Europe has launched many cooperation and aid programs in the energy field throughout the world. The European Union speaks with a single voice within organizations such as the International Energy Agency (IEA), the International Atomic Energy Agency (IAEA) and the International Energy Forum (IEF). Europe has signed up to the Sustainable Energy for All initiative launched in 2011 by the UN to help a further 500 million people in the developing countries to gain access to sustainable energy by 2030. Closer to its borders, the European Union has signed an energy community treaty in order to extend the rules of its internal energy market to 10 or so countries of south-east Europe. Europe also has a structured neighborhood policy with the countries between the EU and Russia, covering energy issues and, in particular, energy transit grids.

To meet the future challenges posed by energy, Europe is taking part in a number of large-scale international projects including ITER, the experimental nuclear fusion reactor being built at Cadarache (France). It is also taking part in the international research project on nuclear reactors of the future (Generation IV).

2020 AND BEYOND: FUTURE CHALLENGES.

Throughout the world, we shall all have to come to terms with a new situation in future: increasingly difficult access to the planet's mineral resources. Oil will be much more expensive and much more difficult to extract. While new oil and gas reserves (shale oil and gas) may well exist, there are many environmental constraints on their extraction. More and more energy will be needed to mine raw materials, as the mineral content of mines will continue to decrease. Lastly, some countries such as China already have a quasi-monopoly over the production of rare metals, a must for high-tech industries. Europe will have to put all its weight into complex negotiations if it is to get the Caspian Sea gas resources across its borders. Access to energy sources will be increasingly dependent on geopolitical considerations. This new world situation will make it impossible to put off a radical rethink of Europe's energy supply security.

2020 ENERGY STRATEGY

By 2020, the EU aims to reduce its greenhouse gas emissions by 20%, increase the share of renewable energy to at least 20% of consumption, and achieve energy savings of 20% or more. All EU countries must also achieve a 10% share of renewable energy in their transport sector.

Through the attainment of these targets, the EU can help combat climate change and air pollution, decrease its dependence on foreign fossil fuels, and keep energy affordable for consumers and businesses.

In order to meet the targets, the 2020 Energy Strategy sets out five priorities:

Priority 1: Achieving an energy-efficient Europe

Action 1: Tapping into the biggest energy-saving potential — buildings and transport

– The energy efficiency renovation rate should be accelerated by investment incentives, wider use of energy service companies, innovative financial instruments with high leverage factors and financial engineering at European, national and local levels. In this context, division of investment incentives between owners and tenants and energy labeling of buildings (certificates used in the real estate market and public support policies) will be addressed in forthcoming proposals by the Commission.

– Public authorities need to lead by example. Energy criteria (regarding efficiency, renewables and smart networking) should be used in all public procurement of works, services or products. Programs and technical assistance facilities are needed that build the capacities of energy services market participants to develop and structure finance for projects that target both public authorities and private actors. EU financial programs will target energy savings projects and make energy efficiency a strong condition for allocating financial support.

– The forthcoming White Paper on future transport policy will present a menu of measures to improve transport sustainability and reduce oil dependence. This will include initiatives aimed at increasing the energy efficiency of the transport system, including support for clean urban mobility as well as multimodal transport solutions, intelligent traffic management and energy efficiency standards for all vehicles, adequate economic signals and the promotion of sustainable behavior. In this context, more efficient car-labeling systems should be explored.

Action 2: Reinforcing industrial competitiveness by making industry more efficient

– The Commission will seek to support European industries' competitiveness through energy efficiency by widening the Eco-design requirements for energy and resource-intensive products complemented by system level requirements where relevant. The potential effect of voluntary agreements with energy and resource-intensive industry branches should be explored. More extensive energy labeling should be introduced to ensure more comprehensive comparison between products.

– Energy management schemes (e.g. audits, plans, energy managers) should be implemented in industry and in the services sector. A particular emphasis on SMEs through dedicated support mechanisms should be established.

Action 3: Reinforcing efficiency in energy supply

– Energy efficiency, in both production as well as distribution, should become an essential criterion for the authorization of generation capacities, and efforts are needed to substantially increase the uptake of high-efficiency cogeneration, district heating and cooling.

– Distribution and supply companies (retailers) should be required to secure documented energy savings among their customers, using means such as third-party energy services, dedicated instruments such as ‘white certificates’, public benefit charges or equivalent and speeding up the introduction of innovative tools such as ‘smart meters’ which should be consumer-oriented and user-friendly so that they provide real benefits for consumers.

Action 4: Making the most of National Energy Efficiency Action Plans

– The National Energy Efficiency Action Plans provide comprehensive benchmarking on energy efficiency, including measurable objectives and indicators to monitor progress, taking into account the relative starting positions and national circumstances. An annual review mechanism should feed into the Europe 2020 objective for energy efficiency.

Priority 2: Building a pan-European integrated energy market

Action 1: Timely and accurate implementation of the internal market legislation

– The Commission will continue to ensure correct and timely implementation of the existing internal energy market and a forceful competition policy. For further integration of the energy market, the regulatory framework needs to be consolidated (e.g. network codes), complemented by other actions such as market coupling, target model development and a robust framework for traded markets through effective transparency and oversight. If these measures prove not to be sufficient or ACER’s remit too narrow, further legislative measures will be envisaged.

Action 2: Establishing a blueprint of the European infrastructure for 2020-30

– The Commission’s forthcoming infrastructure communication will allow Europe to identify priority infrastructure to be deployed in order to have a functioning internal market, ensure integration of large-scale production of renewables and guarantee security of supply, in line with the vision for a sustainable European energy system by 2050. By 2015, no Member States should be isolated from the European internal market. Cross-border corridors will also be covered. The 10-year network development plans of ENTSO-E and ENTSO-G will be taken forward with the help of ACER, together with all other relevant stakeholders. This exercise will build on successful regional initiatives such as the one in the Baltic region and will also include an assessment of the necessary storage facilities and climate adaptation measures, including possible future needs for CO2 transportation infrastructure in the EU.

– The Commission’s proposal also aims at preparing the grid for the inevitable changes in demand which will ensue from energy and transport policies, such as electro-mobility and an increase in decentralized as well as large-scale renewable power generation.

– A set of policy tools will be proposed by the Commission next year to implement strategic infrastructure priorities in the next two decades. They will include a new method for defining the strategic infrastructures which will be essential for the European Union as a whole in terms of competitive energy provision, environmental sustainability and access to renewables as well as security of supply. These vital sections will be clearly identified in the overall mapping exercise and awarded a label of ‘European interest’ so that they can benefit from an improved permitting procedure and concentrated funding if necessary. Selectivity will be of the essence in this work. Network connections with third countries will be duly taken into account.

– ACER, ENTSO-E and ENTSO-G will be given a mandate to develop the blueprint of European electricity and gas grids by 2020-30. This should be followed by a longer-term vision on the basis of the energy 2050 roadmap to be presented in 2011.

Action 3: Streamlining permit procedures and market rules for infrastructure developments

– The Commission will propose to introduce a permitting scheme applying to projects of "European interest" to improve the current process through, for example, the nomination of a single authority at national level, while respecting safety and security standards and ensuring full compliance with EU environmental legislation. The streamlined and improved procedures will provide for more transparency and ensure open and transparent debates at local, regional and national level to enhance public trust in and acceptance of the installations. In addition, ways of positively rewarding, through enhanced access to public fund regions and Member States that constructively engage and succeed in facilitating the timely construction of projects of European interest will be explored.

– To establish market coupling by 2014, ACER will, within the scope of its mandate, ensure the definition and implementation of all necessary technical (harmonization, standardization, etc.) and regulatory issues linked to the interconnection of networks across borders; access to renewables; and the integration of new technologies. A detailed program of action will be presented accordingly to assist the Member States in the process of rolling out smart metering/smart grids (including the issue of display of information for consumers) and encouraging new energy services.

Action 4: Providing the right financing framework

– Acknowledging the fact that most of the infrastructure development is of a commercial nature, a methodology will be defined by the Commission to analyze the optimum balance between public and private financing (on the following principles to be applied across the Union: 'user pays', 'beneficiary pays' - in terms of cross-border cost-benefit allocation, and 'tax payer pays' - burden-sharing for commercially non-viable and 'EU-wide benefit' infrastructure). This will be defined in accordance with applicable state aid rules. For projects of 'European interest' which have no or poor commercial viability, innovative funding mechanisms will be proposed for maximum leverage of public support to improve the investment climate for the coverage of main risks or to speed up project implementation. The development of proper energy infrastructure is critical and urgent; it requires a broader view of new funding instruments (both public and private) as well as the mobilization of additional resources under the next multi-annual financial framework.

Priority 3: Empowering consumers and achieving the highest level of safety and security

Action 1: Making energy policy more consumer-friendly

– Active competition policy enforcement at European and national levels remains indispensible to foster competition and guarantee that consumers have access to energy at affordable prices.

– The Commission will propose measures to help consumers better participate in the energy market in line with the third energy package. These measures will include the development of guidance based on best practice in the area of switching suppliers, the further implementation and monitoring of billing and complaint-handling recommendations, and the identification of best practices in alternative dispute resolution schemes. A price comparison tool based on a methodology to be developed by energy regulators and other competent bodies should be available to all consumers, and all suppliers should provide updated information on their tariffs and offers. Finally, further efforts should be aimed at moving focus from energy prices to energy costs by developing the market for energy services.

– The Commission will publish regular benchmark reports assessing the level of implementation of the regulatory provisions relating to consumers and the overall level of protection across the internal market. Particular emphasis will be given to vulnerable customers and to practices which enable consumers to reduce energy use.

– Efforts to improve the functioning of the retail market should be stepped up by regulatory authorities with the help of the London Citizens' and the Sustainability (Bucharest) To the.

Action 2: Continuous improvement in safety and security

– The safety conditions of offshore oil and gas extraction are being reviewed by the Commission in the light of the Deepwater Horizon accident, with the aim of introducing stringent measures from prevention to response and liability issues which will guarantee the highest level of protection throughout the EU and the rest of the world.

– The legal framework for nuclear safety and security will be further enhanced through the mid-term review of the Nuclear Safety Directive, the implementation of the Nuclear Waste Directive, the redefinition of the basic safety standards for the protection of workers and the population, and a proposal for a European approach on nuclear liability regimes. Greater harmonization of plant design and certification at the international level should also be actively pursued. All these measures should allow the EU to keep its leadership in safe nuclear energy and contribute to responsible use of nuclear energy worldwide.

– The same security and safety considerations will also be upheld in the development and deployment of new energy technologies (hydrogen safety, safety of CO2 transportation network, CO2 storage, etc.).

Priority 4: Extending Europe's leadership in energy technology and innovation

Action 1: Implementing the SET Plan without delay

– The Commission will reinforce the implementation of the SET Plan, in particular the Joint Programs of the European Energy Research Alliance (EERA) and the six European Industrial Initiatives (wind; solar; bio energy; smart grids; nuclear fission; CCS). Work will intensify with Member States to finance the activities of the Technology Roadmaps for 2010-20 and to ensure the success of related large-scale demonstration programs such as under the New Entrants Reserve (NER300) program. Available Community funding will be concentrated on the SET Plan initiatives.

– The Technology Roadmaps of the European Industrial Initiatives for 2010-20 are being implemented from this year on and will be given additional support. They will be the cornerstone for the preparation of the next financial framework as regards a consolidated, regularly assessed, more efficient and focused energy research program. In this context, the Commission will promote the development of strategic energy research infrastructures in Europe as they strongly contribute to the shortening of the distance between research and technological development. It will also pursue other avenues with great potential, such as marine renewable energy and renewable heating and cooling.

Action 2: The Commission will be launching four new large-scale European projects

– The Commission will take forward a major European initiative on smart grids to link the whole electricity grid system, from the offshore wind farms in the North Sea, solar plants in the South and existing hydro-electric dams, to individual households, while making power networks more intelligent, efficient and reliable.

– Re-establishing Europe's leadership on electricity storage (both large-scale and for vehicles). Ambitious projects will be developed in the fields of hydro capacity, compressed air storage, battery storage, and other innovative storage technologies such as hydrogen. These will prepare the electricity grid at all voltage levels for the massive uptake of small-scale decentralized and large-scale centralized renewable electricity.

– Implementing large-scale sustainable biofuel production, including in the light of the ongoing review concerning the impact of indirect land use change. The €9 billion European Industrial Bioenergy Initiative will be launched shortly to ensure quick market uptake of sustainable second-generation biofuels.

– Providing cities, urban and rural areas with ways of making greater energy savings. The 'Smart Cities' innovation partnership to be launched early 2011 will bring together the best from the areas of renewable energies, energy efficiency, smart electricity grids, clean urban transport such as electro mobility, smart heating and cooling grids, combined with highly innovative intelligence and ICT tools. EU regional policy can play an important role in unlocking local potentials. Rural areas also have a significant potential in this respect and could make use of the EARDF that provides financial means to support such innovation projects.

Action 3: Ensuring long-term EU technological competitiveness

– In order to lay the foundations of our future competitiveness in the face of strong international competition, the Commission will propose a €1 billion initiative to support the frontier research needed to deliver science necessary for low-carbon energy breakthroughs.

– EU leadership must also be maintained in the global flagship research project ITER. The Commission will ensure effective governance (including cost containment) and industrial value creation from ITER and the European fusion program.

– The Commission will develop an EU research program for energy materials, allowing the EU energy sector to stay competitive despite dwindling rare earth resources.

Priority 5: Strengthening the external dimension of the EU energy market

Action 1: Integrating energy markets and regulatory frameworks with our neighbors

– The Energy Community Treaty should be implemented and extended to all those EU neighbors who are willing to adopt the EU market model. In this context, market integration and regulatory convergence should be pursued through comprehensive EU agreements based on EU rules in the countries covered by the European Neighborhood Policy and the Enlargement process, in particular in the Mediterranean region and with transit countries such as Ukraine and Turkey. Moreover, the Energy Community Treaty should be deepened by extending the new acquis to the signatories to the Treaty. This approach would strengthen the participation of neighboring countries in the internal market, while providing a level playing field and a safeguard against the risk of carbon leakage through the power sector.

– Mechanisms will be proposed by the Commission to align existing international agreements (notably in the gas sector) with the internal market rules and to strengthen cooperation between Member States for the conclusion of new ones. Proposals will also be made to set the required regulatory framework between the EU and third countries to develop strategic routes from new suppliers, notably around the southern corridor and the Southern Mediterranean. Supply issues, including network development and possibly grouped supply arrangements as well as regulatory aspects, notably concerning the freedom of transit and investment security, would be covered.

– EU technical assistance will be mobilized for the effective implementation of the internal market acquis and the modernization of the energy sector in neighboring countries, while improving the coordination of support schemes provided by the EU, its Member States and the international community.

Action 2: Establishing privileged partnerships with key partners

– While pursuing diversification of import sources and routes, reinforced energy partnerships will be established by the EU with key suppliers and transit countries. They will be aimed at promoting key principles such as those contained in the Energy Charter Treaty (for example the freedom of transit, transparency, safety, investment opportunities as well as compliance with international law).

Action 3: Promoting the global role of the EU for a future of low-carbon energy

– Energy efficiency, clean technologies and safe and sustainable low-carbon energy should be integrated into EU and bilateral cooperation activities, particularly with major consumer and emerging economies and with global partnerships.

– The Commission will launch a major cooperation with Africa on energy initiatives in order to progressively provide sustainable energy to all citizens, in line with the Green Paper on Development Policy.

Action 4: Promoting legally binding nuclear-safety, security and non-proliferation standards worldwide

– The Commission will develop initiatives aiming at encouraging partner countries to make international nuclear safety, security and non-proliferation standards and procedures legally binding and effectively implemented around the globe, in particular through reinforced cooperation with the International Atomic Energy Agency and the conclusion of Euratom agreements with key nuclear suppliers and user countries.

APPLICATION IN MINING INDUSTRY

The mining industry is a major energy user and mining companies are increasingly focusing on both energy efficiency measures and cost effective ways of generating power – including fuel cells.

Access to reliable and cost-effective forms of energy is a strategic priority for the global mining sector.

The mining industry has traditionally relied on conventional fossil-based fuel sources (diesel, oil, coal and natural gas) to meet its growing energy demand. The industry is now tasked with responding to the challenges of increasing fuel prices while commodity prices tighten, resulting in ever-narrowing operating margins and increased opposition from communities to new conventional energy sources.

- The mining sector is expanding into new and often remote locations as a response to increasing demand from growing emerging markets. This often means having to deal with unreliable power supply from the grid and uncertain power prices. In most instances, grid-connected electricity needs to be supplemented with on-site generation, typically large-scale diesel generation, resulting in a dependency on diesel fuel. The more remote the mine, the more likely off-grid power solutions are required.

- The sector is experiencing volatility in commodity prices and rising fossil fuel prices, placing margins under pressure. With global demand for energy set to increase 36% by 2035, the industry faces greater energy price increases and volatility. Managing costs sustainably is a priority for the sector.

- The mining sector is facing growing demand from governments, customers, communities and other key stakeholders to operate in a sustainable manner. Doing so has a growing influence on the mining industry's "social license" to operate.

Many of the world's largest mining companies are evaluating greater use of renewable energy plants (a trend set to intensify rapidly) as part of a broader strategy to lock in long-term fixed electricity prices and availability while minimizing exposure to regulatory changes, market pricing and external fuels.

Renewable energy-strategic role

Site-appropriate renewable energy solutions provide cost-competitive energy while delivering greater energy supply reliability and consistency.

Reliable access to cost-efficient energy sources is a strategic imperative for mining companies. It is essential to their bottom lines and increasingly, their licenses to operate. In parallel, the sector is challenged with meeting growing demand for mineral resources often located in countries and sites where the supply of energy is not always available, reliable or cost-effective.

The transformation of the mining sector is driven by a number of strong converging trends, including:

- Energy security concerns
- A recent history in most countries of rising and volatile energy prices, coupled with a consensus that such trends will continue over the medium-to-long term
- The shift to a resource-efficient and low-carbon economy that will ensure community acceptance In response, the international mining sector is deploying innovative energy-saving strategies and making substantial industry-wide direct investments into renewable energy infrastructure.

At the heart of recent innovations in corporate mining energy strategies lie the construction and acquisition of renewable energy-generating assets, on- and off-site, and the direct contracting for renewable energy through power purchase agreements.

Renewable energy plants can be developed, funded, built and operated by third-party developers as captive plants, with the mine committing to purchase the generated electricity at a fixed price over a certain time period.

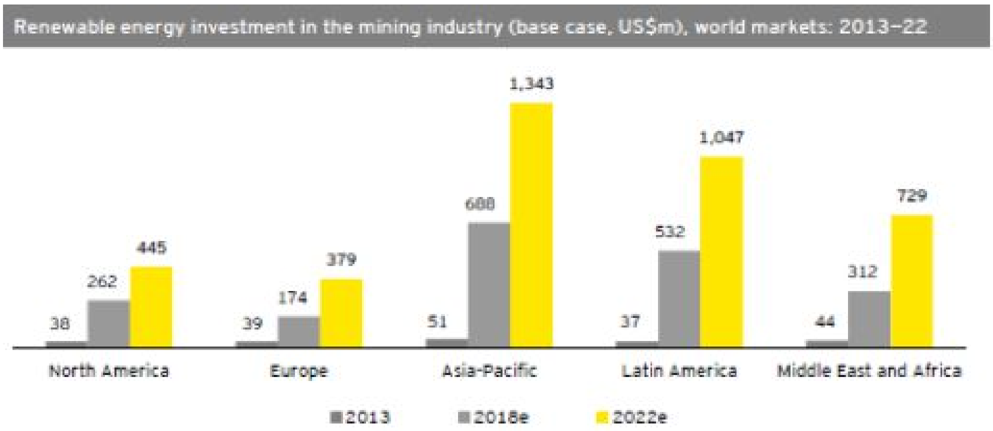


Table1-2

Saving energy in the mining sector: regional and local perspective

The mining companies typically appear to pay only limited attention to cost levels in boom times. The case for implementing energy efficiency measures has received a boost with the onset of the global recession and corresponding decline in commodity prices. And it is an issue in regions where there is a shortage of energy. Mines in northern Chile have reduced power consumption to avoid the introduction of rationing, so energy security is clearly rising up the agenda as an issue – but typically regulatory pressure is a much stronger driver for mining companies to take action than economics.

In discussions with mining and mineral processing companies it became apparent that they are facing common problems as they attempt to do more using less energy. The challenge for mining and mineral processing companies is that they currently don’t have sufficient information to make decisions to reduce energy (identify EEOs), or forecast energy use accurately.

Complex energy forecasting tools are available to better forecast energy use, but don’t take into account the context of excess energy use, or the historical and future production data, therefore not delivery accurate forecasts.

Mining and mineral processing companies are investing in meters and enterprise Energy Management (EM) software to monitor and visualize/report on energy use. Providing information on energy use is only partially solving the problem of determining new opportunities to reduce energy use, and in turn comply with EEOs. Along with energy use, information’s required on what is actually happening in the plant at the time, in other words there has to be context supporting the energy use. For example near real time information like kWh/tone or kWh/ounce of production.

Mining and mineral processing companies tend to have information systems that provide production and delay accounting (downtime) information, but do not combine or integrate with energy systems to provide more useful information. This level of information provides accurate forecast models and perhaps new EEOs. Production and downtime are obviously key factors in energy use, therefore integrating production and energy systems have potential benefits.

The integration of Energy Management (EM) with Manufacturing Execution Systems (MES) can be given the general term Production Energy Optimization (PEO).

The key problem that these companies face is timely access to accurate energy information. They either:

do not have the information available at all *(example: either it is not captured, or a manual process and not available to everyone)*,

the information is not granular enough *(example: there is insufficient power information for the entire facility)*, or

provide information that is isolated and has no context in with which it was used *(example: energy figures do not link to what was actually happening in the plant).*

Added to this, is the lack of ability to accurately forecast energy use. Both under and over forecasting energy use often results in financial penalties from utility companies or dedicated energy providers.

There is sufficient evidence to support the capacity for mining and mineral processing operations to reduce their energy use. The two following graphs from the US Department of Energy certainly indicate the opportunity exists.

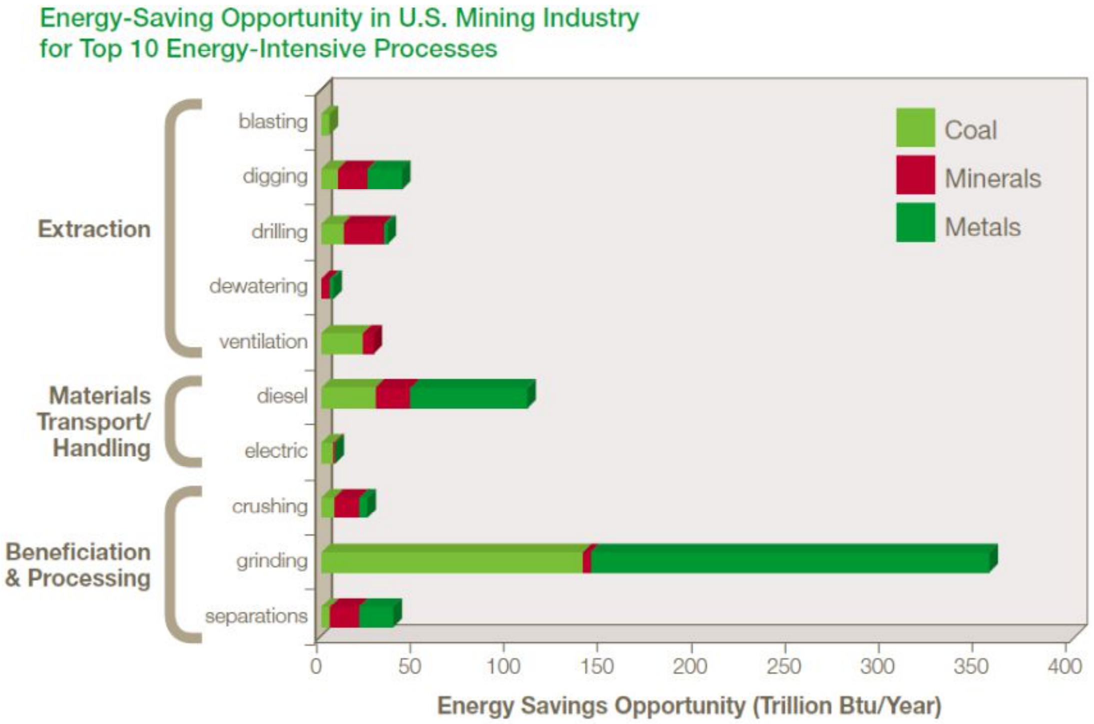


Figure 1-2

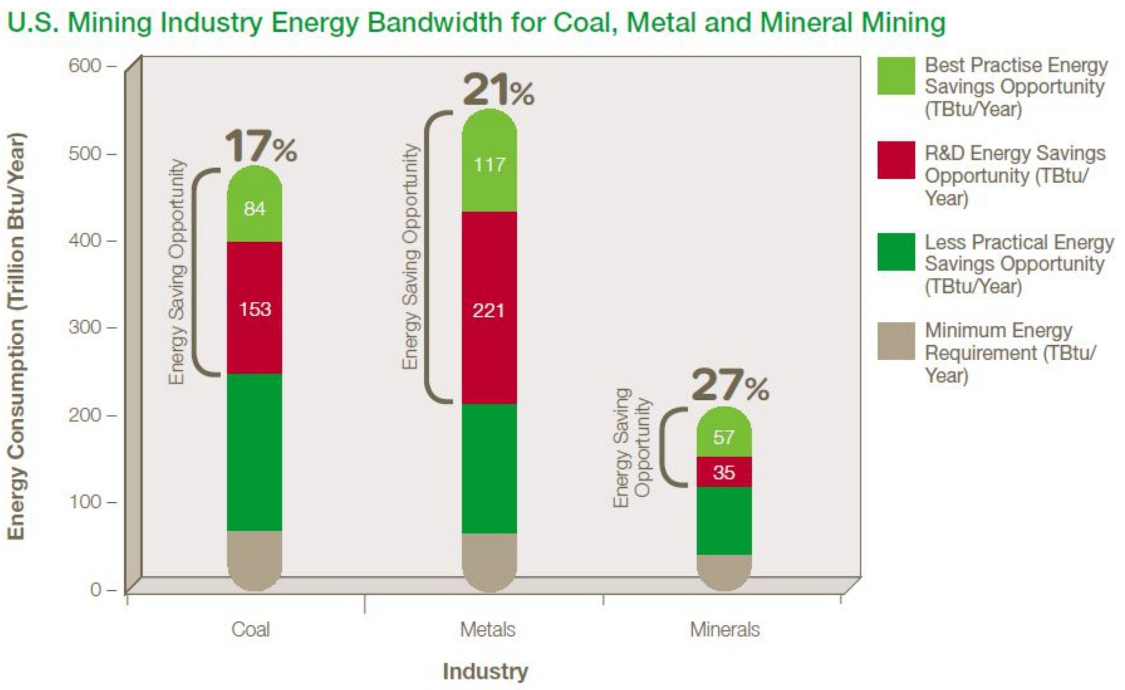


Figure 1-3

Whatever the drivers, a host of companies are committing to implement energy efficiency measures.

AngloGold Ashanti promised in 2008 to cut the energy used in producing an ounce of gold by 15% in the short to medium term. It has focused on reducing compressed air consumption at its deep underground South African operations, and has achieved a 30% reduction in compressed air use since 2004 using technologies including off-peak pressure reduction, optimal compressor scheduling and leak repair strategies.

Anglo Platinum and Gold One, meanwhile, have been using water rock drills, which consume less energy than compressed air drills, since 2008, according to pump manufacturer Cemo Pumps, which supplies the Crown V4 micro hydropower system.

Lonmin has identified energy security as a key issue, in the context of energy shortages faced by South African mining industries. To address energy security, Lonmin has set a target to improve its energy fficiency by 10% by 2012, based on 2007 efficiency levels.

Rio Tinto is developing the Mine of the Future, a robotic mine at the West Angelas iron ore mine in Pilbara, Australia. The mine will rely more on remote controlled equipment and is developing energy efficient solutions. Rio Tinto is developing mining technology jointly with GE through the latter's Ecomagination program and has collaborated with the Rocky Mountain Institute to reduce energy use.

Technology developments are facilitating the introduction of energy efficiency measures in the mining industry. In exploration, developments include non-invasive technologies such as remote sensing, which can minimize exploratory digging and drilling. In excavation, new technologies include the use of adjustable speed drives (ASDs) in applications with highly varying load requirements.

Companies working on innovations for the mining industry include Siemens VAI, which has developed drive technology for rolling mills, alternating-current drive systems for the heavy trucks used in opencast mines (which ensure that diesel engines run within their optimal speed ranges) and gearless drive (GD) systems. Energy saving motors have been mandated in the US, China, Canada and Australia, and Siemens VAI has developed low-speed applications, such as grinding mill drives, mine winder drives, bucket chain excavators and drag chains. The company argues that, if every electrical drive worldwide was brought up to the latest technology standards, the annual energy savings would be in the region of 130 TWh (financial cost: €9 billion). In 2008 Siemens introduced conveyors equipped with variable frequency drives to open pit mines owned by Neyveli Lignite Corporation, in Tamil Nadu, India - the first project in India to be equipped with variable frequency drives.

Siemens is also working on applications involving pumps, condensers, conveyors and refrigeration, and measures such as the replacement of mechanical throttles with frequency converters. In applications where large loads are moved or where a lot of braking energy is needed (hoisting devices, rolling routes, conveyor belts, etc) savings can be achieved through the use of frequency converters with regeneration capability.

Elsewhere, Magnetek recently introduced its M-Force 240/480/575-volt general purpose AC variable frequency drives for mining applications, designed for use with pumps, fans and conveyors in mining environments.

A number of mining companies are working on the development of low emission technologies for the industry - either directly, or through funding for research. BHP Billiton committed to spending US$300 million between 2008 and 2012 to support the research and development of low emissions technologies. Vale established the Vale Technology Institute (ITV) in 2009 to promote scientific research and technological development. Amongst its objectives is the generation of know-how for a sustainable mining industry. Research fields to be developed at the research centre in Belém (Pará) include mining and sustainable engineering.

Mining companies sometimes evolve into electricity providers for local communities. AngloGold Ashanti refers to “community expectations that the mine is responsible for the electrification” of the town of Siguiri, next to its Siguiri mine.

Some companies go a step further and become directly involved in electricity generation. Rio Tinto, for example, has its own hydropower generating facilities with combined generating capacity of over 3,500MW. Control over electricity generation tends to be part of an internal risk management strategy. Vale, a major investor in power generation in Brazil, comments that this is part of a strategy to “systematize information to help us take strategic decisions and reduce risks” – to protect the business from price volatility and minimize regulatory, climatic and supply-side risks.

Vale has investments in a host of different energy sources, including natural gas and petroleum. It is, however, committed to developing projects to boost the use of renewable energy sources and generates a significant portion of its energy requirements through hydroelectric power plants, owning stakes directly in eight hydroelectric plants.

Vale Soluções em Energia (VSE), a partnership between Vale and BNDES, the national development bank of Brazil, is developing power generation technologies, equipment and systems, with a focus on environmentally sustainable processes and the use of renewable energy sources. VSE’s technology centre at São José dos Campos Technology Park in the state of São Paulo focuses on technological innovation in power generation; high efficiency solutions for reducing overall costs; and environmentally sustainable solutions, especially renewable energy sources.

VSE has a particular focus on opportunities in the distributed power distribution market and has an investment program of US$720 million for this area. It has a joint venture with Scania of Sweden for the development of ethanol and gas-powered industrial engines for the Brazilian market. A series of single-speed stationary engines is being developed, intended for use in the agriculture and mining industries, to generate electricity and drive pumps and compressors – a market estimated at 3,000 engines per year in Brazil alone.

Separately, Vale has invested in biodiesel company, Biovale - a joint venture with Biopalma da Amazônia S.A. Biovale will produce a 20% biodiesel/80% mineral diesel blend which will power its entire fleet of 216 locomotives in the North System, as well as heavy machinery at the Carajás mines.

Elsewhere, Lonmin is investigating alternative, low emission energy sources including options for geothermal energy use and bio-energy generation.

In the US alone, according to the US Environmental Protection Agency (EPA), 400 mines operate 8,300 diesel powered vehicles. In addition to the greenhouse gas emissions from the diesel or the fossil fuel energy dependency, the exposure of miners to high concentrations of particulate matter is also a major environmental concern. Fuel cell-powered mine vehicles offer the potential for widespread use in the mining industry in the future.

Placer Dome tested a fuel cell-powered underground mining haulage vehicle, which was developed by the Fuelcell Propulsion Institute and Vehicle Projects/Vehicle Projects Inc. in 2002. The four-ton locomotive, developed as part of a $1.2 million project which was funded by the US Department of Energy, was powered by PEM fuel cells with reversible metal-hydride storage. The hydride storage system and ‘balance of plant’ was designed by Sandia. The vehicle was tested at the Val-d’Or mine in Quebec, Canada and provided a much superior performance to a battery vehicle. The locomotive then worked at Placer Dome’s Campbell mine in Red Lake Ontario. Placer Dome was subsequently acquired by Barrick Gold, which has invested in wind energy in Chile and Argentina, and hydro electric power in Tanzania.

More recently, Anglo Platinum (Angloplat) has led the way in the use of stationary fuel cell engines in mining, for power generation. Angloplat launched a fuel cell demonstration plant in Limpopo, South Africa last year which produces 200kW of electricity from coal-bed methane.

Fuel cells can use a variety of feedstreams, particularly hydrogen, but also ammonia, ethanol, methanol and liquid petroleum gas, to generate electricity. If methane is present at the mine – either as coal bed or coal mine methane (CBM, CMM), or as a product of underground coal gasification (UCG) – then the hydrogen feedstream can be derived from reforming the methane or as a by-product from any gas-to-liquid process undertaken. Otherwise a fuelling infrastructure will have to be deployed.

Earlier this year Angloplat’s Platinum Group Metals Development Fund (PGMD) formed Clean Energy Incorporated, a partnership with Altergy Systems of the US and the South African Department of Science and Technology. Clean Energy will focus on stationary fuel cells for the South African market, initially as a distributor and ultimately as a manufacturer. The telecommunications sector is one of the first target markets. Of the world’s total platinum group metals, 75% are located in South Africa, and the South African Government is keen to develop a local hydrogen economy to help transform the country’s mining industry into an exporter of processed minerals. The initiative is considered by Science and Technology Minister Naledi Pando to be in line with the “… goal of promoting SA as a source of world-class, high technology transfer and infrastructure opportunities”.

While most mining companies are now focusing on energy efficiency, to meet regulatory requirements, if not because of economics, the more far-sighted are moving beyond their traditional business and becoming producers of energy in their own right. Typically the focus is on distributed energy, which is also appropriate for their own needs. We can expect to see growing numbers of mining companies investing in clean technologies, including fuel cells, over the coming years.

2 IDENTIFICATION OF SYNERGIES: POTENTIAL DEMANDANTS OFENERGY/PRODUCT (AGRICULTURE, INDUSTRY,BUILDING…)

If life gives lemons, prepare lemonade.

Quote

Synergy consists on the interaction of elements that when combined produce a total effect that is greater than the sum of the individual elements, contributions… When it refers to industry, it refers to aspects or products from an especific industry that become potentially profitable in other hands.

Related to the mining industry, the main important synergy is the final product itself, that has a huge weight in other industries, but also the mining wastes may be profitable for other industries such as the agriculture, and even the presence of the mine itself influences hugely the social situation of the people that live around.

2.1 How Successful M&A Deals Split the Synergies

Academic research has repeatedly confirmed that about two-thirds of all mergers and acquisitions (M&A) among public companies destroy value for the acquirer, at least in the short term. Even when acquirers justify deals by pointing out the ample synergy opportunities that they offer, capital markets remain skeptical. Yet a significant minority of acquisitions do manage to create value for the owners of both the acquirer and the target, demonstrating that despite the doubters in the capital markets, the overriding M&A rationale—value creation—remains valid.

Of course, the specific path to value creation varies widely by company, depending on the economics of its business, its valuation in the marketplace, and the terms of any given M&A transaction. But whether by buying out-of-favor targets near their cyclical lows, realizing cost efficiencies, or boosting the top line through organic growth, acquirers and M&A partners *can* create value—provided the transaction is accurately priced and specific value-creation strategies are executed effectively.

Most acquirers seek to create value by capturing cost synergies. But there is more to value creation than simply identifying synergies and executing strategies to realize those synergies. The Boston Consulting Group teamed up with the Technische Universität München (TUM) to compile new research demonstrating that in successful deals, buyers and sellers share the synergies. Acquirers cannot expect to capture 100 percent of those synergies for themselves; sellers will anticipate the buyers' synergies and demand takeover premiums, reasoning that the target is worth more in the hands of the acquirers than in their own. Our research suggests that sellers collect, on average, 31 percent of the average capitalized value of expected synergies. However, in practice, the seller’s share varies widely.

Potential synergies may include closing redundant plants or production lines, realizing economies of scale in purchasing, centralizing administrative functions, reducing headcount, or pushing forward other forms of streamlining. Not every acquisition has synergistic potential, however. In regulated industries such as transportation, utilities, and telecommunications, for example, there are sometimes few synergies available—even though they often operate as part of “natural monopolies” that, in theory, have high potential for synergies. Companies in such industries tend to be influenced and constrained by national regulators that generally bar them from realizing all available synergies for the benefit of the end consumer, and thus the net value of any synergies disclosed at the time of a merger announcement is relatively low.

Industries with a high ongoing level of international consolidation, on the other hand, can generate significant synergies, ranging from 2 to 10 percent of the target company’s latest annual sales (a median of 4.8 percent), or 1 to 3 percent of the combined sales of target and acquirer (a median of 1.5 percent). (See Exhibit 1.) Among the industries with ample opportunities for realizing synergies are mining and chemicals, which have experienced a wave of global consolidation in recent years, and health care, especially early-stage pharmaceutical companies that can dramatically increase value by joining forces with large organizations that have the manufacturing and distribution clout needed to overcome the lofty barriers to international market entry.

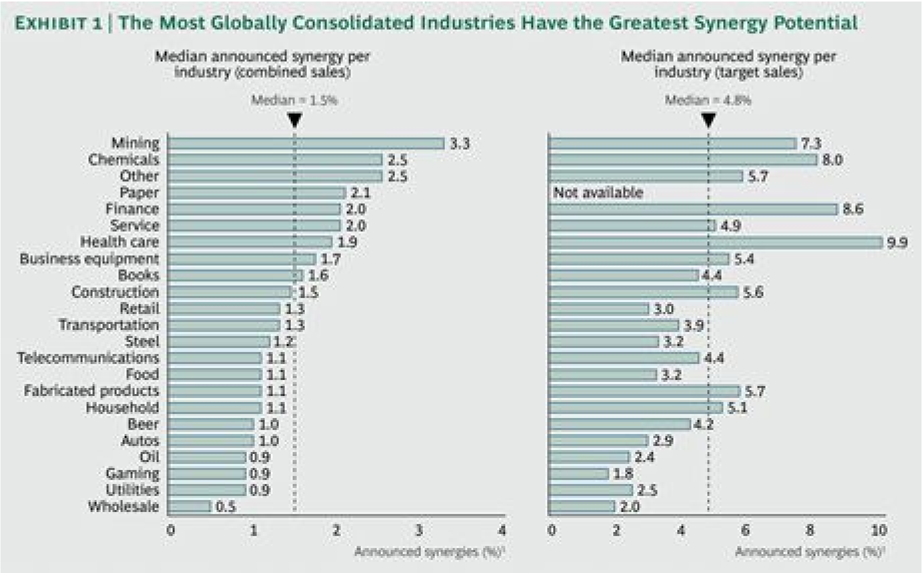


Figure 2.1

2.2 Synergies with the mining industry

Since mining industry belongs to the primary sector, many other industries will depend on the products of the mining industry. Actually, most of current industries depend absolutely on the availability of metals and minerals extracted by mining. Their abundance or scarcity may condition the future price of the final products, or even the sustainability of the whole industry in the case of key materials, unless a possible substitute will be discovered.

2.3.1 Building and machinery industry

Steel production may also be included here, since it is the most used metal in this industry. The principal component of steel production is iron, but other substances must be considered due to their importance in different kinds of steel:

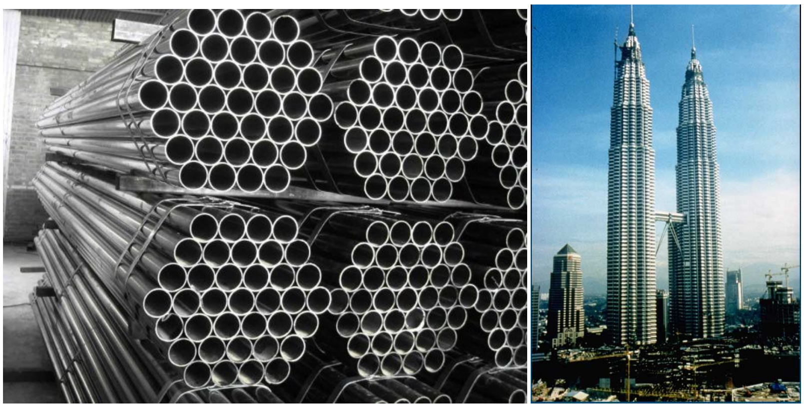


Figure 2.2 Steel Bars and Petronas Twin Towers

Chromium is critical in the manufacturing of stainless steel. Most stainless steel contains about 18% chromium; it is what hardens and toughens steel and increases its resistance to corrosion, especially at high temperatures. Because stainless steel does not rust and is easily sterilized, it is a part of many items we use in our daily lives. Some of the most recognizable of these items include kitchen appliances, food processing equipment, and medical and dental tools.

Zinc has strong anticorrosive properties and bonds well with other metals. Consequently, about one-half of the zinc that is produced is used in zinc galvanizing, which is the process of adding thin layers of zinc to iron or steel to prevent rusting.

Fewer people know that it is also made of manganese. Although the amount of manganese used to make a ton of steel is small, it is just as essential as iron to produce this fundamental building block of modern societies. Domestic consumption of manganese is about 500,000 metric tons each year, predominantly by the steel industry. Manganese is essential and irreplaceable in steelmaking, and its global mining industry is dominated by just a few nations. It is therefore considered to be one of the most critical mineral commodities for the United States. Manganese removes oxygen and sulfur when iron ore (an iron and oxygen compound) is converted into iron. It also is an essential alloy that helps convert iron into steel.

As an alloy, it decreases the brittleness of steel and imparts strength. The amount of manganese used per ton of steel is rather small, ranging from 6 to 9 kg. About 30% of that is used during refinement of iron ore, and the remaining 70% is used as an alloy in the final steel product.

Approximately 80% of the primary (not recycled) nickel consumed was used in alloys, such as stainless steel and superalloys. Because nickel increases an alloy's resistance to corrosion and its ability to withstand extreme temperatures, equipment and parts made of nickel-bearing alloys are often used in harsh environments.

Other materials important in the building sector are silver (brazing and soldering, mirrors and glasses due to its completely reflective properties when polished) and cupper (45% of cupper demand).

Figure 2.3 Statue of Liberty and skyscrapers

2.4.2 Jewelry, coining and financial issues

This is one of the most important uses of metal and minerals along the story, and explains by itself the huge importance of mining industry especially when speaking about these materials. Due to its value in the world society gold shines over the rest.

When Spanish explorers first arrived in the "New World" they met the native South Americans. These two cultures had been separated by a vast ocean, they had never touched one another, they spoke different languages and lived entirely different lives. Yet they had one thing in common - they both held gold in highest esteem and used it to make some of their most important objects.

Gold has been used to make ornamental objects and jewelry for thousands of years. Gold nuggets found in a stream are very easy to work and were probably one of the first metals used by humans. Today, most of the gold that is newly mined or recycled is used in the manufacture of jewelry. About 78% of the gold consumed each year is used in the manufacture of jewelry.

Special properties of gold make it perfect for manufacturing jewelry. These include: very high luster; desirable yellow color; tarnish resistance; ability to be drawn into wires, hammered into sheets or cast into shapes. These are all properties of an attractive metal that is easily worked into beautiful objects. Another extremely important factor that demands the use of gold as a jewelry metal is tradition. Important objects are expected to be made from gold.

Pure gold is too soft to stand up to the stresses applied to many jewelry items. Craftsmen learned that alloying gold with other metals such as copper, silver, and platinum would increase its durability. Since then most gold used to make jewelry is an alloy of gold with one or more other metals.

Figure 2.4 Gold jewelry and medals

The gold used as a financial backing for currency was most often held in the form of gold bars, also known as "gold bullion". The use of gold bars kept manufacturing costs to a minimum and allowed convenient handling and storage. Today many governments, individuals and institutions hold investments of gold in the convenient form of bullion.

Figure 2.5 Gold coins and ingots

Today gold coins are no longer in wide use for financial transactions. However, gold coins issued in specific weights are popular ways for people to purchase and own small amounts of gold for investment. Gold coins are also issued as "commemorative" items. Many people enjoy these commemorative coins because they have both a collectable value and a precious metal value.

Silver has traditionally served, with gold, as the metal used in coins. As a precious metal, silver is rare and valuable, making it a convenient store of wealth. In the past, people accumulated their wealth in the form of silver coins; today, they invest in investment-grade silver bullion. The fact that silver does not corrode and only melts at a relatively high temperature, means that it can last, and the fact that it has high luster makes it attractive. Its malleability makes silver a good choice for designing and minting local currency.

Figure 2.6 Silver coins and ingots

In greater abundance, and therefore less expensive, than gold, silver has been used more prevalently as currency. Until the 20th century, many countries used a silver or gold standard, backing up the value of currency with the presence of gold or silver in the treasury. Today, countries use less expensive metals, such as copper and nickel, to produce coins, and they use fiat currency, in which government regulation controls the value, instead of a gold or silver standard.

Still, silver retains its value as a commodity. Many individuals choose to invest in silver through financial instruments, like stocks and mutual funds, or by actually buying and storing 99.9% pure silver bullion bars, coins, or medallions. Countries sometime produce silver collector's edition coins, which they sell to buyers at a price exceeding the value of the silver used to make the coin.

Other materials for coining are copper and nickel. All U.S. circulating coins except the penny are made of alloys that contain nickel, while copper remains a component of coinage used in many countries. For jewelry titanium is also used.

From mining many other materials used in jewelry are extracted. Some of them are diamonds, emeralds, sapphires and rubies.

Figure 2.7 Precious stones

2.4.3 Automobile and aerospace industry

As in the building and machinery industry, proper steels are essential in the manufacturing of diverse vehicles, according to the needs of security and less weight in order to decrease the consumption of energy during the transport.

Copper is an essential component in the motors, wiring, radiators, connectors, brakes, and bearings used in cars and trucks. The average car contains 1.5 km of copper wire, and the total amount of copper ranges from 20 kg in small cars to 45 kg in luxury and hybrid vehicles.

Figure 2.8 Car components

Titanium is as strong as steel but weights about half as much. It is twice as strong as aluminum but only about 60% heavier. This quality makes titanium especially useful for jet engines and aerospace industry.

Figure 2.9 Jet

It combines with iron, aluminum, vanadium, nickel, molybdenum and other metals to produce high-performance alloys. Jet engines, spacecraft, military equipment, bearings, body armor, and other high-tech products need parts made with these alloys.

If billions of dollars are going to be spent on a vehicle that when launched will travel on a voyage where the possibility of lubrication, maintenance and repair is absolutely zero, then building it with extremely dependable materials is essential. This is why gold is used in hundreds of ways in every space vehicle that NASA launches.

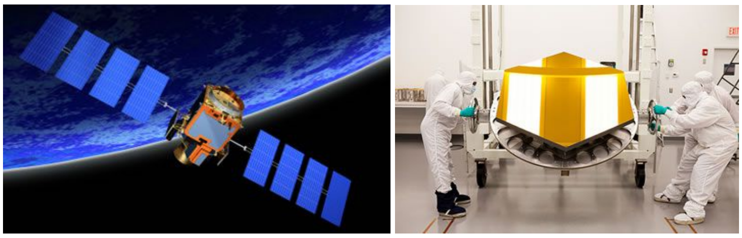


Figure 2.10 Space Industry Components

Gold is used in circuitry because it is a dependable conductor and connector. In addition, many parts of every space vehicle are fitted with gold-coated polyester film. This film reflects infrared radiation and helps stabilize the temperature of the spacecraft. Without this coating, dark colored parts of the spacecraft would absorb significant amounts of heat Gold is also used as a lubricant between mechanical parts.

In the vacuum of space, organic lubricants would volatilize and they would be broken down by the intense radiation beyond Earth's atmosphere. Gold has a very low shear strength and thin films of gold between critical moving parts serves as a lubricant - the gold molecules slip past one another under the forces of friction and that provides a lubricant action.

2.4.4 Electronic and electrical industry

The number one use of silver in industry is in electronics. Silver's unsurpassed thermal and electrical conductivity among metals means it cannot easily be replaced by less expensive materials.

For example, small quantities of silver are used as contacts in electrical switches: join the contacts, and the switch is on; separate them and the switch is off. Whether turning on a bedroom light using a conventional switch or turning on a microwave using a membrane switch, the result is the same: the current can pass through only when the contacts are joined. Automobiles are full of contacts that control electronic features, and so are consumer appliances. Industrial strength switches use silver, too.

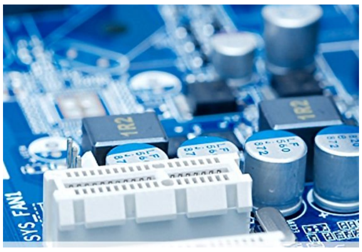


Figure 2.11 Silver Electronics Components

How does silver get from the earth to these electronic devices? Silver comes from silver mines or from lead and zinc mines from which silver is a by-product. Smelting and refining removes silver from the ore. Then, the silver is usually shaped into bars or grains. Electronics demand silver of the highest purity: 99.99% pure, also known as having a fineness of 999.9.

Dissolving pure silver in nitric acid produces silver nitrate, which can be formed into powder or flakes. This material, in turn, can be fabricated into contacts or silver pastes, like conductive paste made with a silver-palladium alloy.

Silver paste has many uses, such as the membrane switch already mentioned and the rear defrost in many cars. In electronics, circuit paths, as well as passive components called multilayer ceramic capacitors (MLCCs), rely on silver paste. One of the fastest growing uses of silver paste is in photovoltaic cells for the production of solar energy.

Figure 2.12 Silver Solar Pannels

Nanosilver, silver with an extremely small particle size (1-100 nm), provides a new frontier for technological innovation, requiring much smaller amounts of silver to get the job done. Printed electronics work by using nanosilver conductive inks. One example of a printed electronic is the electrode in a supercapacitor, which can charge and discharge repeatedly and quickly. Regenerative breaking is an automotive innovation that allows the kinetic energy of a slowing vehicle to be stored in a supercapacitor for reuse. Radio frequency identification (RFID) tags offer another powerful application of printed electronics.

These tags are better than bar codes for tracking inventory because they store more information and can be read from a greater distance, even without a direct line of sight. Silver has its place in consumer electronics, too. Your plasma television set may rely on silver for more than just the on-off switch if it contains a silver electrode aimed at giving a higher quality image. Light emitting diodes (LED) also use silver electrodes to produce low-level, energy efficient light. Meanwhile the DVDs and CDs you play probably have a thin silver recording layer.

Figure 2.13 Nanosilver

Another electronic application of silver is in batteries that employ silver oxide or silver zinc alloys. These light-weight, high-capacity batteries perform better at high temperature than other batteries. Silver-oxide is used in button batteries that power cameras and watches, as well as in aerospace and defense applications. Silver-zinc batteries offer an alternative to lithium batteries for laptop computers and electric cars.

On the cutting edge of technology are superconductors. Silver is not a superconductor, but when paired with one, the two together can transmit electricity even faster than the superconductor alone. At very low temperatures, superconductors carry electricity with little or no electrical resistance. They can be used to generate magnetic energy for turning motors or propelling magnetic levitation trains.

The myriad applications of silver in electronics offer an eye-opening view into how one of the most famous metals in history has become a cutting edge material of the future. Due in part to its unique property of having the highest thermal and electrical conductivity of all metals, silver is often a must-have over other, less expensive materials.

Copper is an essential material in the manufacturing of wires used in electronic as in the electrical energy transport. Other element used to produce energy transport wires is aluminum.

Figure 2.14 Silver electric components

The most important industrial use of gold is in the manufacture of electronics. Solid state electronic devices use very low voltages and currents which are easily interrupted by corrosion or tarnish at the contact points. Gold is the highly efficient conductor that can carry these tiny currents and remain free of corrosion. Electronic components made with gold are highly reliable. Gold is used in connectors, switch and relay contacts, soldered joints, connecting wires and connection strips.

A small amount of gold is used in almost every sophisticated electronic device. This includes: cell phones, calculators, personal digital assistants, global positioning system units and other small electronic devices. Most large electronic appliances such as television sets also contain gold.

Figure 2.15 Gold cell phone components

One challenge with the use of gold in very small quantities in very small devices is loss of the metal from society. Nearly one billion cell phones are produced each year and most of them contain about fifty cents worth of gold. Their average lifetime is under two years and very few are currently recycled. Although the amount of gold is small in each device, their enormous numbers translate into a lot of unrecycled gold.

Other elements used in electronics and electric are zinc, titanium and beryllium.

2.4.5 Mining chemical

According to new report by Global Industry Analysts (GIA), “the world market for mining chemicals is projected to surpass $25.7 billion by the year 2017. Growth in the future will be driven largely by revival of a large number of feasibility studies that were stalled by mining companies during the heat of the recession and waxing demand for mineral resources from developing countries to fuel their rapidly growing economies.” Mining chemicals play a vital role in enhancing the productivity and efficiency of mining processes such as the recovery and extraction of minerals and target materials from ore. “Presently,” GIA reports, Asia-Pacific and the USA dominate the world mining chemicals market. Explosives & drilling application [to be examined in detail in September’s Fragmentation article] represents the largest and fastest growing market for mining chemicals worldwide, with impetus for the segment expected to be provided primarily by the coal industry, which is presently the largest end user of explosives.

Figure 2.16 Explotion

On the other hand, market for mineral processing is expected to be dominated by precious metals (sic) industry such as copper, due to the importance of leaching and flotation in these markets. In upcoming years, legal and regulatory laws regarding environment and safety concerns are expected to propel investments in developing chemicals which are safer and environmentally friendly.” The importance of mining chemical in the value chain is likely to grow in coming years as the industry strives for efficient recoveries from ever lower grade ores.

Figure 2.17 Chemicals

It could be also that mining chemicals come to have greater influence on the profitability of mining operation. GIA also suggests that "increased R&D and investments in developing and commercializing newer, more sophisticated chemicals will gradually push currently cheaper yet less efficient and environmentally hazardous alternatives out of the market." The Clean Mining Alliance announced its birth in mid-May and is sure to have some influence in mining chemicals. This new industry association is aimed at supporting and advocating technological advancements to make the mining industry cleaner and more environmentally responsible.

"Frameworks exist to increase social responsibility in mining, but despite advancements in exploration, extraction, production and reclamation technology, the industry has struggled to present itself as having grown beyond the mining days of old," says Dallas Kachan, Executive Director of the alliance. "The Clean Mining Alliance exists to help promote new and emerging technology developments that are making mining more environmentally responsible." It is an international non-profit organization based in Vancouver, British Columbia, Canada. It was introduced during British Columbia Mining week, a time when the province celebrates the contributions the mining industry brings to the province, its communities and businesses.

Members include companies on the forefront of innovative breakthroughs in the mining industry, as well as leading research organizations. "We're thrilled to be able to showcase case studies from industry, and world leading research members like CERM (The University of British Columbia's Centre for Environmental Research in Minerals, Metals and Materials), which has proven through its work at the local Britannia mine site that innovation can vastly improve mine reclamation. It's these types of innovations that are leading towards a cleaner mining industry."

Clean technologies, or "cleantech," employed by member organizations include membrane-based water filtration, hydrometallurgical processes, biologic remediation, carbon capture, near-zero emissions processes, closed-loop systems and other innovation. Kemetco Research, for example, is developing a means of recovering gold without the use of cyanide leaching, as well as treating acid rock drainage (ARD) with biologically safe materials. It is developing a cyanide-free extraction method that would remove the harmful chemical compound from gold processing, thereby creating a safer and more environmentally friendly process for gold extraction and processing. Kemetco Research is also developing anaerobic biological processes relying on the activity of sulphate reducing bacteria for the treatment of ARD and other heavy metal containing effluents. This biological process aims to be an environmentally viable option for current and past mine sites for the treatment of ARD.

2.4.6 Health

Many products come from mining industry have many influences and applications in the population's health, directly or indirectly. Here a list of some of them is explained:

Surgical tools are made from stainless steel, titanium. Medical equipment, cookware, and cutlery are often made of stainless steel because it is easy to clean and sterilize.

Figure 2.18 Surgeon components

Plumbs to transport water are often made from copper, aluminum and lead. A significant shift in the uses of lead had taken place in the United States as a result of compliance with environmental regulations and the substitution of other materials for lead in nonbattery products, such as gasoline, paints, solders, and water systems.

Figure 2.19 Plumbs

Besides steel manufacturing, and related with health, manganese uses include micronutrients in fertilizers, micronutrients in animal feed, water treatment chemicals, textiles and tiles. The product “manganese violet” is used for the coloration of plastics, powder coatings, artist glazes, and cosmetics.

A significant use of zinc is in the production of zinc oxide (the most important zinc chemical by production volume), which is used in rubber manufacturing and as a protective skin ointment. Zinc is also a necessary element for the proper growth and development of humans, animals, and plants. The adult human body contains between 2 and 3 grams of zinc, which is the amount needed for the body's enzymes and immune system to function properly. It is also important for taste, smell, and to heal wounds. Trace amounts of zinc occur in many foods, such as oysters, beef, and peanuts.

Silver ions act as a catalyst by absorbing oxygen, which kills bacteria by interfering with their respiration. This antibiotic property, along with its non-toxicity, has given silver an essential role in medicine for thousands of years. Before widespread use of antibiotics, silver foil was wrapped around wounds to help them heal, and colloidal silver and silver-protein complexes were ingested or applied topically to fight illness. Silver has also been used in eye drops and in dental hygiene to cure and prevent infection.

While silver is not toxic, repeat intake of small amounts of silver over time can result in argyria. In people with this condition, silver builds up in body tissue, giving it a gray-blue appearance when exposed to the sun. In addition, the ingestion of large amounts of silver can have negative effects on the body. For these reasons, medical doctors discourage the use of colloidal silver, discounting claims by some that colloidal silver is a cure-all dietary supplement.

Today, the presence of antibiotic-resistant superbugs increases the demand for silver in hospitals. Small amounts of silver can coat hospital surfaces and medical equipment to prevent the spread of pathogens. Silver in surgical equipment, wound dressings, and ointments protect wounds from infection. Silver sulfadiazine is especially useful for burn victims because it kills bacteria while also allowing the skin to regrow. Silver ion treatments can heal bone infections and allow regeneration of damaged tissue.

Figure 2.20 Colloidal silver vs antibiotics

Gold is used as a drug to treat a small number of medical conditions. Injections of weak solutions of sodium aurothiomalate or aurothioglucose are sometimes used to treat rheumatoid arthritis. Particles of a radioactive gold isotope are implanted in tissues to serve as a radiation source in the treatment of certain cancers.

Figure 2.21 Drugs of sodium aurothiomalate

Small amounts of gold are used to remedy a condition known as Lagophthalmos, which is an inability of a person to close their eyes completely. This condition is treated by implanting small amounts of gold in the upper eyelid. The implanted gold "weights" the eyelid and the force of gravity helps the eyelid close fully.

Radioactive gold is used in diagnosis. It is injected in a colloidal solution that can be tracked as a beta emitter as it passes through the body. Many surgical instruments, electronic equipment and life-support devices are made using small amounts of gold. Gold is nonreactive in the instruments and is highly reliable in the electronic equipment and life-support devices.

2.5 Mining regions

The opening of a large mine has economic, environmental, and social consequences at the national, state or provincial, and local levels. Large mines generate foreign exchange earnings and tax revenues and create employment directly and indirectly.

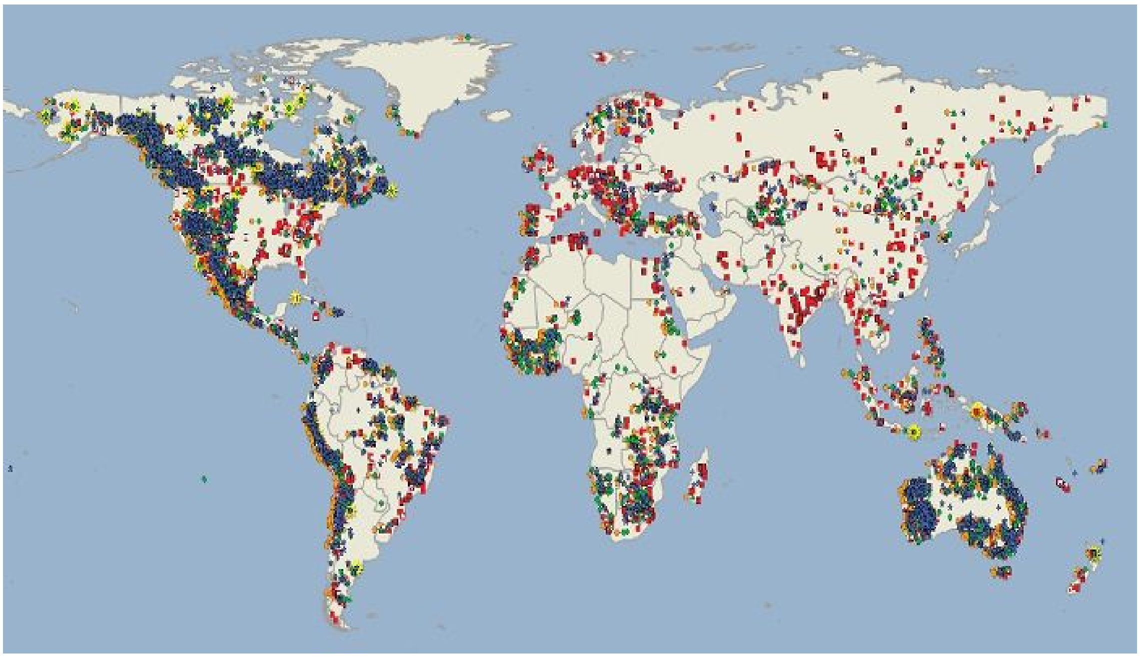


Figure 2.22 Mining world map

Large mines also impact the physical environment and can have strong social and cultural repercussions on local communities, especially indigenous populations. Yet the mine's impact – positive and negative – can vary significantly at the local, state or provincial, or national levels, depending on the "rules of the game" – as set by the regulatory framework – and depending on the management of the operation.

Over the past years, the ground rules for opening and operating large mines have shifted: Governments have begun to focus on their role as regulators rather than owners of mines, and the international community has come to expect mining companies to behave responsibly with regard to the environment and their relationships with local communities. It is now generally accepted that avoiding the potential detrimental effects that mining can have on fragile ecosystems and local communities should be made a priority. Experience has shown that large international mining companies are generally better environmental citizens than smaller, domestically owned mines. Yet a number of negative incidents have drawn widespread interest in and criticism of their practices, as well. Local and international environmental groups have become increasingly involved in mining disputes.

Meanwhile, local communities have become more and more concerned that they shoulder all the negative impacts of mining but receive few of the benefits. This is especially the case because capital intensive large mining operations generate only a fraction of the jobs that they did a generation or two ago.

Figure 2.23 The first picture corresponds to a protest against San Marcos mining, in Guatemala ('no to mining, yes to life'). The second one is a demonstration in Honduras for ecological issues.

2.5.1 Economic benefits

The sources of income that a mine generates – directly and indirectly – at the national, state or provincial, and local levels are diverse. The impact at each level can vary substantially, depending on the rules established by the national legal and fiscal frameworks and the management attention given to the relevant issues. The level of the tax burden, including indirect taxes, is still an important issue. However, many countries have reduced taxation levels and eased repatriation requirements in order to attract foreign investment. These steps, in turn, should generate additional taxation, as well as increased economic activity at each level. However, in some countries, obsolete fiscal regulations still prevail, depriving the host country of a fair share of the benefits. At the same time, many other countries have been decentralizing tax and expenditure systems, resulting in more benefits for regional and local governments. More importantly, a proactive company policy of training and employing of locals and of engaging local contractors will yield benefits, in the form of greater local incomes – and taxes – that companies with a more passive approach may not generate.

Then there is the issue of how the benefits are allocated within the host country. The division of taxes and royalties among different levels of governments – national, state or provincial, or local – will be an important factor in determining the ultimate distribution of the benefits and costs of the mine. Similarly, employment policies will affect the geographic distribution of benefits and costs, to the extent that they treat all nationals on an equal basis or favor locals. The influx of new migrants from other regions of the same country will put great strains on the existing social and economic infrastructure. It is essential that some mechanism exist to ensure an orderly expansion of activities and provision of services.

Table 2.1 Investment and Revenues Generated by Large and Medium Mines

Mines (number and size)	**Investment** (US$ million)	**Export revenues** (US$ million/year)	**Fiscal revenues** (US$ million/year)
5 large	6200	4000	400
2 medium	110	40	1

2.5.2 Environmental and health issues

Critics sometimes charge that large international mining companies seek pollution havens in which to conduct their operations. There does not seem to be any hard evidence to substantiate this claim. With some exceptions, international mining companies use the same technology in developing countries that they do in their home countries, and they often supersede local environmental standards. Yet management teams at the operational level have, in some cases, been stretched thin. This has caused a number of large incidents in recent years, which mining critics eagerly point out. In this study, the researchers assessed the general environmental performance of the mining operations and their general compliance with national and international processes and standards. The assessment was based primarily on discussions with the various stakeholders.

Figure 2.24 Acid mine drainage in the Rio Tinto River.

The health impacts of the opening of a large mine are an important factor from the environmental, social, and cultural perspectives. Potential negative health impacts associated with mining generally receive most of the attention. The most direct of these are occupational health and safety issues. Other important types of health impacts stem from environmental issues, such as flow contamination, or the presence of pollution stocks, accumulated in years of operation or through environmental accidents. Nevertheless, a large mine opening also can have significant positive health impacts if it leads to higher incomes and tax dollars spent locally on health care provision, including better medical facilities.

2.5.3 Social and cultural issues

The greatest concerns with respect to the opening of a new mine are often social and cultural repercussions, particularly when indigenous populations are affected. (Of course, these social and cultural impacts also have strong economic implications.) The influx of migrant workers may lead to social problems stemming from a lack of adequate housing and infrastructure, an easing of access to the area through the development of roads, and deficiencies in over-extended educational and medical facilities. Moreover, workers from other regions of the country or from abroad will often bring different lifestyles and patterns of behavior with them and may create local resentments. Usually, the average “imported” worker will be wealthier than the local population, which may magnify their importance in the eyes of some local residents, especially the young. The growth of bars and prostitution could be an undesirable outcome, particularly when the workers live at or near the mine site without their families. The uneven distribution of benefits and costs among the locals may upset existing social hierarchies and have dramatic cultural consequences. Notably, the cultural adaptation of indigenous and nonindigenous local communities may be quite different. On the other hand, if managed properly, the increased employment, wealth, commerce, and infrastructure caused by the mine opening can lead to a cultural revival, especially in a depressed area.

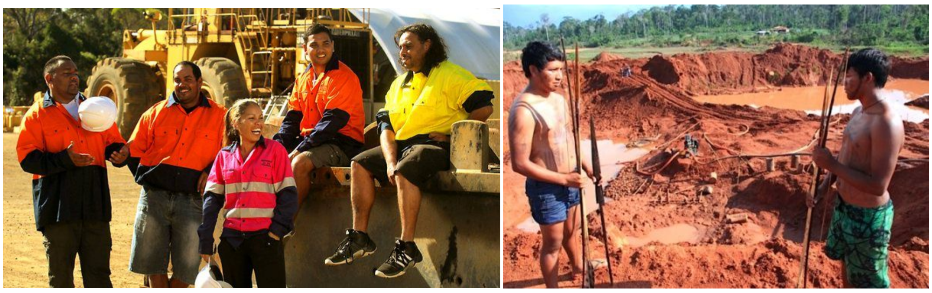


Figure 2.25 Mine workers

As with economic benefits and costs, the distribution of social benefits and costs is likely to be unequal among different population groups. This is particularly true if indigenous populations are affected. In the past, companies often acted as a surrogate government, providing infrastructure, schools, and medical care. While in recent years this may have continued to be true for the company’s employees, it has been less and less true for the community at large. Therefore, local governments need to be empowered and financed to provide such services. An important part of the analysis in this study was to analyze the implicit distributional effects of the provision of government and company services. The related impact on poverty reduction was also a focus of the study.

2.5.4 Legal and management issues

With regard to legal and management issues, two factors are of particular importance. The first is the regulatory framework in effect at the time of project development. The second is the management of the process by the company. This includes the consultative processes followed in the negotiations leading to the opening of the mine, as well as mediation methods for any conflicts that may develop later.

The outcomes of negotiations will also be greatly influenced by the existing legal and institutional framework. Three factors are particularly important: the rights of local and indigenous communities with respect to natural resources; environmental regulation, monitoring, and enforcement; and the general state of judicial systems and law enforcement. Yet the cornerstone of a process that will lead to the successful integration of the mining operation in the development effort of the region will be the establishment of a trilateral dialogue in which the state fully participates in the definition of programs and relationships with the company and the locals.

2.5.5 Mining and development (CD)

Mining usually brings with it rapid development and significant change, such as opportunities for employment, a large influx of capital and in some cases in-migration and resettlement. For some communities, particularly with no history of mining, taking advantage of the benefits while at the same time coping with adverse mining impacts can be daunting. Adding to people's vulnerability is the fact that the legal frameworks of many mining frontiers fail to adequately protect citizen rights or are ineffective, corrupt or not trusted. The ICMM concludes that governance weakness, particularly at the sub-national level, is the main factor limiting positive development impacts from large-scale mining (McPhail, 2008). Mining may have potential to have positive development impacts, but companies can inadvertently or carelessly exacerbate an already poor situation for some community members, particularly those with the least resources (Sarin et al., 2006).

Along the pro-anti mining continuum, case studies in scholarly literature provide insight into CD activities (or lack thereof) at mining locations around the world (Kapelus, 2002; Mackenzie and Pooley, circa 2003; Muradian et al., 2003; Yakovleva and Alabaster, 2003; Manteaw, 2007; Muthuri, 2007a). Case studies highlight impacts and activities at particular locations or by different companies, but comparative or evaluative research about CD, either by region, commodity, country, or otherwise is rare. One of the few exceptions is a country-wide study of CD and mining commissioned by The World Bank and the Ministry of Mines and Geology in Guinea (Synergy-Global, 2007). Lack of research about local-level CD practice in mining reflects the general trend that business and development remains profoundly under-researched (Visser, 2008). Empirical or grounded practice-based research does not adequately inform conceptual or theoretical understandings of mining and CD.

Mining's contribution to development has been subject to intense scrutiny through 'resource curse' theories (Auty and Warhurst, 1993; Sachs and Warner, 1997; Davis, 1998) a focus on revenue transparency (EITI, 2006), distribution of benefits from national to local levels (Reed, 2002) and disputes about impacts on local communities (Oxfam Australia, 2001–2008; Manteaw, 2007). This attention reflects the complex social, political, economic and physical conditions of mining, its non-renewable, temporary and often short-term nature and the significant challenge of ensuring community benefits, including after mine closure. Garvey and Newell (2005) identify numerous factors relating to governments, companies and communities that influence the inherent value of community-based strategies. Such conditions include government policies, effective legal frameworks and a corporation's approach to citizen participation.

As elaborated in the next section, the mining industry's operating philosophy has been subject to change, including formalization of commitments to CD. Still, there is a question about the extent to which companies should be judged for their CD performance. Hayes and Walker (2005) argue that companies should only be judged on core business impacts, rather than their 'voluntary' development contributions. Alternative perspectives position CD within a conceptual framework that influences core business (Synergy-Global, 2007). Others observe that CSR has little sway over core business, even where there are significant social impacts (Hamann and Kapelus, 2004). The scope and focus of CD in mining remains ambiguous.

There have been numerous calls for business, including mining companies, to make their approach to CSR more development and social justice-orientated (Fox, 2004; Newell, 2005; Manteaw, 2007; Visser, 2008), particularly those companies headquartered in developed countries with operations in developing countries, although with this comes the critique about exporting Northern values to the South (Kapelus, 2002; Bendell, 2005). Questions have also been asked about the extent to which CSR is 'rewriting' development (Harcourt, 2004, p. 1). Considerations driving business to increase its focus on development priorities can be attributed to a 'constellation of drivers' (Muthuri, 2007a, p. 179), including civil society's increased focus on human rights (Utting, 2007) and social justice concerns (Newell and Frynas, 2007), the rise of global communications and associated media campaigns, emergence of voluntary regulation through standardization of social performance expectations (Schiavi and Solomon, 2007), pressure from shareholder activists, lenders and financial institutions though initiatives such as the Equator Principles (2006) and the aforementioned governance gaps.

Mining operations are sometimes the only viable option that remote communities have for social development (IIED, 2002), particularly when governments manage to redistribute some of the revenue stream from mineral taxes and royalties back to the local community level. This scenario raises important issues about the ability of aggrieved groups to oppose company activities for fear that action may threaten much-needed company-funded projects (Newell, 2005) and community dependency on services following mine closure. In many ways, the issue of community dependency on company-funded services goes to the heart of the debate about the mining industry's ability to facilitate sustainable local legacies.

2.6 Waste materials at mine sites. How are they managed?

The type, amount, and properties of mine waste produced at different mines vary depending on the resource being mined, process technology used, and geology at the mine site. While many mine wastes are benign, mining companies manage their waste in order to deal with the large volumes of waste produced and to prevent the release of contaminates into the environment. Waste management plans are developed as part of the mine approval process in Canada, and consist of waste storage area selection and design, strategies to address problematic waste, and long-term stabilization of waste as part of mine closure.

2.6.1 Origins of waste at mine sites

Like the majority of human activities, mining operations produce waste materials. “Waste” is a general term for material which currently has little or no economic value. The soil and rock which is removed to gain access to buried ore, and the material (water, solids, and gases) left behind after the ore has been processed to remove the valuable commodities, are considered to be waste materials. However, the difference in mineral content between ore and waste rock can change depending on market conditions and available extraction technology, and there are a number of cases where material that was once considered waste has become a resource for modern mining operations.

2.6.2 Types of mine waste

There are different types of mine waste materials which vary in their physical and chemical composition, their potential for environmental contamination, and how they are managed at mine sites. Types of mine waste include:

- **Overburden:** Overburden includes the soil and rock that is removed to gain access to the ore deposits at open pit mines. It is usually piled on the surface at mine sites where it will not impede further expansion of the mining operation – moving large volumes of material is expensive. Overburden generally has a low potential for environmental contamination, and is often used at mine sites for landscape contouring and revegetation during **mine closure**.
- **Waste rock:** Waste rock is material that contains minerals in concentrations considered too low to be extracted at a profit. Waste rock is often stored in heaps or dumps on the mine site, but may be stored underwater with tailings if it contains a lot of sulphide minerals and has a high potential for **acid rock drainage** formation. Waste rock dumps are generally covered with soil and revegetated following mine closure, although there are cases of waste rock being re-mined due to an increase in mineral market prices or improvements in extraction technology.
- **Tailings:** **Tailings** are finely ground rock and mineral waste products of mineral processing operations. Tailings can also contain leftover processing chemicals, and are usually deposited in the form of a water-based slurry into tailings ponds (sedimentation lagoons enclosed by dams built to capture and store the tailings), although offshore tailings disposal has been successful in some cases. Tailings dams are discussed in further detail below.
- **Slags:** **Slags** are non-metallic by-products from metal smelting, and were historically considered to be waste. Slags are largely environmentally benign, and are being used increasingly as aggregate in concrete and road construction.
- **Mine water:** Mine water is produced in a **number of ways** at mine sites, and can vary in its **quality** and potential for environmental contamination. Water at mine sites is frequently **monitored** and various **water management strategies** have been developed to reduce the amount of mine water produced, and treat the water before it is discharged to the environment.
- **Water treatment sludge:** Sludge is produced at active **water treatment plants** used at some mine sites, and consists of the solids that had been removed from the water as well as any chemicals that had been added to improve the efficiency of the process. Although ways of recycling the sludge are being explored, the majority of sludge has little economic value and is handled as waste. Disposal of water treatment residues in underground mine workings is the least expensive option where it is permitted and environmentally safe. In extreme cases where the sludge is rich in cadmium or **arsenic**, it may be classified as hazardous waste and require special handling and disposal.

- **Gaseous wastes:** Gaseous wastes include particulate matter (dust) and sulphur oxides (SOx). The majority of emissions to the atmosphere are produced during high-temperature chemical processing such as smelting, and vary in their composition and potential for environmental contamination. Environmental control technologies such as gravity collectors, cyclones, and electrostatic precipitators are capable of removing up to 99.7% of dust and fumes, and wet scrubbers typically remove 80-95% of sulphur oxide emissions. In Canada, the atmospheric sulphur dioxide emissions from metal smelters have decreased by 37% between 2003 and 2010.

2.6.3 Environmental impacts of mine wastes

The environmental impact of mine waste depends on its type and composition, which vary considerably with the commodity being mined, type of ore, and technologies used to process the ore. For instance, where waste rock and tailings contain significant quantities of sulphide minerals and are exposed to air and water, **acid rock drainage** (ARD) can occur. As a result, every mine requires its own waste characterization, prediction, monitoring, control, and treatment. Many mine wastes are environmentally benign, and can be used for landform reconstruction, vegetation covers, and road and dam construction.

The major environmental impacts from waste disposal at mine sites can be divided into two categories: the loss of productive land following its conversion to a waste storage area, and the introduction of sediment, acidity, and other contaminates into surrounding surface and groundwater from water running over exposed problematic or chemically reactive wastes.

2.6.4 Management of mine wastes

Mine wastes require careful management to ensure the long-term stability of storage and disposal facilities, and to prevent and minimize air, water, and soil contamination. The inappropriate or unsafe management of wastes at mining operations continues to generate opposition from local communities, the general public, and non-government organizations, and has contributed to the negative public perception of the mining industry. Technological advances and changes in regulations have resulted in significant changes in waste management practices over the last 10 to 20 years, and mine wastes at modern mines are generally better managed than they have been in the past. Waste management plans are frequently developed before a mine is constructed, and the reclamation of waste rock dumps and tailings ponds are increasingly incorporated into the designs of new mines. In addition, in many parts of the world authorities require a proper waste management plan before they will issue a mining permit.

Mine waste management practices and storage facilities used at different mines are based on common design principles, but are optimized by mine engineers depending on specific site conditions. These designs take into account the potential for extreme events, such as earthquakes and floods. Guidelines on waste management and mine closure have been developed at international, national, and regional levels, and provide an advisory framework for best practices in mine waste management.

The usual approach to managing wastes is to contain and collect them at the point of production, treat the wastes to make them environmentally safe if necessary, and dispose of them to the land, water, or air. The waste management method used at a particular mine depends mainly on an evaluation of cost, environmental performance, and risk of failure. Successful management of tailings and waste rock is based on selecting appropriate waste storage locations, and proper material characterization, including the accurate prediction of long-term chemical behavior. Solid mine waste (overburden, waste rock, solidified tailings, slag, dust) can be used as backfill in underground or open pit workings, stored in piles on site or underwater to prevent ARD from occurring in the case of problematic wastes, used in construction of roads and dams at the mine, or recycled. Water can be recycled and reused for dust suppression and mineral processing, or treated and discharged into the environment.

2.6.5 Tailings management

Because tailings are composed of fine particles (sand, silt, and clay-sized material), and often have a high water content, they have been particularly troublesome to manage. In the past, tailings were deposited directly into rivers or wetlands, which would introduce sediment and contaminates into those water bodies and in many cases adversely affect aquatic life. Tailings are currently used as backfill in underground mines, stored in open pits, dried and stacked, or pumped into tailings ponds on site.

Although there have been a number of incidents where the dams securing tailings ponds have been breached, mining engineers have been learning from the enquiries into tailing dam failures, and have improved tailings dam design and execution. A compilation of worldwide tailings dam failure statistics between 1909 and 1999 shows an improving trend as mining companies have learned from past mistakes and as regulators have imposed more stringent regulations and conducted more inspections. In the 1970s, there were 44 tailings dam failures, in the 1980s, 27 failures, and in the 1990s, only 7 failures. Modern tailings dam design is very technical, and takes a number of site-specific factors into consideration, such as rainfall and flooding predictions, earthquake response, seepage control, tailings discharge method and rate, and changes over the lifetime of the dams. Non-critical structures are typically designed to withstand a 1-in-100-year flood, while more critical structures are designed for a 1-in-1000-year event or above.

In response to concerns over tailings dam failures and **water contamination**, some mines are opting to produce thickened tailings, which are pressed or have chemicals added to remove excess water. Thickened tailings can be mixed with cement and used in construction or as backfill in underground mines. Although producing thickened tailings is often more expensive than storing the tailings in a pond, the use of thickened tailings is increasing, especially in arid areas where water availability is an issue.

2.6.6 Turning mine wastes into a resource

The large volumes of waste produced at mining operations are expensive to manage, and are frequently cited as an obstacle in the environmental sustainability of mining. The mining industry plays a leading role in waste management, and is one of few industries that recycles its own waste. Uses of mine waste include:

- **Waste rock:** Can be reprocessed to extract minerals and metals, used as backfill, landscaping material, aggregate in road construction, or feedstock for cement and concrete
- **Manganese tailings:** Manganese tailings have been used in agro-forestry, buildings and construction materials, coatings, resin, glass, and glazes
- **Clay-rich tailings:** Clay-rich tailings have been used for making bricks, floor tiles, and cement
- **Slag:** Slag is often used for road construction, and in concrete and cement
- **Red mud:** Bauxite red mud is solid alkaline waste produced in aluminium refineries. Red mud has been used as a soil amender, in waste water treatment, and as a raw material for glass, ceramics, and bricks
- **Mine water:** Mine water is used for dust suppression and mineral processing, industrial and agricultural uses, as a coolant, and as a source of drinking water
- **Water treatment sludge:** Sludge from ARD treatment, which is high in iron, has been sold commercially for use in pigments
- **Sulphur oxide emissions:** Many smelters have installed acid plants to convert sulphur dioxide to sulphuric acid, a useful industrial chemical

2.6.7 Management of waste following mine closure

Despite the recycling and reuse of many wastes at mine sites, the majority of waste produced is still placed into storage facilities, and the **reclamation** and long-term management of these facilities has become an important part of modern mine development and mine closure. Regulators may require any waste storage structures to remain stable for a minimum of 100 to 200 years, which means they must withstand extreme events such as floods and earthquakes. Mine closure activities often involve containing and covering tailings to prevent their escape into the environment; minimizing the amount of water seeping from the tailings into surface or groundwater; covering waste rock piles and exposed materials with topsoil and planting vegetation to prevent erosion; and designing the final land formation to minimize erosion and post-closure maintenance. Plans for mine closure and site cleanup are required as part of the mine permitting process in Canada and these plans are updated after additional study. It is also common in Canada for government agencies to issue a new permit on shutdown to cover mine closure.

3 IDENTIFICATION OF POTENTIALLY APPLICABLE LOW CARBON ENERGIES (LCE)

When we are not longer able to change a situation, we are challenged to change ourselves

- Viktor E. Frankl -

Access to reliable and cost-effective forms of energy is a strategic priority for the global mining sector. The mining industry has traditionally relied on conventional fossil-based fuel sources — diesel, oil, coal and natural gas — to meet its growing energy demand. The industry is now tasked with responding to the challenges of increasing fuel prices while commodity prices tighten, resulting in ever-narrowing operating margins and increased opposition from communities to new conventional energy sources.

- The mining sector is expanding into new and often remote locations as a response to increasing demand from growing emerging markets. This often means having to deal with unreliable power supply from the grid and uncertain power prices. In most instances, grid-connected electricity needs to be supplemented with on-site generation, typically large-scale diesel generation, resulting in a dependency on diesel fuel. The more remote the mine, the more likely off-grid power solutions are required.

- The sector is experiencing volatility in commodity prices and rising fossil fuel prices, placing margins under pressure. With global demand for energy set to increase 36% by 2035, the industry faces greater energy price increases and volatility. Managing costs sustainably is a priority for the sector.

- The mining sector is facing growing demand from governments, customers, communities and other key stakeholders to operate in a sustainable manner. Doing so has a growing influence on the mining industry's "social license" to operate.

3.1 Mining: the growing role of renewable energy

Many of the world's largest mining companies are evaluating greater use of renewable energy plants — a trend set to intensify rapidly — as part of a broader strategy to lock in long-term fixed electricity prices and availability while minimizing exposure to regulatory changes, market pricing and external fuels.

3.1.1 Renewable energy to play a strategic role

Site-appropriate renewable energy solutions provide cost-competitive energy while delivering greater energy supply reliability and consistency.

Reliable access to cost-efficient energy sources is a strategic imperative for mining companies. It is essential to their bottom lines and increasingly, their licenses to operate. In parallel, the sector is challenged with meeting growing demand for mineral resources often located in countries and sites where the supply of energy is not always available, reliable or cost-effective.

The transformation of the mining sector is driven by a number of strong converging trends, including:

- Energy security concerns

- A recent history in most countries of rising and volatile energy prices, coupled with a consensus that such trends will continue over the medium-to-long term

- The shift to a resource-efficient and low-carbon economy that will ensure community acceptance

In response, the international mining sector is deploying innovative energy-saving strategies and making substantial industry-wide direct investments into renewable energy infrastructure.

At the heart of recent innovations in corporate mining energy strategies lie the construction and acquisition of renewable energy-generating assets, on- and off-site, and the direct contracting for renewable energy through power purchase agreements.

Renewable energy plants can be developed, funded, built and operated by third-party developers as captive plants, with the mine committing to purchase the generated electricity at a fixed price over a certain time period.

Table 3.1

Mining innovators embrace renewable energy

Rio Tinto

- Invested in a 9MW wind farm at Diavik Mine in Arctic conditions

- Aims to generate 10% of 20MW—25MW mine demand from renewables

- Expects to reduce its diesel use by approximately 4 million liters and its CO2 emissions by 12,000 tons

Codelco

- Replaced 85% of diesel demand with 51.8GWh solar thermal energy at one facility

- Stands to save the expense of almost 2 months of fuel annually

Other examples of renewable power adoption

- **Glencore Xstrata:** looking to meet half of its needs from wind power at Raglan Mine (off grid)

- **Collahuasi**: Pozo Almonte solar plant to provide 60GWh clean energy

3.1.2 The role of minerals and metal in a low carbon economy

The mining and metals industry is well placed to contribute to the resolution of the climate change challenge.

Many mining and metals companies are measuring, managing and reducing their own greenhouse gas (GHG) emissions. More significantly the industry is also supplying the materials needed to build a low carbon future. This latter role is less well understood and is the focus of this publication. Lowering GHG emissions is a considerable challenge for many industry sectors. In the future, factors such as rapid population growth, high levels of industrialization and continued economic development in a number of regions will make this all the more challenging. Such future trends are expected to increase aggregate and per capita consumption levels of minerals and metals as increasing population and development translates into rising demand for goods, infrastructure and housing. Minerals and metals are integral inputs to human development and the advancement of society. The industry already plays a critical role in supplying the inputs for current technologies and production practices. Similarly, it will provide vital inputs for fully realizing GHG emissions abatement opportunities across all sectors of the economy in the transition to a low carbon future.

Mining and metals industry emissions

A recent study commissioned by ICMM estimated that the global mining and metals industry makes up around 2% of global emissions. Approximately half of the industry's emissions are from fuel use in mining and processing operations, for transportation of ore and electricity generation at remote sites and from fugitive emissions (known as Scope 1). The other half are from electricity use, primarily in refining and smelting operations (known as Scope 2). Depending on the type and location of mineral resources and accessibility and fuel mix of the electricity grid, there are widely differing technical approaches to resource extraction and processing. With this in mind each site will therefore have a specific GHG profile. Similarly, changing ore grades and characteristics are significant determinants of the energy profile of a mine. Factors include the depth of the ore body, the size and spread of the mineralized system and the designed production rate. These factors contribute to energy demand and associated GHG emissions per kg of mineral and metal extracted and processed. Lowering GHG emissions is one of many drivers for energy efficiency improvements in the mining and metals industry. The underlying diversity of energy and emissions across mine sites makes sector-wide assessments a challenge. This is in contrast to the standardized approaches for reporting emissions taken by other industries. ICMM and its members recognize their contribution to global GHG emissions and have introduced strategies to manage these emissions in a dynamic operating environment. ICMM members have taken significant steps to introduce emissions reduction strategies, ensuring the efficient use of natural resources and investments in low carbon technology research and development.

Material contribution to the broader low carbon economy

In addition to managing their own emissions, the mining and metals industry also makes a broader contribution in providing the minerals and metals required for the transition to a low carbon economy. Many abatement options have the potential for reducing global GHG emissions, including reducing consumption, low carbon energy technologies and improvements in transportation systems and building infrastructure. The examples in this publication are illustrative rather than exhaustive. Further work is needed to understand the net impact of low carbon technologies on metals demand compared with current technologies. Once this has been achieved, policies can then be developed to incentivize the low carbon transition in a feasible and sustainable way. An additional consideration will be the emissions profile associated with the production of these metals. A continual challenge for the industry will be to address emissions in the context of increasing demand and output of their products. Two key areas of mitigation potential are in energy efficiency improvements and low carbon power generation.

Energy efficiency

The transition to a low carbon economy will require a focus on energy efficiency on many fronts. The International Energy Agency's World Energy Outlook, 2011 projects that in order to stabilize global temperature increases to 2°C above current levels, half of the emissions abatement will come from energy efficiency measures. Energy efficiency initiatives in the mining and metals industry are already driven by cost savings opportunities and security of supply considerations. Emissions management is another driver. Well-designed policies will encourage further energy efficiency improvements across all sectors of the economy in the transition to a low carbon economy. The material implications of more energy efficient production practices need to be understood more fully. Multiple opportunities relating to energy efficiency are in the buildings and transport sectors. As illustrated below, there is currently only anecdotal evidence on the implications of these initiatives on demand and the use of minerals and metals.

Buildings

According to UNEP, buildings account for approximately 40% of global GHG emissions. There are a variety of potential abatement options through more efficient use of energy for lighting and heating, cooling and ventilation and the use of appliances. Buildings are mostly concentrated in cities; urban communities are currently home to 50% of the world's population and make-up 75% of global GHG emissions according to Arup Associates. The UN estimates that by 2050, 70% of the world's population will live in cities. The demand for increasing efficiency and resilience to a changing climate in buildings will rapidly increase. Demand for metals in constructing these new buildings may also rise beyond current requirements. As well as being crucial inputs into the infrastructure of a building, minerals and metals have an additional role to play in making buildings more energy efficient.

As an example, ICMM member Norsk Hydro has developed advanced façade technologies using aluminium to reduce energy and emissions from heating, cooling, ventilation and lighting. Façades are also manufactured from stainless steel containing molybdenum for added strength and corrosion resistance. These technologies create more energy efficient buildings with the aim of making them energy neutral. Norsk Hydro has introduced the façade technology at its ThyssenKrupp AG headquarters in Essen. It has eliminated the need for air conditioning and the building's energy requirements are expected to be 20–30% below Germany's statutory requirements. Similarly, in 2009 Norsk Hydro opened the Wicona Test Center Ulm in southern Germany. The building is energy positive meaning the building is able to generate more power than it uses. On average, conventional new buildings have an energy demand of 100 kWh per square metre a year. Norsk Hydro's building consumes less than 40 kWh per square metre. This energy demand was fully met over the course of a year by the building's own power generation from solar panels and an advanced ground water heat pump system.

Transport

The transport sector provides further energy efficiency opportunities with possible implications for the mining and metals sector. Different technologies will have different metals profiles. For example, nickel alloys have been used to allow for more efficient fuel combustion in jet engines. Similarly, lighter and more fuel efficient vehicles will often be made of higher strength steels incorporating niobium, molybdenum or lightweight metals such as aluminum. Similar to conventional vehicles, the various components of hybrid cars are made up of a multitude of metals as indicated in figure 1. More transformative low emissions technologies such as electric vehicles also have a different demand profile for metals. Electrification of the transport system has the potential to significantly reduce direct GHG emissions from transportation and will lead to a rise in the consumption of a number of metals across the supporting infrastructure. Changing the infrastructure and modernizing the power distribution to support an electrified transport system will require a number of metals including copper, zinc, nickel and steel.

Low carbon power generation

A range of technologies exist to reduce the emissions intensity of power generation, including energy systems based on renewables and carbon capture and storage (CCS) technologies. Each option has its own profile of mineral and metal inputs which needs to be understood more fully. Renewables Many different minerals and metals are required to construct wind turbines and solar panels as indicated in figure 2 and 3. Both of these technologies need to be scaled up if they are to lower the carbon intensity of the global energy mix. The International Energy Agency (IEA) suggests the share of non-hydro renewable energy in power generation will increase from 3% in 2009 to 15% in 2035, with wind and solar power seeing the largest increase. The metal requirements for the physical structures of both wind turbines and solar panels are significant. It is not just low carbon technologies like wind turbines and solar panels that require the use of metals. Biomass energy based on rape seed oil is estimated to use around five times more iron per kWh of electricity produced than regular fossil fuel based energy. This is due to high amounts of fertilizers and capital goods required. Expansion of nuclear capacity would increase demand for uranium and hydrogen fuel cells which could dramatically increase the demand for metal catalysts.

Hydrogen fuel cells

Hydrogen fuel cells, as the name suggests, use hydrogen to generate electricity, heat and water. Fuel cells offer high efficiency, versatility and scalability. A number of metals can be used as catalysts, e.g. zinc, aluminum, magnesium and platinum, to ensure zero emissions from electricity during the use-phase. Anglo American Platinum profiled this low carbon technology at the UN Framework Convention on Climate Change COP17 conference in Durban in December 2011. They recently invested in platinum-based technology and development businesses in South Africa to accelerate the use of fuel cells in the small and large scale provision of electricity in mobile, stationary and portable applications.

Carbon capture and storage (CCS)

The wide-scale introduction of CCS, as anticipated in IEA scenarios towards the middle of the 21st century, would similarly increase the demand for many metals. A 2011 study into metal requirements of low carbon energy by R. Kleijn et al estimates that applying CCS technology would increase metal requirements by 10–30% compared with the current electricity mix. This is due to the additional infrastructure needed to capture, transport and store CO2 emissions. The exact trajectory and proliferation of these different low carbon power generation and storage options is not yet fully known. However, according to expert assessments, their uptake is crucial for making the transition to a low carbon economy. Each option will have a different mineral and metals profile and further work is required to understand the potential implications on metals demand if these technologies are introduced at a large scale.

3.1.3 Mining’s contribution to sustainable development

The mining and metals industry

The mining and metals industry spans a complex interdependent web that includes a formal component, an informal component, and many affiliated interests – support services (such as investors, contractors and suppliers), government, Indigenous Peoples and their organizations, mining affected communities, civil society organizations, organized labour, academia and research institutions and downstream users. The industry interacts with these interests either directly and/or through multi-stakeholder initiatives such as the Extractive Industries Transparency Initiative, the Global Reporting Initiative, the IFC Performance Standards and the Voluntary Principles on Security and Human Rights. At the core of the formal mining industry are publicly traded and state-owned companies as described in Table 1 overleaf. Together, these companies employ about 2.5 million people world-wide. About half of these are employed with the global and senior companies (and ICMM’s 22 member companies come from this group). The formal mining industry operates under a legal and fiscal framework determined in each country it operates. It is linked by various national, regional and commodity-focused associations committed to representing the industry, protecting its interests and improving performance. (34 of these associations are members of ICMM.) In contrast to the above, artisanal and small-scale mining comprises an informal component of the mining and metals industry. There is typically no legal or fiscal framework, or if there is one it is difficult to enforce, although this is slowly changing as countries or local jurisdictions address this gap. While the informal sector provides employment for some of the world’s poorer people, potential instability can arise from the fact that many of these people work unsafely and illegally and may fall prey to exploitation by criminal networks and armed groups. The World Bank estimates that today, some 15 to 20 million artisanal and small scale miners are operating in 30 countries with about 80 to 100 million people depending on such mining for their livelihood. Working conditions in artisanal mining are typically harsh. Cultural conflict, crime and corruption, health problems, gender and child labour issues, and serious environmental degradation are common. Public and private services to provide essential health care and education usually do not exist.

Company category	Approximate asset base	Approximate numbers of companies	Comment
Global	Exceeds US$10 billion	50	Global and senior companies which have access to the largest portion of available capital
Seniors	US$3 - US$10 billion	100	
Intermediates	US$1 - US$3 billion	350	Companies often on a growth path to become seniors
Juniors (producers)	US$0.5 - US$1 billion	1500	Companies which often have one mine
Juniors (exploration)	US$5 - US$500 million	2500	Volatile and share market dependent; they are finders,not producers and their focus is on their exploration activities
Juniors - juniors	Below US$5 million	1500	Focus is on accessing venture capital and enhancing their stock price

Table 3.2: Profile of the formal mining industry

Broad categories of the minerals and metals produced by the industry include:

- ferrous and non-ferrous metals: iron and steel, nickel, lead, zinc, copper, aluminium, tin, tungsten, molybdenum, tantalum, cobalt, bismuth, cadmium, titanium, zirconium, antimony, manganese, beryllium, chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium, thallium and rare earth metals
- precious minerals and metals: diamonds, gold, silver, platinum group metals (platinum, palladium, iridium, ruthenium, rhodium, osmium)
- energy minerals: coal, uranium
- industrial minerals: clays, silica sand, talc, salt, limestone, gypsum, pumice, potash, refractory bauxite, chromite, rutile and ilmenite (titanium), zircon, magnesite, borates, fluorspar, barites, sulphur and phosphate rock
- building materials: stone, sand and gravel. The mine projects to produce this broad range of minerals and metals as well as the resulting products follow a life cycle as illustrated in figures 1 and 2.

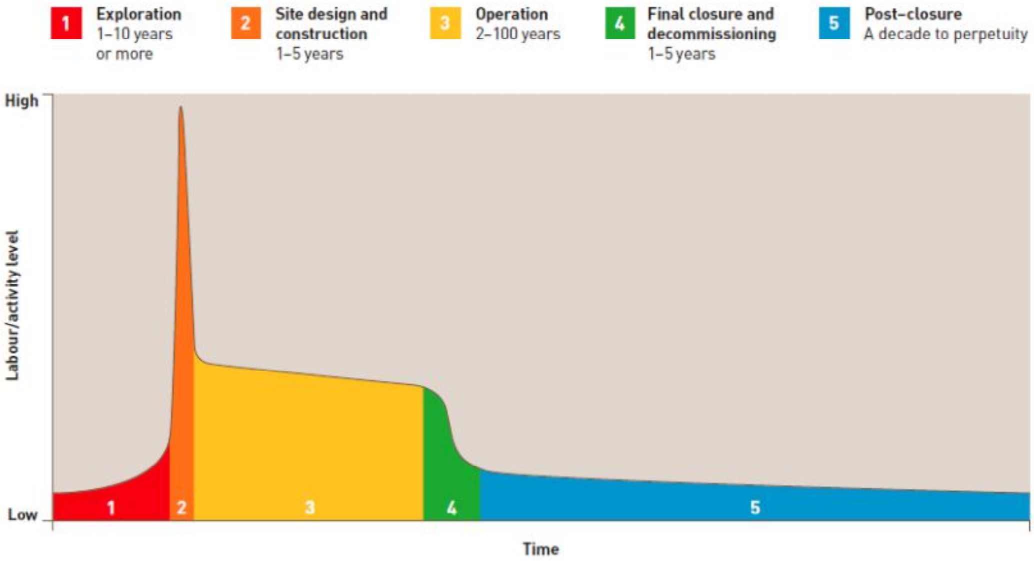


Figure 3.1 The mine project life cycle

Allowing for the time required for exploration and to find an orebody to develop a mine, as well as the decades or more for construction, operation, closure and post-closure management, a 20–30 year mine can often involve five to seven generations of relationships between an industry player (more than one company will likely be involved) and the host community. Many mining operations have an even longer lifespan which further extends the multi-generational relationship with communities. A critical feature of metals is their capacity to be recycled. While metals have been recycled for many centuries, the realization in the last few decades of the potential cost savings and reduction of environmental and social impacts achieved by recycling (linked for example to air and water emissions and reduced energy use) has led to an increased emphasis on recycling by regulators, business and consumers. This topic is described more fully in a later publication in this series, Uses of minerals and metals.

Mining and metal's contribution to sustainable development

At the heart of the concept of sustainable development lies the idea that any human activity, including mining, should be undertaken in such a way that the activity itself and the products produced provide a net positive long-term contribution to human and ecosystem well-being. The focus is not on how mining can be sustainable (recognizing that any individual mining operation has a finite lifespan) but on how mining, minerals and metals can contribute to sustainable development. This is a conceptual shift away from a singular analysis and mitigation of impacts to a more comprehensive analysis that looks at the wider contribution of the industry and its products.

The focus on contribution is a tougher but fairer approach. This is so because it demands a demonstration of positive results and not just mitigation of negative impacts. Such an approach is essential if mining and metals-related activities and the resulting products are to make the sustainable development contribution demanded by society and sought by industry leaders.

Today's regulatory systems are based on environmental and social impact analyses that emerged in the 1960s and 1970s. These recognized that many negative environmental and social implications of human activity were not included in traditional economics-driven cost-benefit analyses. Accordingly, the main focus has been on identifying and mitigating the negative, with less emphasis on recognizing, assessing and acknowledging the positive.

In other words, a legal mining license to operate is granted when the negative impacts are deemed to be well-defined and the mitigating strategies are adequate, rather than because the net contribution of a given project over the long term is positive.

Beyond the legal license, the concept of a social license to operate has been widely accepted by the industry as an essential attribute of success. It has prompted companies to look well beyond their self interest. However in practice, the social license too, tends to be focused on more immediate decisions and actions. A contribution perspective would push the boundaries and open opportunities for greater stability over the longer term.

Today's society is challenging the assumptions of the traditional social and environmental impact approaches. For its part, the industry has a key role to play in capturing and communicating the full value of its mining and processing activities and products. Box 1 shows a set of questions for addressing the sustainable development contribution of mining. This approach was first championed by the Mining, Minerals and Sustainable Development project in 2002, a project that undertook a far-reaching examination of industry practices and that contributed to the decision by leaders in the mining industry to form ICMM.

There can be no doubt that mining projects and the resulting mineral and metal products have a significant impact on human society and on the global ecosystem.

Mine projects are a source of livelihood and well-being for millions of people. For emerging nations they attract foreign direct investment, domestic investment, foreign earnings and government revenues. At the local level they provide an opportunity for employment, support for entrepreneurs to provide goods and services needed by mining activities and contribute to infrastructure and services in the local community.

Often located in remote areas, mining can provide a unique means for stimulating local economic activity. Throughout history, mineral discoveries have catalyzed the development of sparsely populated and remote areas. The discovery and development of mineral resources has provided an opportunity for addressing poverty reduction and helping countries in achieving the Millennium Development Goals (Table 3.3).

Goal	Description
1	Eradicate extreme poverty and hunger
2	Achieve universal primary education
3	Promote gender equality and empower women
4	Reduce child mortality
5	Improve maternal health
6	Combat HIV/AIDS,malariaand other diseases
7	Ensure environmental sustainability
8	Develop a global partnership for development

Table 3.3 Millennium Development Goals

However, local social and environmental implications are significant and can result in major socio-economic challenges. When mismanagement occurs (whether by government, company or community), the resulting impact can be adverse and severe. If a perceived or real inequitable distribution of costs, benefits, risks and responsibilities occurs, tensions can split a community, undermine a company's reputation and at worst, lead to conflict.

Importantly, while minerals and metals provide a material foundation for contemporary society, they are also a means for transforming current society into one marked by greater efficiencies, lower environmental stresses and more effective public services. Just as the businesses that produced them must be carefully managed, so too should the contribution these products can make to ensure that the benefits from their usage are realized.

Many of the complex issues facing modern mining and metals operations require collaborative involvement of multiple stakeholders. If such collaborations are to be effective, the responsibilities carried by companies, governments, communities and civil society must be clearly defined. These definitions must be accompanied by a monitoring, reporting and evaluation system that facilitates the enforcement of these responsibilities and enables stakeholders to learn from mistakes and successes.

Change and progress in the mining and metals industry

Achieving positive change in the mining and metals industry so that it can adjust to its evolving operating environment is a significant challenge for those inside and outside the sector.

In the early 1990s, concerns linked to mining activities in developing countries – particularly those characterized by high poverty - led some to suggest that mineral endowment constituted a kind of resource curse for these countries. We now know that this does not need to be the case. When managed responsibly and effectively, and in a context of good governance, mining and metals production can contribute meaningfully to an improvement in living standards, particularly in communities directly impacted by these operations.

In the late 1990s, CEOs from some of the world's leading mining companies launched an effort to reposition the industry in terms of both performance and perception. Faced with a groundswell of public criticism, it commissioned the International Institute for Environment and Development (IIED) to undertake a global review of practices and develop an agenda for strengthening the industry's contribution to sustainable development. Some 50,000 people from around the world participated in the resulting process that came to be known as the Mining, Minerals and Sustainable Development (MMSD) project. Out of that review emerged an agenda for change to strengthen the contribution of mining, minerals and metals to sustainable development. ICMM was created in 2001 to facilitate delivery of that agenda working with its members and others in pursuit of continuous performance improvement.

A decade later, what has been accomplished and which challenges remain? From an ICMM perspective, the following ten indicators highlight how the industry has changed markedly over the past decade. This list is far from comprehensive.

1. Reporting and assurance

Amongst leading companies there is now full acceptance and familiarity with annual reporting of performance against sustainable development principles using an independent third-party assured process. There has also been a steep increase in interest on the part of investors in the social and environmental performance of mining and metals companies, as well as the development of initiatives such as the Equator Principles and the IFC Performance Standards.

2. Mining and development

A clear formula for avoiding the resource curse now exists and is being followed in many parts of the world. More and more developing and emerging nations are finding that the role of mining and metals in their national economies can be a positive factor, that their dependency on mining and metals for economic strength is growing and that mining and metals can play a key role in addressing poverty reduction and other developmental issues. For their part, companies are accepting this developmental role, though the boundaries of responsibility between company, community and government remains a concern for all parties.

3. Revenue transparency

Today’s support for enhanced revenue transparency, as reflected in the commitment by governments, companies, investors and civil society organizations to the Extractive Industries Transparency Initiative, did not exist a decade ago.

4. Human rights

The committed focus on human rights by mining companies has increased significantly in the last decade, and the industry is now considered to be one of the leaders though many significant challenges remain.

5. Environment

Environmental management systems with a substantive focus on performance related to critical issues such as biodiversity protection and water management are now accepted priorities of most mining companies.

6. Health and safety

Clear progress on the introduction of robust systems that emphasize a health and safety culture. Significant reductions in lost-time injury incidents year-on-year have been achieved as well as similar improvements in occupational health. The industry still faces the challenge of eliminating fatalities in work-related accidents.

7. Climate change

The mining and metals industry’s committed entry into the climate change arena through engagement at the country level by both companies and national associations, regional association engagement in Europe and ICMM’s championing of a generic set of principles for guiding the development of climate change-related public policy, represents a significant change. Closely linked to this is ongoing work on enhancing energy efficiencies, reducing carbon emissions contributing more effectively to local energy needs, and recognizing the role of minerals and metals in a low carbon economy.

8. Relationship building and shared value

The industry’s recognition of the importance of relationship building and the creation of shared value – for communities, companies, and governments – reflects a dramatic change to previous business approaches. The recent statement by a CEO that “the greatest insurance policy I have is community trust”, reflects this recognition. Unfortunately, there are many locations where this degree of trust does not exist.

9. Full project life cycle, long time horizon

Recognition by the industry, communities, civil society and government to consider the full project life cycle – from exploration through to the long post-closure period – in a mine's design and financial analysis reflects a major evolution. The impact of this life cycle approach on a project's technical, financial, environmental and social outcomes remains to be seen. Unfortunately, the thorny issue of addressing legacy and orphaned sites is being resolved slowly in most countries.

10. Sustainability footprint and tracking responsible performance across the full life cycle Initially driven by concerns over illicit support of factions in conflict areas ("blood diamonds"), the increased interest in tracking performance across the full product life cycle of metal and metal products, has resulted in a strong focus on life cycle assessment. The development of an integrated "sustainability footprint" would not have been considered necessary a decade ago.

The mining and metals industry as an agent of change

Mining and metals operations bring significant change – social, environmental, and economic. Change is inevitable. In raising the concept of contribution, this series of publications is explicitly recognizing the role of the industry as an agent of change. They begin to describe the design and performance criteria needed to ensure that the net result of the industry's impact is positive over the long term.

3.2 Geothermal Power Plants

The generation of electrical power using the thermal energy contained in the fluid circulating in deep lying formations in geothermal areas is typically quite feasible in the fluid temperature range of 200°C to 320°C, which characterizes so called high-temperature (high enthalpy) geothermal areas.

Geothermal fluid of this temperature is generally mined using current technology at resource depths between about 1200 m to 2500 – 3000 m in Iceland and most other geothermal areas of the world, for instance the USA, the Philippines, Indonesia, Japan, New Zealand, Mexico, Kenya and El Salvador to name a few.

Geothermal energy is renewable, when measured relative to human age spans, and generally categorized as such. It is environmentally benign ("green") and has many advantages over other renewable energy resources, such as hydro, wind, bioenergy and wave energy. The following are the more important of these advantages:

High degree of availability (>98% and 7500 operating hrs/annum common).

Low land use.

Low atmospheric pollution compared to fossil fuelled plants.

Almost zero liquid pollution with re-injection of effluent liquid.

Insignificant dependence on weather conditions.

Comparatively low visual impact.

In compliance with current environmental, resource and economic sustainability principles it (Axelsson et al., 2001, 2003, and 2005) is important to select technologies and operational systems for the highest possible over all thermal efficiency for extracting the useful thermal energy, contained in the fluid, before it is returned back to the reservoir. The advantage of adopting such policies is the reduced number of production and injection wells required, less replacement drilling, higher level of sustainability, and greater environmental benefits.

These advantages may be attained in several ways, the optimal of which are multiple use (e.g. simultaneous electricity plus hot water production) systems and hybrid power plants.

The following chapter addresses the most common types of technologies applied in the conversion of geothermal energy into electric power; reviews some of the associated problems, and available countermeasures.

3.2.1 Overview of Power Plant Designs

This chapter addresses the geothermal to electrical power conversion systems typically in use in the world today. These may be divided into three basic systems, wiz:

Flashed steam/dry steam condensing system; resource temperature range from about 320°C to some 230°C.

Flashed steam back pressure system; resource temperature range from about 320°C to some 200°C.

Binary or twin-fluid system (based upon the Kalina or the Organic Rankine Cycle); resource temperature range between 120°C to about 190°C.

In addition to the above three basic power conversion systems, there are in use, the so called hybrid systems, which are in fact a combined system comprising two or more of the above basic types in series and/or in parallel.

Condensing and back pressure type geothermal turbines are essentially low pressure machines designed for operation at a range of inlet pressures ranging from about 20 – 2 bar, and saturated steam.

They are generally manufactured in output module sizes of the following power ratings, i.e. 25 MW, 35 MW, 45 MW, 55 MW and 105 MW (the largest currently manufactured geothermal turbine unit is 117 MW). Binary type low/medium temperature units, whereof the Kalina Cycle or Organic Rankine Cycle type, are typically manufactured in smaller modular sizes, i.e. ranging between 1 MWe and 10 MWe in size. Larger units specially tailored to a specific use are, however, available typically at a somewhat higher price.

3.2.1.1 Back pressure type systems

Back pressure type systems are the simplest of the above, least expensive and have the lowest overall thermal efficiency. Currently they are largely used in multiple use applications (such as combined electricity and hot water production), to provide temporary power during resource development, in the mineral mining industry where energy efficiency has low priority, and most importantly as part of a hybrid system. Their stand-alone scope of application covers the whole of the normally useful geothermal resource temperature range, i.e. from about 320°C to some 200°C.

3.2.1.2 Condensing type systems

Condensing type systems are somewhat more complex in as much as they require a condenser, and gas exhaust system. This is the most common type of power conversion system in use today. The turbine is an expansion machine and the unit normally comprises two turbine sets arranged coaxially cheek to cheek (hp end to hp end) to eliminate/minimize axial thrust. To improve its thermal efficiency and flexibility, the unit is also available in a twin pressure configuration (say 7 bar/2 bar), where the lower pressure (say 2 bar) steam is induced downstream of the third expansion stage.

When these condensing turbines are used in a co-generation scheme they may be fitted with extraction points to provide low pressure steam to the district heating side. The hallmarks of the condensing system are long and reliable service at reasonable over all thermal efficiency, and good load following capability.

Their stand-alone scope of application covers the high to medium (200–320°C) geothermal resource temperature range.

3.2.1.3 Binary type systems

Binary type systems are of a quite different concept. The thermal energy of the geothermal fluid from the production well field is transferred to a secondary fluid system via heat exchangers. The geothermal fluid is thus isolated from the secondary fluid, which comprises a low boiling point carbohydrate (butane, propane etc.) or specially designed low boiling point fluid, which complies with low ozone layer pollution constraints, in the case of the Organic Rankin Cycle. In the case of the Kalina Cycle, the secondary or motive liquid comprises water solution of ammonia. This heated secondary fluid thereupon becomes the motive fluid driving the turbine/generator unit.

The hallmark of the binary system is its ability to convert low-temperature (120–190°C) geothermal energy to electric power albeit at a relatively low overall thermal efficiency, and to isolate scaling, gas and erosion problems at an early point in the power conversion cycle in a heat exchanger.

The binary system is quite complex and maintenance intensive. Typical geothermal back pressure, condensing, binary and hybrid systems are depicted in diagrams, Figures 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7.

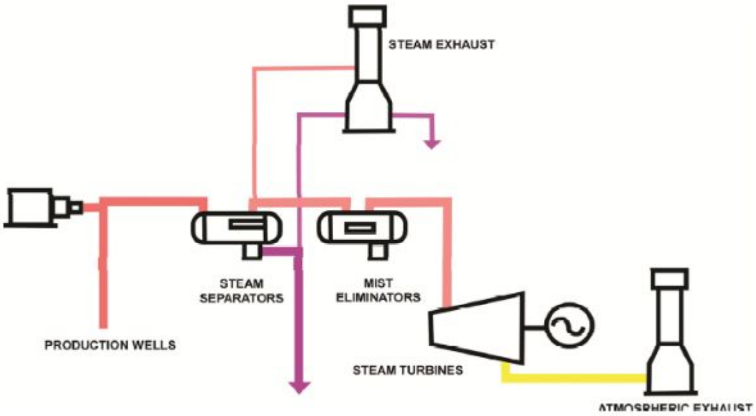


Figure 3.2 Typical backpressure turbine generator conversion system

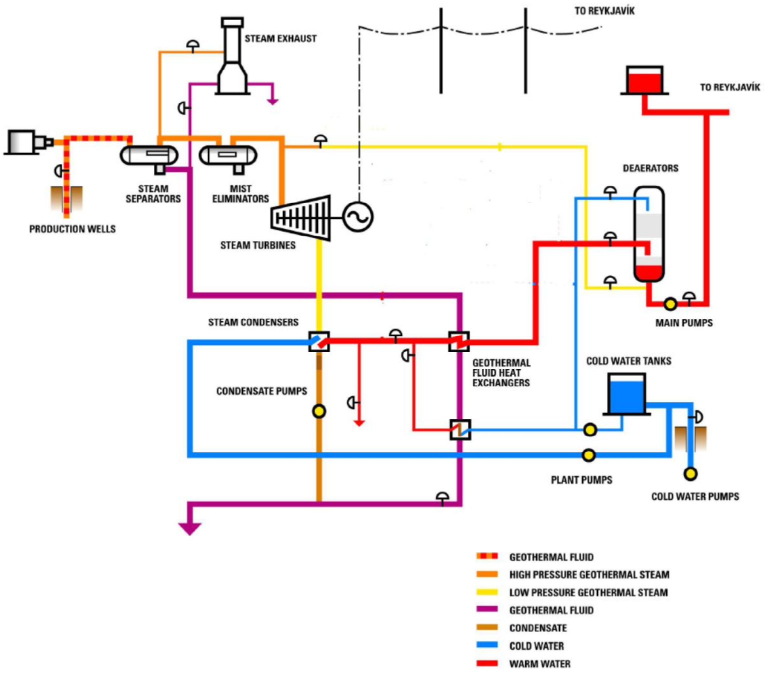


Figure 3.3 Condensing type turbine generator unit in combined utilisation (Reykjavik Energy)

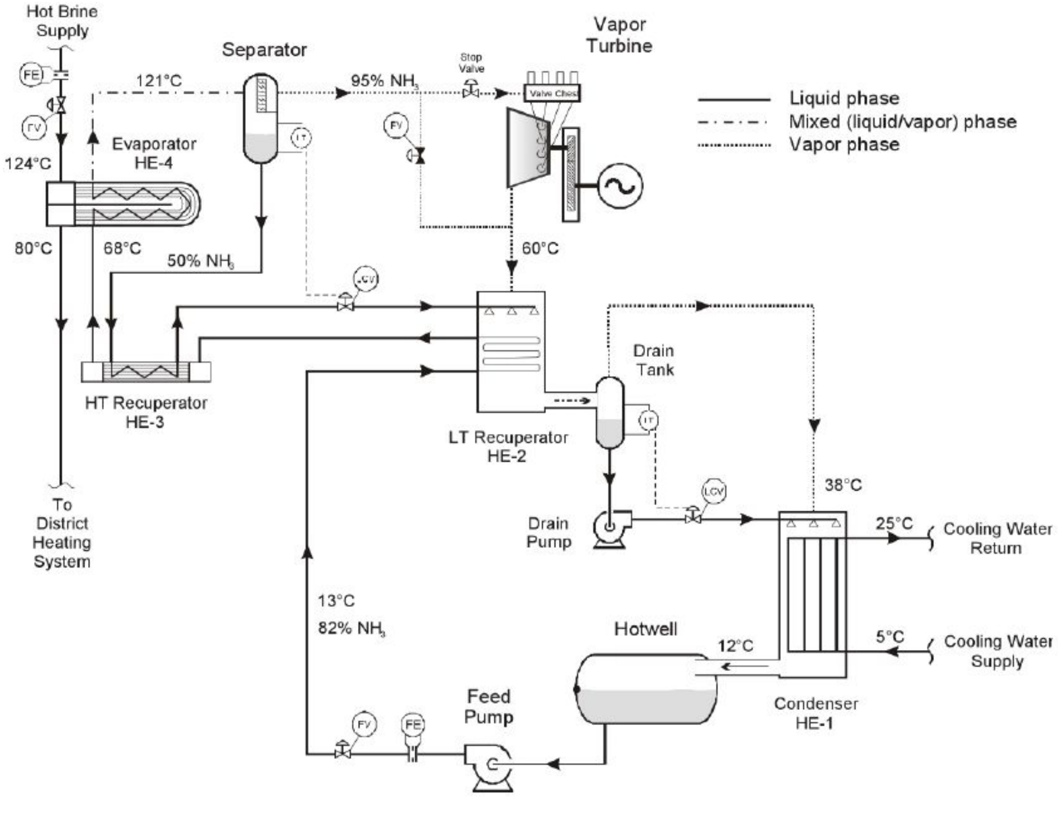


Figure 3.4 Kalina cycle converter(Xorka Ltd.)

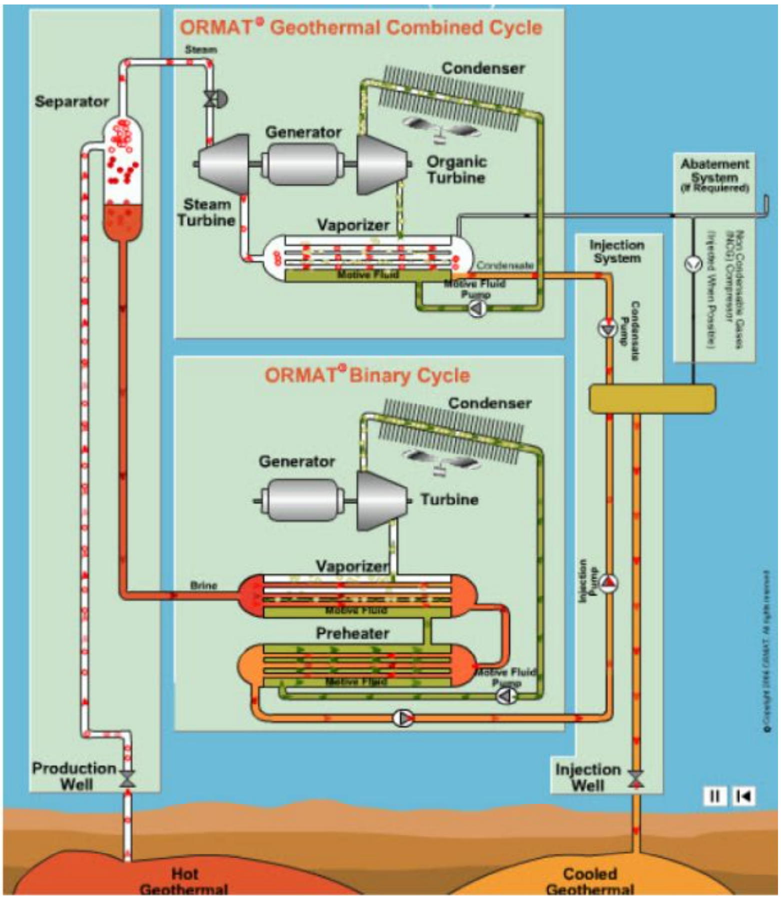


Figure 3.5 Ormat type Organic Rankine Cycle (Ormat Technologies Inc.)

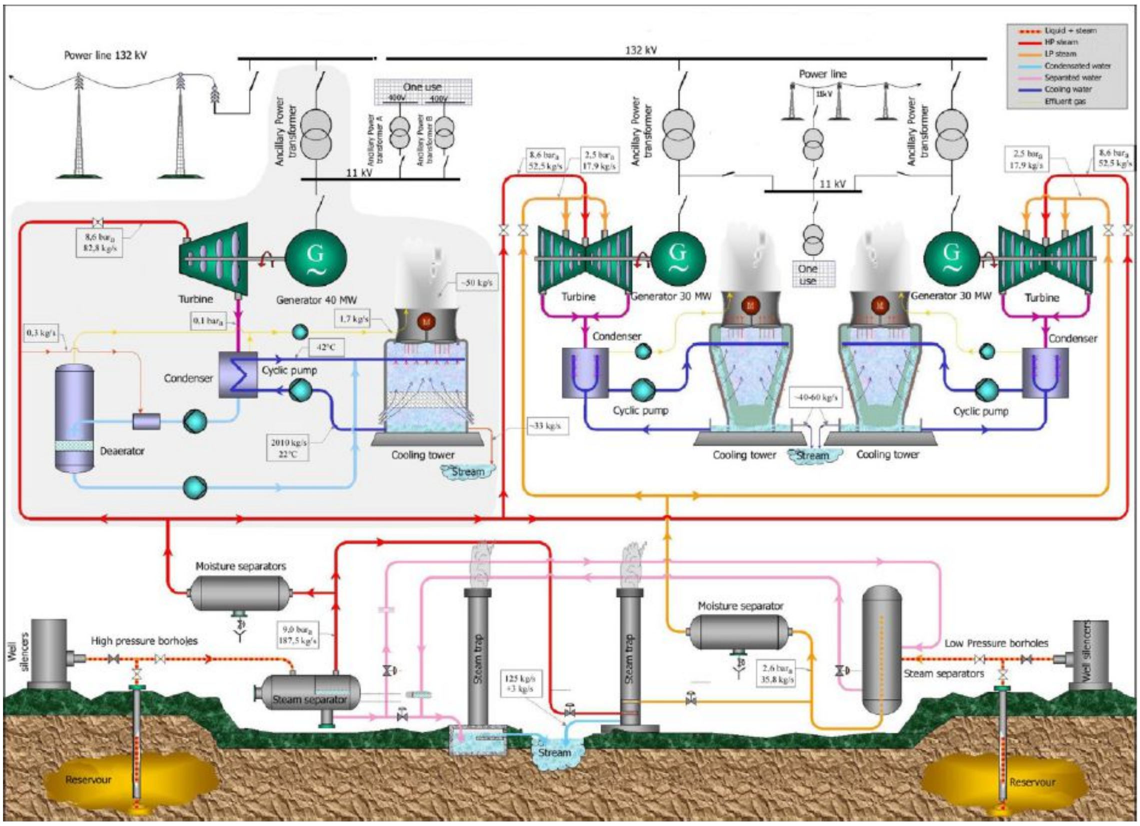


Figure 3.6 Condensing single and twin pressure t/g unit (Landsvirkjum, Iceland)

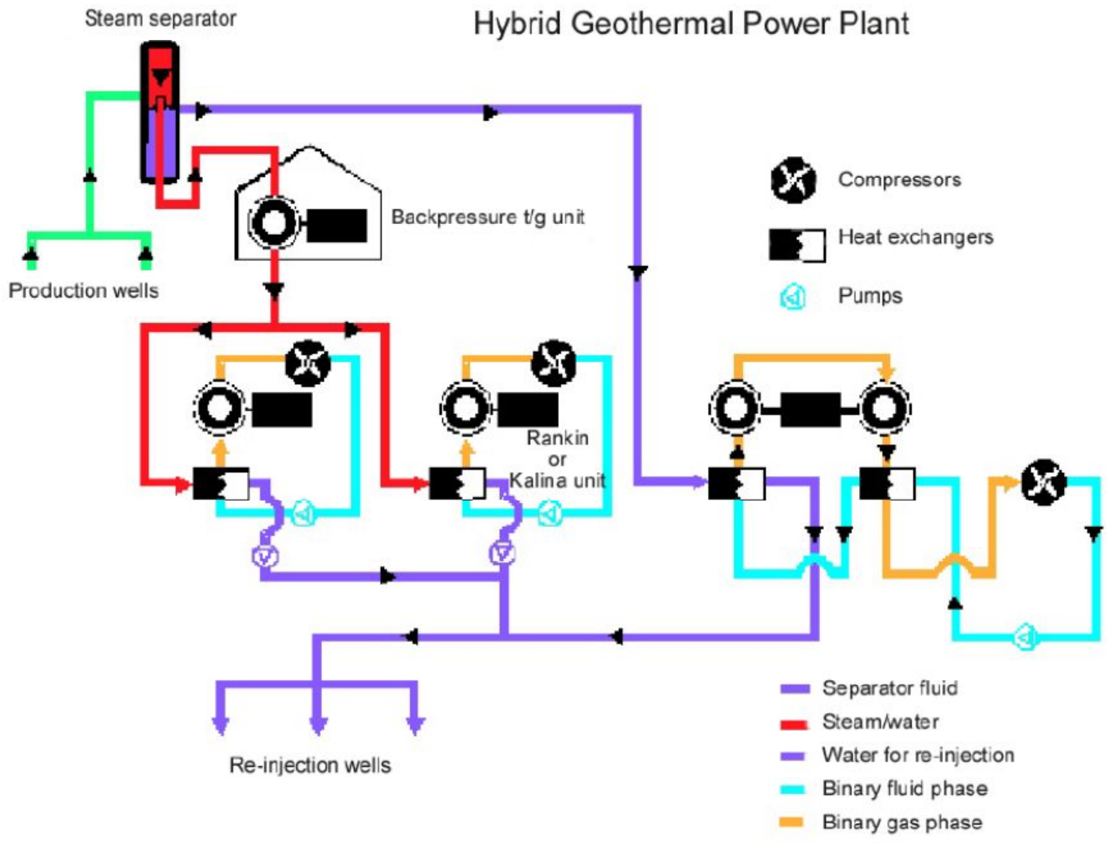


Figure 3.7 Hybrid conversion system

3.2.1.4 Hybrid conversion system

The hybrid conversion system is a combined system, as said before, encompassing two or more of the basic types in series and/or in parallel. Their hallmark is versatility, increased overall thermal efficiency, improved load following capability, and ability to efficiently cover the medial (200–260°C) resource temperature range (Tester, 2007).

To illustrate the concept a hybrid configuration encompassing a backpressure flashed steam turbine/generator unit and three binary units in series is depicted in Figure 4. Two of the binary units utilize the exhaust steam from the back pressure unit, and the remaining binary t/g unit utilizes the energy content of the separator fluid. The fluid effluent streams are then combined for re-injection back into the geothermal reservoir, so maintaining sustainability of the resource in a most elegant manner.

3.2.2 Prevailing Problem Types and Countermeasures in Operation of Power Plants

Different parts of the surface components of power generation system have associated different problem flora. It is therefore expedient to divide the system into the following seven principal portions:

Power house equipment: Comprising of turbine/generator unit complete with condenser, gas exhaust system.

Automatic control and communication system: Consisting of frequency control, servo valve control, computer system for data collection, resource and maintenance monitoring, internal and external communication etc.

Cooling system: Cooling water pumps, condensate pumps, fresh water (seawater) cooling, or cooling towers.

Particulate and/or droplet erosion: This is an erosion problem that is typically associated with the parts of the system where the fluid is accelerated (e.g. in control valves, turbine nozzles, etc.) and/or abruptly made change direction (e.g. via pipe bends, T-fittings or wanes).

Heat exchangers: These are either of the plate or the tube and shell type. These are generally only used in binary and hybrid type conversion systems, and/or in integrated systems.

Gas evacuation systems: High temperature geothermal fluid contains a significant quantity of non-condensable gases (C02, N2, H2S, and others). These have to be removed for instance from the condensing plant for reasons of conversion efficiency.

Some countries require the gas to be cleaned of H2S or Hg to minimize atmospheric pollution.

Re-injection system: Comprising liquid effluent collection pipelines, injection pumps, injection pipelines, injection wells and control system.

Chemical injection system: In order to reduce scaling of calcite in production wells sometimes a scale inhibitor is injected through a capillary tubing down hole. Similar injection is applied with caustic soda to neutralize acid wells to reduce the corrosivity.

Acid is used for pH modification in order to arrest the scaling of silica in waste water going to reinjection, for cases where the water is supersaturated. Chemical control of pH by caustic soda and of biofilms is also applied to the cooling water (turbine condenser/cooling towers).

The problem areas typical for each of these conversion components are now outlined in turn each under its own chapter heading. It must, however, be emphasized that the featured problems and counter measures can only be addressed in general terms because of their site and locality specific nature. A locality specific case by case pre-engineering study is decidedly required in order to address this subject matter in any detail.

3.2.2.1 Power house equipment

3.2.2.1.1 Turbine

The problems potentially associated with the turbine are scaling of the flow control valve and nozzles (primarily in the stator inlet stage); stress corrosion of rotor blades; erosion of turbine (rotor and stator) blades and turbine housing.

The rate and seriousness of scaling in the turbine are directly related to the steam cleanliness, i.e. the quantity and characteristics of separator "carry-over". Thus the operation and efficiency of the separator are of great importance to trouble free turbine operation. Prolonged operation of the power plant off-design point also plays a significant role.

Most of the scaling takes place in the flow control valve and the first stator nozzle row. The effect of this scaling is:

A significant drop-off in generating capacity as sufficient steam cannot enter the turbine, and;

Sluggish response to load demand variations.

This situation is easily monitored, since the build-up of scales causes the pressure in the steam chest between the control valve and the inlet nozzles to increase over time.

Significant turbine and control valve scaling is avoided by the adoption of careful flasher/separator plant operating practices that minimize "carry-over", and moreover selecting a high efficiency mist eliminator by the power plant.

Significant scaling in turbine and control valve requires scheduled maintenance stops for inspection and cleaning, every second or third year.

Another means of reducing turbine cleaning frequency, is to inject condensate into the inlet steam during plant operation and run the turbine at say 10% wetness for a short period. This washes away nozzle scaling, in particular the calcite component thereof, and simultaneously weakens the silica scale structure, which then tends to break off. This cleaning technique if properly applied has been found to reduce the frequency of major turbine overhaul.

3.2.2.1.2 Generator

It must be pointed out here that high-temperature steam contains a significant amount of carbon dioxide CO2 and some hydrogen sulphite H2S and the atmosphere in geothermal areas is thus permeated by these gases. All electrical equipment and apparatus contains a lot of cuprous or silver components, which are highly susceptible to sulphite corrosion and thus have to be kept in an H2S free environment. This is achieved by filtering the air entering the ventilation system and maintaining slight overpressure in the control room and electrical control centres.

The power generator is either cooled by nitrogen gas or atmospheric air that has been cleaned of H2S by passage through special active carbon filter banks.

3.2.2.1.3 Condenser

The steam-water mixture emitted from the turbine at outlet contains a significant amount of non condensable gases comprising mainly CO2 (which is usually 95–98% of the total gas content), CH4 and H2S, and is thus highly acidic. Since most high-temperature geothermal resources are located in arid or semi-arid areas far removed from significant freshwater (rivers, lakes) sources, the condenser cooling choices are mostly limited to either atmospheric cooling towers or forced ventilation ones.

The application of evaporative cooling of the condensate results in the condensate containing dissolved oxygen in addition to the non-condensable gases, which make the condenser fluid highly corrosive and require the condenser to be clad on the inside with stainless steel; condensate pumps to be made of stainless steel, and all condensate pipelines either of stainless steel or glass reinforced plastic. Addition of caustic soda is required to adjust the pH in the cooling tower circuit. Make-up water and blow-down is also used to avoid accumulation of salts in the water caused by evaporation.

A problem sometimes encountered within the condenser is the deposition of almost pure sulphur on walls and nozzles within the condenser. This scale deposition must be periodically cleaned by high pressure water spraying etc.

3.2.2.2 Automatic control and communication system

Modern power plants are fitted with a complex of automatic control apparatus, computers and various forms of communication hardware. These all have components of silver and cuprous compounds that are extremely sensitive to H2S corrosion. They are therefore housed inside “clean enclosures”, i.e. airtight enclosures that are supplied with atmospheric air under pressure higher than that of the ambient atmospheric one and specially scrubbed of H2S. Entrance and exit from this enclosure is through a clean air blow-through antechamber to prevent H2S ingress via those entering the enclosure.

A more recent design is to clean all the air in all control rooms by special filtration and maintain overpressure.

Most other current carrying cables and bus bars are of aluminium to prevent H2S corrosion. Where copper cables are used a field applied hot-tin coating is applied to all exposed ends.

3.2.2.3 Cooling tower system

3.2.2.3.1 Cooling tower and associated equipment

Most high-temperature geothermal resources are located in arid or semi-arid areas far removed from significant freshwater (rivers, lakes) sources. This mostly limits condenser cooling choices to either atmospheric cooling towers or forced ventilation ones. Freshwater cooling from a river is, however, used for instance in New Zealand and seawater cooling from wells on Reykjanes, Iceland.

In older power plants the atmospheric versions and/or barometric ones, the large parabolic ones of concrete, were most often chosen. Most frequently chosen for modern power plants is the forced ventilation type because of environmental issues and local proneness to earth quakes.

The modern forced ventilation cooling towers are typically of wooden/plastic construction comprising several parallel cooling cells erected on top of a lined concrete condensate pond. The ventilation fans are normally vertical, reversible flow type and the cooling water pumped onto a platform at the top of the tower fitted with a large number of nozzles, through which the hot condensate drips in counterflow to the airflow onto and through the filling material in the tower and thence into the condensate pond, whence the cooled condensate is sucked by the condenser vacuum back into the condenser. To minimize scaling and corrosion effects the condensate is neutralized through pH control, principally via addition of sodium carbonate.

Three types of problems are found to be associated with the cooling towers, i.e.

Icing problems in cold areas.

Sand blown onto the tower in sandy and arid areas.

Clogging up by sulphitephylic bacteria.

The first mentioned is countered by reversing the airflow cell by cell in rotation whilst operating thus melting off any icing and snow collecting on the tower.

The second problem requires frequent cleaning of nozzles and condensate pond. The last mentioned is quite bothersome. It is most commonly alleviated by periodic application of bacteria killing chemicals, and cleaning of cooling tower nozzles by water jetting. The sludge accumulation in the condensate pond, however, is removed during scheduled maintenance stops. A secondary problem is the deposition of almost pure sulphur on walls and other surfaces within the condenser. It must be periodically cleaned by high pressure water spraying etc., which must be carried out during scheduled turbine stops.

3.2.2.4 Condenser pumping system

The condensate pumps must, as recounted previously, be made of highly corrosion resistant materials, and have high suction head capabilities**.** They are mostly trouble free in operation.

The condensate pipes must also be made of highly corrosion resistant materials and all joints efficiently sealed to keep atmospheric air ingress to a minimum, bearing in mind that such pipes are all in a vacuum environment. Any air leakage increases the load on the gas evacuation system and thus the ancillary power consumption of the power plant.

3.2.2.5 Particulate/droplet erosion and countermeasures

Geothermal production wells in many steam dominated reservoir have entrapped in the well flow minute solids particles (dust), which because of the prevailing high flow velocities may cause particulate erosion in the well head and downstream of it. Such erosion in the well head may, in extreme cases, cause damage of consequence to wellhead valves, and wellhead and fittings, particularly in T-fittings and sharp bends in the fluid collection pipelines. This is, however, generally not the case and such damage mostly quite insignificant. It is, however, always a good practice to use fairly large radius pipe bends to minimize any such erosion effects.

Droplet erosion is largely confined to the turbine rotor and housing. At exit from the second or the third expansion stage the steam becomes wet and condensate droplets tend to form in and after the expansion nozzles. Wetness of 10% to 12% is not uncommon in the last stages. The rotor blades have furthermore reached a size where the blade tip speeds become considerable and the condensate droplets hit the blade edges causing erosion. The condensate water which has become acidic from the dissolved non condensable gas attaches to the blades and is thrown against the housing. This water has the potential to cause erosion problems. The most effective countermeasures are to fit the blade edges of the last two stages with carbide inserts (Stellite) that is resistant to the droplet impingement and the housing with suitable flow groves that reduce the condensate flow and thereby potential erosion damage.

In addition to the erosion the blades and rotor are susceptible to stress corrosion in the H2S environment inside the turbine housing. The most effective countermeasure is to exercise great care in selecting rotor, expansion nozzle and rotor blade material that is resistant to hydrogen sulphite corrosion cracking. The generally most effective materials for the purpose are high chromium steels.

3.2.2.6 Heat exchangers

In high-temperature power generation applications heat exchangers are generally not used on the well fluid. Their use is generally confined to ancillary uses such as heating, etc. using the dry steam. In cogeneration plants such as the simultaneous production of hot water and electricity, their use is universal. The exhaust from a back pressure turbine or tap-off steam from a process turbine is passed as primary fluid through either a plate or a tube and shell type heat exchanger. The plate type heat exchanger was much in favour in cogeneration plants in the seventies to nineties because of their compactness and high efficiency. They were, however, found to be rather heavy in maintenance. The second drawback was that the high corrosion resistance plate materials required were only able to withstand a relatively moderate pressure difference between primary and secondary heat exchanger media. Thirdly the plate seals tended to degenerate fairly fast and stick tenaciously to the plates making removal difficult without damaging the seals. The seals that were needed to withstand the required temperature and pressure were also pricy and not always in stock with the suppliers. This has led most plant operators to change over to and new plant designers to select the shell and tube configurations, which demand less maintenance and are easily cleaned than the plate type though requiring more room.

In low-temperature binary power plants shell and tube heat exchangers are used to transfer the heat from the geothermal primary fluid to the secondary (binary) fluid. They are also used as condensers/and or regenerators in the secondary system.

In supercritical geothermal power generation situation it is foreseen that shell and tube heat exchangers will be used to transfer the thermal energy of the supercritical fluid to the production of clean steam to power the envisaged power conversion system.

In all instances it is very important to select tube and/or plate material in contact with the geothermal fluid that will withstand the temperature, pressure and corrosion potential of the fluid. Some inconel, titanium and duplex stainless steel alloys have given good service. It is also important to make space allowance for tube withdrawal for maintenance and/or tube cleaning procedures. High pressure waterjet cleaning has for instance proved its value.

Scaling will normally be present. Provisions should therefore be made timely for scale abatement such as by hydrothermal operation or chemical scale inhibitor injection, and/or mechanical cleaning.

3.2.2.7 Gas evacuation system

As previously stated the geothermal steam contains a significant quantity of non-condensable gas (NCG) or some 0.5% to 10% by weight of steam in the very worst case. To provide and maintain sufficient vacuum in the condenser, the NCG plus any atmospheric air leakage into the condenser must be forcibly exhausted. The following methods are typically adopted, viz.:

The use of a single or two stage steam ejectors, economical for NCG content less than 1.5% by weight of steam.

The use of mechanical gas pumps, such as liquid ring vacuum pumps, which are economical for high concentration of NCG.

The use of hybrid systems incorporating methods 1 and 2 in series.

The advantages of the ejector systems are the low maintenance, and high operational security of such systems.

The disadvantage is the significant pressure steam consumption, which otherwise would be available for power production.

The advantages of the vacuum pumps are the high degree of evacuation possible. The disadvantage is the electric ancillary power consumption, sensitivity to particulate debris in the condenser, and high maintenance requirements.

To reduce the ambient level of H2S in the proximity of the power plant, the exhausted NCG is currently in most countries discharged below the cooling tower ventilators to ensure a thorough mixing with the air as it is being blown high into the air and away from the power plant and its environs. In the USA and Italy H2S abatement is mandatory by law, and in Italy also mercury (Hg) and thus require chemical type abatement measures.

In some of the older Geysers field power plants the H2S rich condenser exhaust was passed through a bed of iron and zinc oxide to remove the H2S. These proved a very messy way of getting rid of the H2S and were mostly abandoned after a few years. In a few instances the Stretford process and other equivalent ones have been used upstream of the power plant to convert H2S gas into sulphur for industrial use. This has proved expensive and complex and is not in use in other geothermal fields than the Geysers field in California.

The main H2S abatement methods currently in use worldwide are (only some are currently used for geothermal NCG):

Claus (Selectox).

Haldor Topsöe – WSA process.

Shell-Paques Biological H2S removal process/THIOPAC.

LO-CAT (wet scrubbing liquid redox system).

Fe-Cl hybrid process.

Aqueous NaOH absorbent process.

Polar organic absorbent process.

Photo catalytic generation process.

Plasma chemical generation process.

Thermal decomposition process.

Membrane technology.

A study into feasible H2S abatement methods for the Nesjavellir Geothermal Project was carried out by Matthíasdóttir (2006). Matthíasdóttir and Gunnarsson, from the Iceland Technology Institute, came to the conclusion that of the above listed methods the following four merited further study for Nesjavellir, i.e the Haldor Topsöe-WSA, THIOPAQ (with bacteria), LO-CAT and the Fe-Cl hybrid process.

3.2.2.8 Re-injection system

In most geothermal areas the geothermal fluid may be considered to be brine because of the typically high chloride content. It may also contain some undesirable tracer elements that pose danger to humans, fauna and flora.

In considering the most convenient way of disposing of this liquid effluent other than into effluent ponds on the surface, the idea of injecting the liquid effluent back into the ground has been with the geothermal power industry for a long time (Stefánsson, 1997). Initially the purpose of re-injection was simply to get rid of the liquid effluent in a more elegant way than dumping it on the surface, into lakes or rivers, and even to the ocean. Many technical and economic drawbacks were soon discovered. The more serious of these were the clogging up of injection wells, injection piping and the formations close to the borehole; the cold effluent migrated into the production zone so reducing the enthalpy of the well output with consequent fall-off in power plant output. Injection into sandstone and other porous alluvial formations was and is fraught with loss of injectivity problems that are still not fully understood.

Soon, however, it became generally understood and accepted that returning the effluent liquid back into the reservoir had even greater additional benefits, viz.:

Greatly reducing the rate of reservoir pressure and fluid yield decline.

Improved extraction of the heat content contained within the reservoir formations.

Reducing the fluid withdrawal effect on surface manifestations, e.g. hot pools, steam vents etc.

All the above items serve to maintain resource sustainability and are thus of significant environmental benefit.

Re-injection should be considered an integral part of any modern, sustainable and environmentally friendly geothermal utilization, both as a method of effluent water disposal and to counteract pressure draw-down by providing artificial water recharge (Stefánsson, 1997). Re-injection is essential for sustainable utilization of virtually closed and limited recharge geothermal systems. Cooling of production wells, which is one of the dangers associated with re-injection, can be minimized through careful testing and research. Tracer testing, combined with comprehensive interpretation, is probably the most important tool for this purpose.

Many different methods have and are still being tried to overcome these technical problems mentioned above such as the use of settling tanks that promote polymerization of the silica molecules and settling in the tanks prior to injection; injection of the effluent liquid directly from the separators at temperatures in the range of 145–160°C, so called “hot injection”, both to avoid contact with atmospheric air and to hinder scaling in the injection system; controlling the pH of the effluent commensurate with reduction in the rate of silica/calcite precipitation using acids and add condensate from the plant to dilute the silica in the brine, to name a few. The danger of production well cooling can be minimized through careful testing and research. Tracer testing, combined with comprehensive interpretation, is probably the most important tool for this purpose. One way to delay the effects of cooling is also to locate the re-injection wells far enough away from the production area, say 2 km.

Another way gaining popularity is to inject deep into the reservoir, even where there is small permeability, by pumping at high pressures (60–100 bar).

Surface disposal contravenes the environmental statutes of most countries and the use of settling tanks has ceased mostly because of associated cost and complexity. The most commonly adopted injection methods are the last two, i.e. hot re-injection and chemical pH control ones. The main disadvantage of the hot re-injection technique is the lowered overall thermal efficiency and the consequent greater fluid production (more wells to yield the same power output) required. The main disadvantage of the pH control scheme is the very large acid consumption (cost) and uncertainties regarding its long-term effects.

Hot re-injection is precluded in low-temperature power generation and the most common technique is to make use of the reverse solubility of calcite in water by operating the conversion system at a pressure level above the CO2 bubble point and only reduce the pressure once the fluid temperature has attained a level low enough to prevent calcite dissipation prior to re-injection.

3.2.3 Geothermal Energy in Mining Developments: Synergies and Opportunities Throughout a Mine's Operational Life Cycle

Mines are heavy energy consumers and energy costs are significantly high for remote mines located far from the grid, due to considerable spending on fuel and fuel transportation. The mining industry is also increasingly aware of the need to shift towards cleaner energy sources in order to reduce its environmental impact. As a reliable source, capable of delivering very high availability factors, geothermal is an important, though often overlooked, energy option for the mining industry. For mines that are located in areas of high geothermal potential, geothermal energy can provide for parts of a mining operation’s electrical power needs.

Geothermal fluids are utilized in a variety of ways during the operational life cycle of a mine. In the production stage, hot fluids are used directly in applications such as raffinate heating in copper production and enhanced heap leaching for the extraction of gold and silver. Underground mines in areas of high geothermal potential must deal with higher ventilation loads; these can be partially provided for by in-situ geothermal power generation. Geothermal fluids can also provide energy for space heating, typically a substantial load for northern mines. In the closure and post-closure phases of a project, hot water irrigation can enhance reclamation rates, while an operating power plant that is turned over to the local community results in jobs creation, and can support community development through projects such as geothermal district heating. In addition, geothermal energy helps reduce a mine's environmental impact and Greenhouse Gas (GHG) emissions and improves its reputation within local communities, while "greening" its portfolio and contributing to sustainable development and the process of acquiring and retaining a social license to operate. The main factors affecting the successful integration of geothermal energy in a mining development are: the presence of a proven, accessible, and extractable resource; the relative price of alternate energy options; the distance from/to the grid; the potential for coproduction and/or minerals extraction; and the availability of communities and other industries in the vicinity of the mine. This paper outlines the synergies between mining and geothermal energy, and explores the ways in which geothermal energy can contribute to the development and operation of a mine.

Central to the argument that geothermal is a highly attractive energy option for mining operators are the many characteristics, resources and processes shared by the two industries, as discussed below.

3.2.3.1 Basic definitions

Mining or *mineral resource extraction* is the process through which economically valuable mineral resources, namely *metals* (including: ferrous metals, such as iron, manganese and tungsten; *base metals*, such as copper, lead and zinc; and *precious metals*, such as gold, silver and platinum), *non-metallic/industrial minerals* (i.e. *nonfuel mineral ores* that not associated with the production of metals, such as phosphate, limestone, and sulfur), or *energy minerals* (e.g. *fossil fuels* such as coal, petroleum, and natural gas, and uranium), are identified, located, extracted, and processed, for their subsequent use in consumer products (Hartman and Mutmansky 2002). Correspondingly, *geothermal energy* production can be defined as the process through which economically valuable hot geothermal fluids are identified, located, extracted and processed, for their subsequent use in electricity generation, or in direct, non-electric applications (Dickson and Fanelli 2003). In this analogy, the extraction of geothermal fluid is seen simply as another mining project, with heat replacing mineral fuels as the economically valuable resource.

Mining and geothermal production also share a dependence to the concepts of *accessibility* and *extractability*. Mineral deposits must have sufficient economic value to be mined at a profit. This means that the ore must be of sufficiently high grade, it must be located in a physically accessible location and at practically attainable extraction depths, and it must be extractable at an economically viable extraction cost (American Geological Institute 2003; Johnson et al. 2010; Johnson et al. 2011). In geothermal production, it is the fluid's heat content (expressed as enthalpy), accessibility (in terms of practically drillable depths), and extractability (in terms of achievable mass flow rates from a given well) that determine whether a geothermal resource is economically valuable and warrants production (DiPippo 2012).

3.2.3.2 Mining, heat, and water use

Heat and water are cardinal elements of geothermal systems. They also play a key role in mining and mineral extraction. As a transport medium, water mixes with crushed ore to produce ore slurry that can be piped through for processing in a more efficient and economic manner to trucking or hauling. As an excess by-product in pits and underground tunnels however, it can disrupt access to the mine workings, and must therefore be removed (International Council on Mining and Minerals 2012). Heat addition to specific mineral processes can significantly enhance yields and production efficiencies. Conversely, excessive heat flow in underground mine galleries located in areas of adverse temperature gradients constitutes a safety hazard for mine workers, and must be continuously cooled and ventilated at a correspondingly higher operational cost.

Heat recovery is only valuable if the recovered heat can be reused. Through careful whole-system analysis and design, heat losses and water use can be monitored in order to balance loads, improve performance, decrease emissions and minimize waste. For a mine with access to low-temperature geothermal resources, the addition of waste heat recovery either from exothermic mineral processes or high-load ventilation and cooling systems, can further improve performance, efficiency, and cost-reduction. The captured heat can be stored on-site or used directly as process heat. For example, the Finish smelter operator Boliden Harjavalta Oy recovers 20 MWth of heat from its sulphuric acid plant; half of this heat energy is used in the company's adjacent copper and nickel plants, and the other half is sold to a local district heating network (AlfaLaval 2011). Alternatively, the recovered heat can be supplied to an Organic Rankin Cycle (ORC) heat engine to generate supplementary electricity; water with temperatures as low as 78°C can be used as a heat source in this manner (Zarrouk and Moon 2014).

3.2.3.3 Co-occurring geothermal and mining resources

High-temperature geothermal systems are associated with volcanism and plate tectonic activity, with the majority of high-enthalpy geothermal resources occurring around the Ring of Fire surrounding the Pacific tectonic plate. About 10,000 MWe of geothermal power capacity has been installed almost exclusively in this region (Sanyal 2010). High-temperature geothermal reservoirs are also associated with high concentrations of hydrothermal alteration minerals, such as gold, copper and silver, due to the tendency of precious metals to precipitate and deposit in response to boiling and mixing of deep geothermal fluids (Browne and Simmons 2000).

The map in Figure 2 comprises of three data layers: one that maps world-wide open-pit and underground mining sites (USGS National Minerals Information Center); a second layer, gives smelter operations around the world (http://minerals.usgs.gov/minerals/). The third layer contains currently operational geothermal power facilities (http://thinkgeoenergy.com/, http://en.openei.org/, and web sites of individual power producers). Tectonic plate boundaries and volcanoes from around the world are also included (courtesy of the Smithsonian Institution, Global Volcanism Program), as indicators of high temperature geothermal potential.

Based on the density of the overlapping data, and under the hypothesis that concentrated activity corresponds to high potential (be it existing or future), six "hot-spot" regions can be identified as being more suited for development that integrates geothermal power/heat with mineral extraction. These are:

(A) California and Nevada in the United States;
(B) El Salvador, Guatemala, Honduras and Nicaragua in Central America;
(C) Chile and Peru on the westernmost extent of South America;
(D) The Republic of the Democratic Republic of Congo (DRC), Eritrea, Ethiopia, and Kenya, on the East African Rift;
(E) The Philippines in the western Pacific region in Southeast Asia; and
(F) the Taupo Volcanic Zone of the North Island in New Zealand.

3.3 Solar, storage and mining: New opportunities for solar power development

The world of energy production is in a transition phase, shifting from conventional to renewable energy sources to deliver power. At the UN Climate Change Conference which took place in Paris at the end of 2015, the global community committed to ambitious climate change efforts, which will only be achievable with a quick and focused roll-out of renewable energy all over the world. Solar is going to be a key part of this equation.

Solar energy has become a cost-effective and clean alternative to conventional energy sources. In many countries, electricity prices from large PV parks are in the same range as those for coal power. However, solar power has many more advantages. Solar is a decentralized energy, which is an excellent means to deliver power for remote consumers. The annual installed capacity of solar power has quickly reached a surprising level, and we are still at the beginning of the story.

On the energy consumption side, it can be observed that a huge amount of energy is used worldwide to extract and process raw material. The mining industry is one of the biggest overall energy consumers. In recent years, the mining industry has been facing many challenges above all with falling commodity prices. Energy is one of the most important cost factors for mining companies. In addition, cost cutting for energy is normally possible with far less resistance than reducing the second big cost factor, which is labor.

Mining companies can improve their cost position and environmental footprint by including solar power into their energy mix. Large-scale solar projects for powering mines have already been realized in various countries. However, the potential is almost untapped. Solar power allows mining companies to reduce their cost position. This means that the mines that use solar power will have competitive advantages and outperform mines fully relying on conventional energy sources.

3.3.1 Solar solutions are creating competitive advantages for mining companies

3.3.1.1 Energy consumption of the mining sector

Approximately 20% of the energy that the mining industry consumes and approximately 10% of world energy consumption is used for extraction and processing of mineral resources.1 This figure makes it clear that power supply in the mining industry is part of the solution in the energy transition process toward a low-carbon economy, as it is one of the main emitters. From an ecological perspective it is important that energy consumption in the mining industry is reduced efficiently and that the minerals that are used for renewable energy infrastructure have a low carbon footprint.

From the mining companies' perspective, costs will be the main driver for changing toward renewable energy. Depending on many factors, the energy consumption typically is in the range of 20-35% of the total operating costs of a mine. Energy costs are normally the second biggest cost factor, directly after labour costs.

From the solar industry perspective mining applications are a good fit, because:

- Mining companies often have to deal with high electricity costs due to remote locations
- In many developing countries mining companies have to deal with unreliable electricity infrastructure which makes it receptive for new solutions
- High energy consumption carries extraordinary potential for large scale solar power plants
- Solar energy is helpful for mining companies regarding their sustainability efforts

It becomes obvious that the mining industry could become a highly attractive customer segment for solar companies with a broad range of possible solutions. Solar power can add value to mines for grid-connected and off-grid mines.

3.3.1.2 Solar power for grid-connected mines

In recent years, we have seen that mining companies close long-term power purchase agreements (PPAs) for renewable energy in regions with high electricity prices or unstable supply from the grid. We find examples, amongst others, in Chile and South Africa.

Some mining companies have also invested in renewable energy infrastructure and generated a part of the energy themselves. Most of the mines have 24/7 operations. In these cases, the mining companies tend to source the rest of their energy requirements from the grid. In grid connected regions, investment into renewable energy or long-term renewable energy commitment through PPAs is very often considered as a hedging mechanism against increasing energy prices. In grid-connected scenarios there are often good economic reasons for mining companies to source solar energy.

3.3.1.3 Solar power for off-grid mines

In many cases, remote mine sites are not grid-connected and generate their electricity onsite, typically with large diesel gensets. The remoteness of these mines leads to high transportation costs for the diesel fuel. Losses during transportation and theft are other factors which drive the costs for diesel up. Normally, solar power is less expensive than electricity from diesel in these remote locations. The cost advantage of solar solutions always depends to some extent on the oil price. Even with the low oil price at the beginning of 2016, solar energy is often up to 50% less expensive than diesel electricity.

In a simple scenario solar power is only used during the daytime and diesel gensets constantly run at partial load, but the fuel consumption is reduced to a large extent. In situations, when the solar power generation drops, the diesel gensets can provide back-up power by increasing their output to full-load. The solar-diesel hybrid business case consists of reducing the diesel consumption which is needed to power the mine.

In advanced scenarios, the diesel gensets can be switched off during the day-time if there is enough irradiation from the sun. Fluctuations of the solar output are balanced by storage solutions. During bad weather periods or during the night, the mine is powered by diesel gensets and the remaining energy is taken from the storage solution in place.

So far, no project example exists for a mine that is fully powered by solar, or wind, energy. The main reason is that storage prices still need to fall in order to make this solution economically viable.

The topic of renewables and mining has gained more importance recently. The first large commercial solar projects, in the MW scale, have already been built and more are under construction – amongst others a 10.6 MWp PV power plant for a mine in Australia. For many mining companies the topic is still rather new and typical project development cycles are one year and more. It can be expected that many projects that are under development in the moment will be built in the near future.

In the meantime, the finance sector has developed sophisticated solutions for mining companies. Independent power producers (IPPs) are, just like grid connected scenarios, more willing to offer long-term PPAs for off-grid mines. The uncertain lifetime of the mines and a new potential threat for investors in the form of the off-taker risk, slowed down the development for some time.

In remote locations, the IPPs depend on a single off-taker. If the off-taker does not fulfill the PPAs, there is often no other off-taker for the solar energy. In the meantime, the investors have gained a better understanding of the off-taker risk and are more willing to invest. The worst case scenario consists of dismantling the plant and rebuilding it in a completely different location.

3.3.1.4 Marketing and sales as one of the main challenges for solar companies

In the past, solar companies mainly differentiated themselves through technical aspects. Marketing and sales did not have the same value as for other industries. For realizing the solar potential in mining markets it is important to provide tailor-made solutions and to address mining companies through efficient communication.

Market-entry or “go-to market” strategies based on market analysis will be one of the key success factors. For solar companies who want to enter the market it is necessary to understand their potential mining customers, to “speak their language” and to use their communication channels.

Market research including market segmentation and market sizing lay the foundation of successful target market strategies.

Mining companies receive intense attention from conventional power plant manufacturers and energy suppliers. It is obvious that this is a challenge for market entrants and that marketing efforts are needed to tap the huge potential that mining markets present for solar solutions. In the solar sector, SolarPower Europe can play an important role in developing the topic in a way that many players benefit.

3.3.2 Outlook

Solar Power is an excellent opportunity for mining companies. As energy is one of the main cost drivers for mining companies, mining companies can benefit from renewables through considerable cost savings. There are already large-scale projects for grid-connected solar parks. In remote locations, the cost savings might be highest for diesel displacement solutions.

“Solar for mining” is, at the moment, still a relatively small niche. Growth of the solar sector and the falling price of solar and storage solutions will be a main driver for further installation. Resources for solar will turn into an even more important multi-billion dollar market. The mining segment could soon develop into a multi-billion market for solar companies. However, it is important to increase marketing efforts to be able to compete with conventional power plant manufacturers and energy suppliers.

In order to create the biggest possible benefits for the whole industry it is important that the industry acts in a coordinated way.

3.3.2.1 Photovoltaic (PV) - Electrical Calculations

Photovoltaic (PV) cells (sometimes called solar cells) convert solar energy into electrical energy. Every year more and more PV systems are installed. With this growing application, it's a good idea for every practicing professional to have an understanding of the calculations associated with PV cells.

There is a vast amount of PV cells in existence, using numerous materials. At a very simple level, PV cells function by using solar energy to generate electron-hole pairs, which then separate and flow in the external circuit as current. Examining the physics of this of how the current generation works is not the intent of this note, rather we will look at the electrical calculations surrounding the actual application of real systems.

3.3.2.2 Electrical Parameters

PV cells are manufactured as modules for use in installations. Electrically the important parameters for determining the correct installation and performance are:

Maximum Power - this is the maximum power output of the PV module (see I-V curve below)
Open circuit voltage - the output voltage of the PV cell with no load current flowing
Short circuit current - the current which would flow if the PV sell output was shorted
Maximum power point voltage - level of voltage on the I-V curve which produces the maximum power
Maximum power point current - level of current on the I-V curve which produces the maximum power
Efficiency - measure of the amount of solar energy converted to electrical peak energy
Parameters for PV cells are measured under specified standard test conditions (STC).

STC is generally taken as 1000 W/m^2, 25 °C and 1.5 AM (air mass).

The maximum power output is the peak power which a solar cell can deliver at STC. While common to rate PV installations based on this value, it is unlikely these power levels will be achieved in practice.

3.3.2.3 Calculation of the output of a system

Nominal rated maximum (kW_p) power out of a solar array of n modules, each with maximum power of W_p at STC is given by:

$$kW_p = n \times W_p / 1000$$

- peak nominal power, based on 1 kW/m^2 radiation at STC

The available solar radiation (E_{ma}) varies depending on the time of the year and weather conditions. However, based on the average annual radiation for a location and taking into account the efficiency (η) of the cell, we can estimate an average PV system energy yield:

$$E_p = E_{ma} \times kW_p \times \eta$$

- average energy per year produced, kWh

Note: *E_{ma} is given in tables for a particular location and a horizontal plane.*

To obtain the anticipated solar radiation requires some research (Internet or local meteorology departments). If you are using software to perform the calculations, this information is normally provided as part of the program.

The overall efficiency (η) of the solar installation (shading losses, inverter losses, reflection losses, temperature losses, etc.), in a well designed system, these will range from 0,75 to 0,85.

The above calculation is carried out on an annual basis, but could easily be done for any time period (hours, day, month, etc.) by substituting the period mean solar radiation for the annual value.

For maximum power, any solar radiation should strike the PV panel at 90°. Depending where on the earth's surface, the orientation and inclination to achieve this varies. Software is normally used for the calculation of this or the use of correction coefficients from the concerned location.

3.3.2.4 Temperature

As the temperature of PV cells increase, the output drops. This is taken into account in the overall system efficiency (η), by use of a temperature derating factor η_t and is given by:

$$\eta_t = 1 - [\gamma \times (T_c - T_{stc})]$$

***Note:** power temperature coefficient (Y) is typically 0,005 for crystalline silicon*

3.3.2.5 Efficiency and Performance

Efficiency: measures the amount of solar energy falling on the PV cell which is converted to electrical energy Several factors affect the measurement of PV efficiency, including:

- wavelength - PV cells respond differently to differing wave lengths of light, producing varying qualities of electricity
- materials - different PV materials behave differently
- temperature - cells work better at lower temperatures, with efficiency dropping off at higher temperatures
- reflection - any reflected light decreases the efficiency of the cell
- resistance - the cells electrical resistance creates losses, affecting the efficiency

Manufactured PV cells or modules are typically sorted by a binning process into different levels of efficiency. More efficient cells would have a greater electrical output and hence higher cost.

With the latest development in solar technologies, PV cell are now starting to reach the theoretical maximum limit for semiconductor devices. The image to the side (click for a larger version) shows the achievable range of efficiencies over differing cell technologies.

In a laboratory, efficiency is measured under standard conditions by the use of I-V curves. I-V curves are obtained by varying an external resistance from zero (short circuit) to infinity (open circuit). The illustration shows a typical I-V curve.

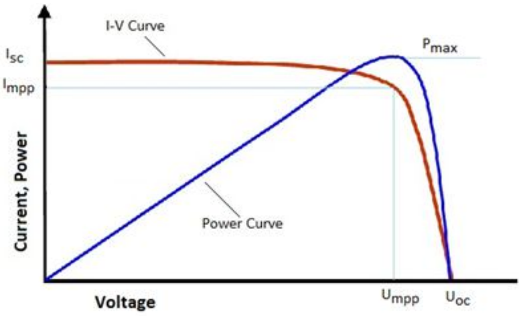


Figure 3.8 PV Cell, I-V and Power Curves

Power delivered by the PV cell is the product of voltage (*V*) and current (*I*). At both open and closed circuit conditions the power delivered is zero. At some point in between (around the knee point) the delivered power is a maximum.

Note: *the maximum amount of current that a PV cell can deliver is the short circuit current. Given the linearity of current in the voltage range from zero to the maximum power voltage, the use of the short circuit current for cable and system dimensioning is reasonable.*

3.3.2.6 Fill Factor

One way to measure the performance of a solar cell is the fill factor. This is the ratio of the maximum power to the product of the open circuit voltage and short circuit current:

$$Fill\ Factor = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{U_{mpp} \times I_{mpp}}{V_{oc} \times I_{sc}}$$

The higher the fill factor the better. As a general rule, commercial PV cells will have a fill factor greater than 0.7. Cells with factors less than this are not really recommended for practical application in larger electricity generation projects.

3.3.2.7 Maximum Power Point Tracking (MPPT)

A PV module's I-V curve can be generated from the equivalent circuit (see next section). Integral to the generation of tie I-V curve is the current I_{pv}, generated by each PV cell.

The cell current is dependent on the amount of light energy (irradiance) falling on the PV cell and the cell's temperature.

As the irradiance decreases not only is the amount of power reduce, but the peak power point moves to the left. Similarly as the temperature of the cell increases, the power output lowers and the maximum power point again shifts to the left.

With the maximum power point being a variable quantity, dependant on the solar irradiance and cell temperature, modern inverters have mechanisms to track this and always deliver the maximum possible power from a PV cell. This is called maximum power point tracking (MPPT).

Note: *control systems used to carry out MPPT vary the operation around the current operating point to see if the maximum power point has moved. They then adjust the operating points accordingly.*

3.3.2.8 PV Cell Equivalent Circuit

To understand the performance of PV modules and arrays it is useful to consider the equivalent circuit. The one shown below is commonly employed.

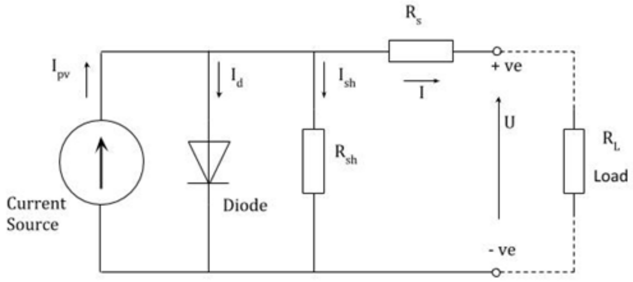


Figure 3.9 PV Equivalent Circuit

PV module equivalent circuit

From the equivalent circuit, we have the following basic equations:

$$I = I_{pv} - I_d - I_{sh}$$

- load current in Amperes

$$U_{sh} = U + IR_s$$

- voltage across the shunt branches

$$I_{sh} = \frac{U_{sh}}{R_{sh}} = \frac{U + IR_s}{R_{sh}}$$

- current through the shunt resistor

The current through the diode is given by Shockley's equation:

$$I_d = I_0\left[e^{\frac{Ush}{nVT}} - 1\right]$$

and

$$V_T = \frac{kT}{q}$$

Combining the above equations give the PV cell (module) characteristic equation:

$$I = I_{pv} - I_0\left[e^{\frac{U+IRs}{nVT}} - 1\right] - \frac{U + IR_s}{R_{sh}}$$

***Note:** the characteristic equations can be used for find both the output voltage and current. Unfortunately, give that voltage and current appear as they do, there is no analytical solution. Typically numerical methods would be used to solve the equation.*

At the limits, it is easy to use the equation to determine the open circuit voltage and short circuit current. During open circuit conditions, I=0 and the equation reduces to:

$$0 = I_{pv} - I_0\left[e^{\frac{Uoc}{nVT}} - 1\right] - \frac{U_{oc}}{R_{sh}}$$

Typically R_{sh} is high compared to the open circuit voltage and the last term can be neglected. Neglecting the term and rearranging the equation gives:

$$U_{oc} \approx nV_T ln\left[\frac{I_{pv}}{I_o} + 1\right]$$

Similarly for the short circuit current, we can set the output voltage to zero, giving:

$$I_{sc} = I_{pv} - I_0\left[e^{\frac{IscRs}{nVT}} - 1\right] - \frac{I_{sc}R_s}{R_{sh}}$$

The assumption that R_{sh} is much higher than Rs and that I_o is small compared to I. With these assumptions, the last two terms can be neglected, giving:

$$I_{sc} \approx I_{pv}$$

The series resistance (Rs), shunt resistance (R_{sh}) and reverse saturation voltage (I_o) are dependent on the area of the PV cell. Generally the bigger the cell the larger I_o (bigger diode junction area) and the lower R_s and R_{sh} will be.

The characteristic equation can be used to evaluate the effect of various parameters on the performance of the PV cell or module:

- **temperature (*T*)** - affects the cell by being part of the exponential term and the value of the reverse saturation voltage. As the temperature increases, while the exponential will decrease the reverse saturation voltage will increase exponentially. The next effect is to reduce the open circuit voltage of the cell. Typically the voltage will decrease by 0,35 to 0,5% for each degree increase in temperature.
- **series resistance (R_s)** - increasing has a similar effect to temperature in that the open circuit voltage will start to drop. Very high values of R_s will in addition reduced the available short circuit current.
- **shunt resistance (R_{sh})** - decreasing will provide a greater path for the shunt current, again lowering the cell voltage.

3.4 Hybrid Solar-Geothermal Energy

As early as in 1975, Finlayson and Kammer reported an assessment of solar-geothermal hybrid system concepts. In the past few decades, much attention has been paid to the hybrid solar-geothermal power generation (Mathur, 1979; Kondili et al., 2006; Ghasemi et al., 2014; DiMarzio et al., 2015). Because of the mutual compensation in structures, the hybrid system contains both of the advantages of the solar and geothermal sources. Thermodynamically, the hybrid plants were found to outperform the stand-alone plants when a fully optimized operating mode was employed. The net power output of the hybrid plant was found to increase as a result of increasing the solar irradiance and/or geothermal fluid temperature or reducing the ambient temperature. Besides, the hybrid solar-geothermal power plants can be cost-competitive.

Lentz and Almanza (2006) investigated the feasibility of using parabolic trough solar field to increase the enthalpy from geothermal wells' flow in order to raise the steam quantity. The increase in steam-water flow rates made it possible to prevent the deposition of some salts since the salt solubility was increased.

Kondili et al. (2006) proposed an integrated methodology for the design of a geothermal–solar greenhouse to minimize the fossil fuel consumption and replace them with geothermal energy. Besides, the methodology had been implemented in a selected area, which showed that the proposed system configuration was also economically attractive.

Ghasemi et al. (2014) designed a model to hybridize the ORC geothermal system and a low-temperature solar trough system utilized in parallel with the geothermal system to vaporize part of the working fluid. The annual performance of the hybrid system was examined by the given solar data of the considered site and demonstrated a 5.5% boost in annual power generation compared with the optimized stand-alone geothermal system. Furthermore, the hybrid system had a higher second-law efficiency up to 3.4% compared to the case of separate geothermal and solar systems at all ambient temperatures. In addition, the hybrid system showed up to 17.9% solar incremental efficiency.

Ayub et al. (2015) developed an integrated model for a hybrid solar-binary geothermal system and reported that LEC (Levelized Electricity Costs) could be decreased by 2% for the hybrid system compared to the stand-alone geothermal system. An optimization of the stand-alone geothermal ORC resulted in about 8% reduction in LEC.

According to the literature available, hybrid solar–geothermal power generation has been the focus of many studies in recent years, with a range of different hybrid configurations being investigated:

- Solar preheating configuration where solar energy is used to preheat the brine either by increasing the brine temperature or its dryness fraction (i.e. the steam quality).

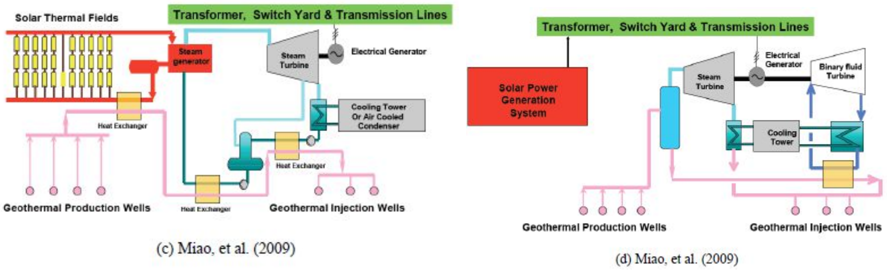
- Solar superheating configuration in which solar energy is mainly used to superheat the working fluid of the geothermal power cycle.

- Geothermal preheating configuration where geothermal energy is used to preheat the feedwater in a steam Rankine cycle type solar thermal power plant.

3.4.1 Solar preheating configurations

The solar preheating configuration is used to preheat the brine by increasing the brine temperature or the dryness fraction. Those configurations used to increase the vapor fraction can be classified to two types:

1) DSG: The geothermal brine is evaporated by flowing directly into the solar collectors. Two configurations of this type reported by Lentz and Almanza (2006) are depicted in Figures 4a and 4b. Lentz and Almanza (2006) tested the feasibility of the solar-geothermal hybrid system in Cerro Prieto geothermal field in Mexico. The flow enthalpy of the geothermal system can be increased by the solar system. Besides, the steam production rates were also increased because of the addition of the solar units. Miao, et al. (2009) also suggested several configurations for integrating the solar and geothermal resources at different levels (see Figures 3.10).



(c) Miao, et al. (2009)

(d) Miao, et al. (2009)

Figure 3.10 Solar preheating DSG configuration

2) Indirect Stream Generation: the geothermal system of this type usually obtains the heat of solar system from a heat exchanger indirectly. Typically, the energy conversion flow is designed to be: (I) solar energy to thermal energy; (II) store heat in the heat transfer fluid (HTF); (III) increasing the geothermal steam fraction through a heat exchanger (HE); (IV) electrical power generation.

Alvarenga et al. (2008) tested a solar-geothermal hybrid system using oil as HTF in the Ahuachapán geothermal field, Central America. Handal et al. (2007) proposed two configurations of the hybrid solar-geothermal power plants: one was operated under the constant mass flow rate condition, while the other was run under condition that output power equals to the one obtained in stand-alone geothermal power plant. The former had an annual increase of 11.36% in the total energy, and the latter demonstrated an increase of 10.36% in geothermal fluid mass flow rate, which could extend the reservoir life cycle. CO2 reduction bonus, fiscal incentives, use of efficiency technology to storage and heat transfer are also advantages to invest in a geothermal-solar hybrid system.

Precipitation of silica dissolved in the geothermal fluid might be a problem in these hybrid systems. Some methods were proposed to quench this problem: injection of hydrochloric acid to a pH of 5; adding an electronic descaler. Lentz and Almanza (2006) proposed a configuration of the hybrid solar-geothermal system (Figure 3.11) by making use of the water from cooling tower. Therefore, the scaling on the pipes from the wells would be lessened and the total salinity decreases when the steam is injected in the brine-steam mixture coming from the well.

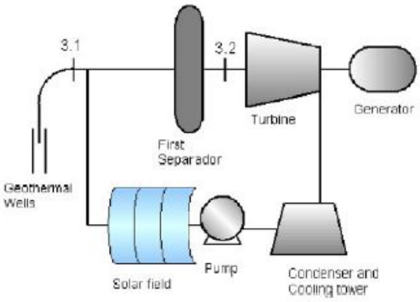


Figure 3.11 Improvedhybrid solar-geothermal system with less scaling problem (Lentz and Almanza, 2006)

3.4.2 Advantages of Hybrid Solar-Geothermal Power Systems

According to the reports and literature available, there are many benefits if solar and geothermal heat sources are combined in an optimized way. The advantages of hybrid solar-geothermal power plants are:

- Increase the temperature or the steam flow rates of relatively low cost geothermal fluids.
- Improve the utility efficiency of the geothermal power plants because of the increased temperature.
- Geothermal fluids can be served as the storage of solar energy.
- Increase the capacity factor of geothermic power plants by increasing the amount of steam generated with the addition of solar heat.
- Match the power load better than standalone systems. The power load is usually higher during the day time than night time, which is exactly the change trend of the power output of hybrid solar-geothermal power plants.
- Improve land use for gathering energy sources above and below ground. Solar systems need many more areas than geothermal power plants for the same power output.
- Prevent the deposition of some salts because the salt solubility increases with temperatures.
- Reduce the risk of uncertainty in geothermal resources and reservoir performance decline over time.
- Decrease the operation, maintenance and the overall costs in a long term under many specific conditions.

3.4.3 Drawbacks of Hybrid Solar-Geothermal Power Systems

The disadvantages of hybrid solar-geothermal power plants are listed as follows:

- The complexity of power generation systems is increased, which may bring about the maintenance difficulty.
- The operation of a power plant sometimes requires constant monitoring of the well mass flow rate according to the availability of thermal energy coming from the solar field, which in practice is complex.
- The initial cost is high and it is not cost-competitive in a short term.
- The cost of the hybrid solar-geothermal systems depends on many factors. The low operation pressure and low temperature in geothermal fields demands a large solar energy to produce steam, which impacts the solar field size and so the capital investments.

4 DEFINITION OF MINING PLANT

Gluck auf!

German mining quote

In this chapter it is pretended to describe an overview of what the mining plants consist on. Starting with a complete description of every stage in the life of a mine to haveaperspective of the different steps needed to the successful exploitaiton.

Afterwards, we will describe in detail the classification of the mines and the equipment required in order to, finally, analyze the energy that every mine could demand depending on the kind of material and amount extracted, the location and the machines implemented.

4.1 Stages in the life of a mine

The overall sequence of activities in modern mining is often compared with the five stages in the life of a mine: *prospecting*, *exploration*, *development*, *exploitation*, and *reclamation*.

- Prospecting and exploration, precursors to actual mining, are linked and sometimes combined. Geologists and mining engineers often share responsibility for these two stages—geologists more involved with the former, mining engineers more with the latter.

- Likewise, development and exploitation are closely related stages; they are usually considered to constitute mining proper and are the main province of the mining engineer. Reclamation has been added to these stages since the first edition, to reflect the times.

- Closure and reclamation of the mine site has become a necessary part of the mine life cycle because of the demands of society for a cleaner environment and stricter laws regulating the abandonment of a mine.

The overall process of developing a mine with the future uses of the land in mind is termed *sustainable development.*

4.1.1 Prospecting

Prospecting, the first stage in the utilization of a mineral deposit, is the search for ores or other valuable minerals (coal or nonmetallics). Because mineral deposits may be located either at or below the surface of the earth, both direct and indirect prospecting techniques are employed.

The *direct method* of discovery, normally limited to surface deposits, consists of visual examination of either the exposure (outcrop) of the deposit or the loose fragments (float) that have weathered away from the outcrop. Geologic studies of the entire area augment this simple, direct technique. By means of aerial photography, geologic maps, and structural assessment of an area, the geologist gathers evidence by direct methods to locate mineral deposits. Precise mapping and structural analysis plus microscopic studies of samples also enable the geologist to locate the hidden as well as surface mineralization.

The most valuable scientific tool employed in the *indirect search* for hidden mineral deposits is geophysics, the science of detecting anomalies using physical measurements of gravitational, seismic, magnetic, electrical, electromagnetic, and radiometric variables of the earth. The methods are applied from the air, using aircraft and satellites; on the surface of the earth; and beneath the earth, using methods that probe below the topography. Geochemistry, the quantitative analysis of soil, rock, and water samples, and geobotany, the analysis of plant growth patterns, can also be employed as prospecting tools.

4.1.2 Exploration

The second stage in the life of a mine, *exploration*, determines as accurately as possible the size and value of a mineral deposit, utilizing techniques similar to but more refined than those used in prospecting. The line of demarcation between prospecting and exploration is not sharp; in fact, a distinction may not be possible in some cases. Exploration generally shifts to surface and subsurface locations, using a variety of measurements to obtain a more positive picture of the extent and grade of the ore body. Representative samples may be subjected to chemical, metallurgical, X ray, spectrographic, or radiometric evaluation techniques that are meant to enhance the investigator's knowledge of the mineral deposit. Samples are obtained by chipping outcrops, trenching, tunneling , and drilling; in addition, borehole logs may be provided to study the geologic and structural makeup of the deposit. Rotary, percussion, or diamond drills can be used for exploration purposes. However, diamond drills are favored because the cores they yield provide knowledge of the geologic structure. The core is normally split along its axis; one half is analyzed, and the other half is retained intact for further geologic study.

An evaluation of the samples enables the geologist or mining engineer to calculate the tonnage and grade, or richness, of the mineral deposit. He or she estimates the mining costs, evaluates the recovery of the valuable minerals, determines the environmental costs, and assesses other foreseeable factors in an effort to reach a conclusion about the profitability of the mineral deposit. The crux of the analysis is the question of whether the property is just another mineral deposit or an ore body. For an ore deposit, the overall process is called *reserve estimation*, that is, the examination and valuation of the ore body. At the conclusion of this stage, the project is developed, traded to another party, or abandoned.

4.1.3 Development

In the third stage, *development*, the work of opening a mineral deposit for exploitation is performed. With it begins the actual mining of the deposit, now called the ore. Access to the deposit must be gained either (1) by stripping the overburden, which is the soil and/or rock covering the deposit, to expose the near-surface ore for mining or (2) by excavating openings from the surface to access more deeply buried deposits to prepare for underground mining.

In either case, certain preliminary development work, such as acquiring water and mineral rights, buying surface lands, arranging for financing, and preparing permit applications and an environmental impact statement (EIS), will generally be required before any development takes place. When these steps have been achieved, the provision of a number of requirements—access roads, power sources, mineral transportation systems, mineral processing facilities, waste disposal areas, offices, and other support facilities—must precede actual mining in most cases. Stripping of the overburden will then proceed if the minerals are to be mined at the surface. Economic considerations determine the *stripping ratio*, the ratio of waste removed to ore recovered; it may range from as high as 45 yd/ton (38 m/ton) for coal mines to as low as 1.0 yd/ton (0.8 m/ton) in metal mines. Some nonmetallic mines have no overburden to remove; the mineral is simply excavated at the surface.

Development for underground mining is generally more complex and expensive. It requires careful planning and layout of access openings for efficient mining, safety, and permanence. The principal openings may be shafts, slopes, or adits; each must be planned to allow passage of workers, machines, ore, waste, air, water, and utilities. Many metal mines are located along steeply dipping deposits and thus are opened from shafts, while drifts, winzes, and raises serve the production areas. Many coal and nonmetallic mines are found in nearly horizontal deposits. Their primary openings may be drifts or entries, which may be distinctly different from those of metal mines.

4.1.4 Exploitation

Exploitation, the fourth stage of mining, is associated with the actual recovery of minerals from the earth in quantity. Although development may continue, the emphasis in the production stage is on production. Usually only enough development is done prior to exploitation to ensure that production, once started, can continue uninterrupted throughout the life of the mine.

The mining method selected for exploitation is determined mainly by the characteristics of the mineral deposit and the limits imposed by safety, technology, environmental concerns, and economics. Geologic conditions, such as the dip, shape, and strength of the ore and the surrounding rock, play a key role in selecting the method. *Traditional exploitation methods* fall into two broad categories based on locale: surface or underground. *Surface mining* includes mechanical excavation methods such as open pit and open cast (strip mining), and aqueous methods such as placer and solution mining. *Underground mining* is usually classified in three categories of methods: unsupported, supported, and caving.

4.1.4.1 Surface Mining.

Surface mining is the predominant exploitation procedure worldwide, producing in the United States about 85% of all minerals, excluding petroleum and natural gas. Almost all metallic ores (98%), about 97% of the nonmetallic ores, and 61% of the coal in the United States are mined using surface methods (U.S. Geological Survey, 1995; Energy Information Administration, 2000), and most of these are mined by open pit or open cast methods. In *open pit mining*, a *mechanical extraction method*, a thick deposit is generally mined in benches or steps, although thin deposits may require only a single bench or face. Open pit or open cast mining is usually employed to exploit a near-surface deposit or one that has a low stripping ratio. It often necessitates a large capital investment but generally results in high productivity, low operating cost, and good safety conditions.

The *aqueous extraction methods* depend on water or another liquid (e.g., dilute sulfuric acid, weak cyanide solution, or ammonium carbonate) to extract the mineral.

Placer mining is used to exploit loosely consolidated deposits like common sand and gravel or gravels containing gold, tin, diamonds, platinum, titanium, or coal.

Hydraulicking utilizes a high-pressure stream of water that is directed against the mineral deposit (normally but not always a placer), undercutting it, and causing its removal by the erosive actions of the water.

Dredging performed from floating vessels, accomplishes the extraction of the minerals mechanically or hydraulically. *Solution mining* includes both *borehole mining*, such as the methods used to extract sodium chloride or sulfur, and *leaching*, either through drillholes or in dumps or heaps on the surface. Placer and solution mining are among the most economical of all mining methods but can only be applied to limited categories of mineral deposits.

4.1.4.2 Underground Mining.

Underground methods—unsupported, supported, and caving—are differentiated by the type of wall and roof supports used, the configuration and size of production openings, and the direction in which mining operations progress. The *unsupported methods* of mining are used to extract mineral deposits that are roughly tabular (plus flat or steeply dipping) and are generally associated with strong ore and surrounding rock.

These methods are termed *unsupported* because they do not use any artificial pillars to assist in the support of the openings. However, generous amounts of roof bolting and localized support measures are often used. *Room-and-pillar mining* is the most common unsupported method, used primarily for flat-lying seams or bedded deposits like coal, trona, limestone, and salt. Support of the roof is provided by natural pillars of the mineral that are left standing in a systematic pattern. *Stope-and-pillar mining* (a stope is a production opening in a metal mine) is a similar method used in noncoal mines where thicker, more irregular ore bodies occur; the pillars are spaced randomly and located in low-grade ore so that the high-grade ore can be extracted. These two methods account for almost all of the underground mining in horizontal deposits in the United States and a very high proportion of the underground tonnage as well.

Two other methods applied to steeply dipping deposits are also included in the unsupported category. In *shrinkage stopping*, mining progresses upward, with horizontal slices of ore being blasted along the length of the stope. A portion of the broken ore is allowed to accumulate in the stope to provide a working platform for the miners and is thereafter withdrawn from the stope through chutes. *Sublevel stopping* differs from shrinkage stopping by providing sublevels from which vertical slices are blasted. In this manner, the stope is mined horizontally from one end to the other. Shrinkage stopping is more suitable than sublevel stopping for stronger ore and weaker wall rock.

Supported mining methods are often used in mines with weak rock structure.

Cut-and-fill stopping is the most common of these methods and is used primarily in steeply dipping metal deposits. The cut-and-fill method is practiced both in the overhand (upward) and in the underhand (downward) directions. As each horizontal slice is taken, the voids are filled with a variety of fill types to support the walls. The fill can be rock waste, tailings, cemented tailings, or other suitable materials. Cut-and-fill mining is one of the more popular methods used for vein deposits and has recently grown in use. *Square-set stopping* also involves backfilling mine voids; however, it relies mainly on timber sets to support the walls during mining. This mining method is rapidly disappearing in North America because of the high cost of labor. However, it still finds occasional use in mining high-grade ores or in countries where labor costs are low. *Stull stopping* is a supported mining method using timber or rock bolts in tabular, pitching ore bodies. It is one of the methods that can be applied to ore bodies that have dips between 10° and 45°. It often utilizes artificial pillars of waste to support the roof.

Caving methods are varied and versatile and involve caving the ore and/or the overlying rock. Subsidence of the surface normally occurs afterward.

Longwall mining is a caving method particularly well adapted to horizontal seams, usually coal, at some depth. In this method, a face of considerable length (a long face or wall) is maintained, and as the mining progresses, the overlying strata are caved, thus promoting the breakage of the coal itself. A different method, *sublevel caving*, is employed for a dipping tabular or massive deposit.

As mining progresses downward, each new level is caved into the mine openings, with the ore materials being recovered while the rock remains behind. *Block caving* is a large-scale or bulk mining method that is highly productive, low in cost, and used primarily on massive deposits that must be mined underground. It is most applicable to weak or moderately strong ore bodies that readily break up when caved. Both block caving and longwall mining are widely used because of their high productivity.

In addition to these conventional methods, *innovative methods* of mining are also evolving. These are applicable to unusual deposits or may employ unusual techniques or equipment. Examples include automation, rapid excavation, underground gasification or liquifaction, and deep-sea mining.

4.1.5 Reclamation

The final stage in the operation of most mines is *reclamation*, the process of closing a mine and recontouring, revegetating, and restoring the water and land values. The best time to begin the reclamation process of a mine is before the first excavations are initiated. In other words, mine planning engineers should plan the mine so that the reclamation process is considered and the overall cost of mining plus reclamation is minimized, not just the cost of mining itself. The new philosophy in the mining industry is *sustainability*, that is, the meeting of economic and environmental needs of the present while enhancing the ability of future generations to meet their own needs (National Mining Association, 1998).

In planning for the reclamation of any given mine, there are many concerns that must be addressed. The first of these is the safety of the mine site, particularly if the area is open to the general public. The removal of office buildings, processing facilities, transportation equipment, utilities, and other surface structures must generally be accomplished. The mining company is then required to seal all mine shafts, adits, and other openings that may present physical hazards. Any existing highwalls or other geologic structures may require mitigation to prevent injuries or death due to geologic failures.

The second major issue to be addressed during reclamation of a mine site is restoration of the land surface, the water quality, and the waste disposal areas so that long-term water pollution, soil erosion, dust generation, or vegetation problems do not occur. The restoration of native plants is often a very important part of this process, as the plants help build a stable soil structure and naturalize the area. It may be necessary to carefully place any rock or tailings with acid-producing properties in locations where rainfall has little effect on the material and acid production is minimized. The same may be true of certain of the heavy metals that pollute streams.

Planning of the waste dumps, tailings ponds, and other disturbed areas will help prevent pollution problems, but remediation work may also be necessary to complete the reclamation stage of mining and satisfy the regulatory agencies.

The final concern of the mine planning engineer may be the subsequent use of the land after mining is completed. Old mine sites have been converted to wildlife refuges, shopping malls, golf courses, airports, lakes, underground storage facilities, real estate developments, solid waste disposal areas, and other uses that can benefit society. By planning the mine for a subsequent development, mine planners can enhance the value of the mined land and help convert it to a use that the public will consider favorable. The successful completion of the reclamation of a mine will enhance public opinion of the mining industry and keep the mining company in the good graces of the regulatory agencies.

The fifth stage of the mine is thus of paramount importance and should be planned at the earliest possible time in the life of the mine.

4.2 Mining bandwidth

4.2.1 Mining Industry Energy Sources

Major energy sources for the mining industry are petroleum products, electricity (purchased and produced onsite), coal, and natural gas. Diesel fuel accounts for 34% of the U.S. mining industry's fuel needs, followed by onsite electricity at 32%, natural gas at 22%, and coal and gasoline supplying the balance. The type of fuel used at a mine site will depend on the mine type (surface or underground) and on the processes employed.

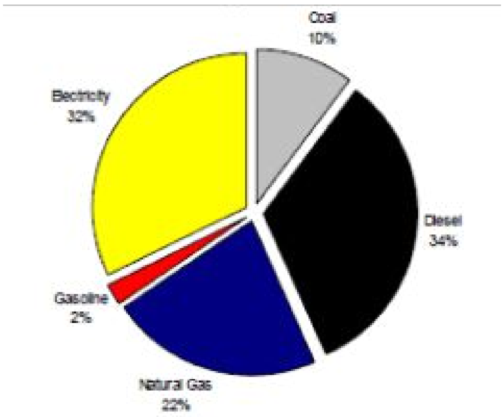


Figure 4.1 Fuels Consumed in the U.S. Mining Industry

4.2.2 Materials Mined and Recovery Ratio

Materials mined can be broadly classified into three categories: coal, metals (e.g., iron, lead, gold, zinc and copper), and industrial minerals (these include phosphate, stone, sand and gravel). Each mined product has a different recovery ratio, which has a significant impact on the energy required per ton of product.

Table 4.1 Mined Material Recovery in 2000 in USA

Commodity	Recovery Ratio	Million Tons Recovered	Million Tons Mined
Coal			
Average	82%	1073	1308.5
Metals			
Iron	19%	69.6	366.3
Copper	0.16%	1.6	1000.0
Lead & Zinc	8%	1.4	17.5
Gold & Silver	0.001%	0.003	300.0
Other*	n/a	< 0.05	
Average	4.50%	72.6	1613.3
** Other category consists of magnesium, mercury, titanium, vanadium, and zirconium*			
Industrial Minerals			
Potash, Soda Ash, Borates	88.30%	13.856	15.7
Phosphate	33%	42.549	128.9
Sand & Gravel	n/a	1,148	
Stone (crushed)	92.60%	1,675.50	1809.4
Other	n/a	320.1	
Average	90%	3,200	3556
Mining Total Average	**67%**	**4,346**	**6,477**

The recovery ratio in mining refers to the percentage of valuable ore within the total mined material. While coal mining has a recovery ratio of 82%, the recovery ratio for metals averages only about 4.5%. This means 1.2 tons of material must be mined for every 1 ton of useful coal product, while 22 tons of material must be mined for every 1 ton of metal product. These recovery ratios exclude waste rock from development operations.

4.2.3 Mining Methods

The extraction of coal, metals and industrial minerals employs both surface and underground mining techniques. The method selected depends on a variety of factors, including the nature and location of the deposit, and the size, depth and grade of the deposit. Surface mining accounts for the majority of mining (65% of coal, 92% of metals, and 96% of minerals mined) with underground mining accounting for the remaining. Underground mining requires more energy than surface mining due to greater requirements for hauling, ventilation, water pumping, and other operations.

Table 4.2 Underground and Surface Mining in the United States

Million Tons Of Material Mined		% Produced in Surface Mines	% Produced in Underground Mines
Coal	1,309	65%	35%
Metals	1,613	92%	8%
Industrial Minerals	3,556	96%	4%

4.3 Mining Equipment

The mining process can be divided into three broad stages, each involving several operations.

- The first stage is **extraction**, which includes activities such as blasting and drilling in order to loosen and remove material from the mine.

- The second stage is materials **handling**, which involves the **transportation** of ore and waste away from the mine to the mill or disposal area.

- At the processing plant, the third stage, i.e., **beneficiation** & **processing** is completed. This stage recovers the valuable portion of the mined material and produces the final marketable product. Beneficiation operations primarily consist of crushing, grinding, and separations, while processing operations comprise of smelting and/or refining.

Similar equipment types that perform a given function were grouped into a single category to benchmark their energy consumption. For example, all types of drills and blasting agents, such as ammonium nitrate fuel oil (ANFO) and loaders are grouped into the drilling category to assign energy data. The different equipment types analyzed are listed below. Operations that consume relatively low amounts of energy were omitted, as they offer poor energy-saving opportunities.

4.3.1 Extraction

The energy-saving opportunities in the extraction stage of mining were evaluated by analyzing the major equipment units used for extraction of commodities.

4.3.1.1 Drilling

Drilling is the act or process of making a cylindrical hole with a tool for the purpose of exploration, blasting preparation, or tunneling. For the purpose of this study, drilling equipment includes ammonium nitrate fuel oil (ANFO) loader trucks, diamond drills, rotary drills, percussion drills and drill boom jumbos. Drills are run from electricity, diesel power and to a lesser extent, indirectly from compressed air. The energy is used to power components of the drill that perform tasks such as hammering and rotation.

4.3.1.2 Blasting

Blasting uses explosives to aid in the extraction or removal of mined material by fracturing rock and ore by the energy released during the blast. The energy consumed in the blasting process is derived from the chemical energy contained in the blasting agents. This sets blasting apart from other processes, which are powered by traditional energy sources, such as electricity and diesel fuel. In this operation, the energy consumed per ton of output is that used directly by the blasting agent, rather than by any equipment used in the operation. Nevertheless, it is important that blasting be included in this report, as blasting efficiency influences downstream processes. Blasting reduces the size of ore before it undergoes crushing and grinding, thereby reducing the energy consumption of crushing and grinding processes. Therefore, optimizing blasting techniques will enable downstream energy savings.

4.3.1.3 Digging

Digging is to excavate, make a passage into or through, or remove by taking away material from the earth. The goal of digging is to extract as much valuable material as possible and reduce the amount of unwanted materials. Digging equipment includes hydraulic shovels, cable shovels, continuous mining machines, longwall mining machines, and drag lines.

4.3.1.4 Ventilation

Ventilation is the process of bringing fresh air to the underground mine workings while removing stale and/or contaminated air from the mine and also for cooling work areas in deep underground mines. The mining industry uses fan systems for this purpose.

4.3.1.5 Dewatering

Dewatering is the process of pumping water from the mine workings. Pumping systems are large energy consumers. This study assumes end-suction pumps (i.e. centrifugal) as the only equipment used for dewatering the mine during extraction.

4.3.2 Materials Handling Equipment

The materials handling equipment were categorized into diesel and electric for the purpose of this energy bandwidth analysis. In general, diesel fuel powers rubber tire or track vehicles that deliver material in batches, while electricity powers continuous delivery systems such as conveyors and slurry lines.

4.3.2.1 Diesel Equipment

Much of the equipment used in the transfer or haulage of materials in mining is powered by diesel engines. Equipment includes service trucks, front-end loaders, bulldozers, bulk trucks, rear-dump trucks and ancillary equipment such as pick-up trucks and mobile maintenance equipment. Diesel technologies are highly energy intensive, accounting for 87% of the total energy consumed in materials handling. Materials handling equipment is powered by diesel 80%, 100%, and 99,5% for coal, metals and industrial minerals respectively.

4.3.2.2 Electric Equipment

Electric equipment includes load-haul-dump (LHD) machines, hoists, conveyor belt systems and pipelines for pumping slurries. The percentage of materials handling equipment run by electricity is 20% for coal, 0% for metals, and 0,5% for industrial minerals.

4.3.3 Beneficiation & Processing Equipment

Beneficiation comprises crushing, grinding and separations, while processing operations include roasting, smelting, and refining to produce the final mined product.

4.3.3.1 Crushing

Crushing is the process of reducing the size of run-of- mine material into coarse particles. The efficiency of crushing in mining depends on the efficiency of upstream processes (rock fragmentation due to blasting or digging in the extraction process) and in turn, has a significant effect on downstream processes (grinding or separations).

4.3.3.2 Grinding

Grinding is the process of reducing the size of material into fine particles. As with crushing, the efficiency of grinding is influenced by upstream processes that fragment the rock prior to the grinding stage. In the case of both crushing and grinding, estimates of their energy efficiency in the literature vary widely based on the metrics involved (creation of new surface area per unit energy applied, or motor efficiency of crushing equipment).

4.3.3.3 Separations

The separation of mined material is achieved primarily by physical separations rather than chemical separations, where valuable substances are separated from undesired substances based on the physical properties of the materials. A wide variety of equipment is used for separations processes, the largest energy-consuming separation method amongst these being centrifugal separation for coal mining, and floatation for metals and minerals mining.

Centrifuges consist primarily of a spinning basket designed to receive solid-liquid slurries and remove the liquid. The “centrifugal force” created by the spinning action sends the liquid out of the bowl through a perforated medium and leaves the desired solid material behind.

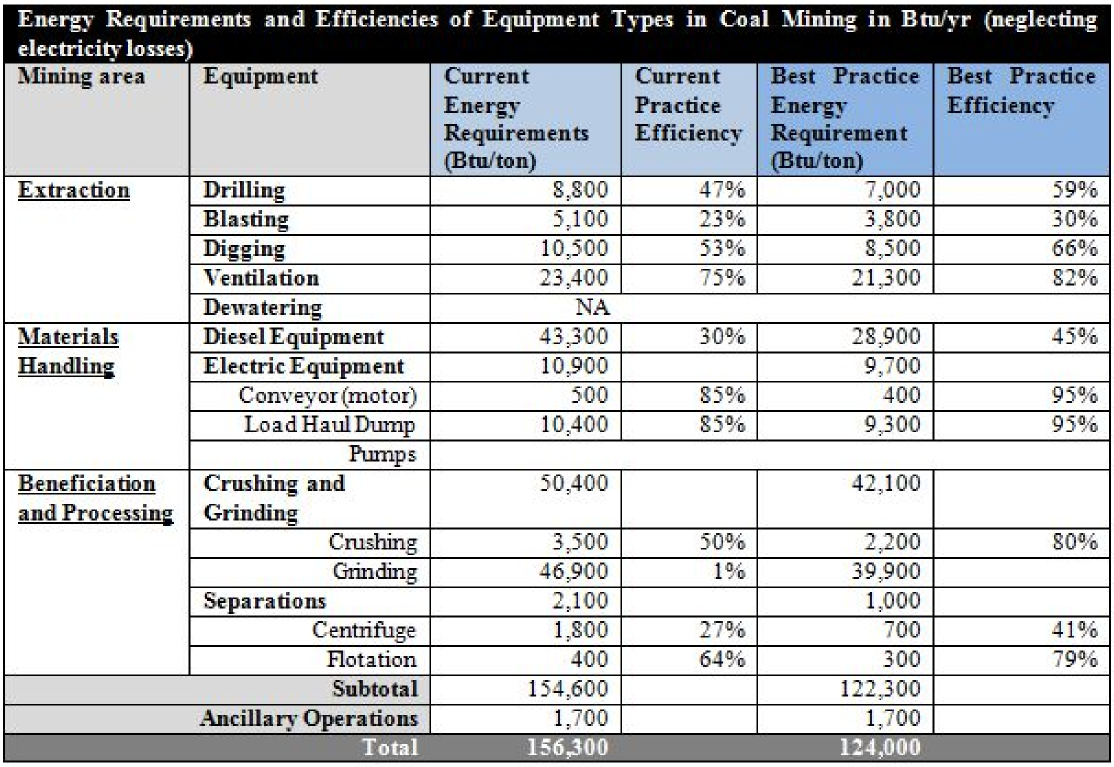
Flotation machines are designed to isolate valuable ore from other non-valuable substances. The surfaces of mineral particles are treated with chemicals that bond to the valuable product and make them air-avid and water-repellent. The ore is suspended in water that is mechanically agitated and aerated. The treated minerals attach to air bubbles and rise to the surface where they can be collected.

4.3.3.4 Final Processing

Final processing includes steps that further prepare the ore to yield the desired product in its purest and most valuable form. Roasting, smelting, and refining are different processes falling under this category. While a component of the mining industry, these processes require relatively much less energy.

4.4 Energy Requirements and Efficiencies of Equipment Types in Coal, Metals and Minerals Mining

Table 4.3



Energy Requirements and Efficiencies of Equipment Types in Coal Mining in Btu/yr (neglecting electricity losses)

Mining area	Equipment	Current Energy Requirements (Btu/ton)	Current Practice Efficiency	Best Practice Energy Requirement (Btu/ton)	Best Practice Efficiency
Extraction	**Drilling**	8,800	47%	7,000	59%
	Blasting	5,100	23%	3,800	30%
	Digging	10,500	53%	8,500	66%
	Ventilation	23,400	75%	21,300	82%
	Dewatering	NA			
Materials Handling	**Diesel Equipment**	43,300	30%	28,900	45%
	Electric Equipment	10,900		9,700	
	Conveyor (motor)	500	85%	400	95%
	Load Haul Dump	10,400	85%	9,300	95%
	Pumps				
Beneficiation and Processing	**Crushing and Grinding**	50,400		42,100	
	Crushing	3,500	50%	2,200	80%
	Grinding	46,900	1%	39,900	
	Separations	2,100		1,000	
	Centrifuge	1,800	27%	700	41%
	Flotation	400	64%	300	79%
	Subtotal	154,600		122,300	
	Ancillary Operations	1,700		1,700	
	Total	**156,300**		**124,000**	

Table 4.4

Energy Requirements and Efficiencies of Equipment Types in Metal Mining in Btu/yr (neglecting electricity losses)					
Mining area	**Equipment**	**Current Energy Requirements (Btu/ton)**	**Current Practice Efficiency**	**Best Practice Energy Requirement (Btu/ton)**	**Best Practice Efficiency**
Extraction	**Drilling**	1,800	45%	1,500	57%
	Blasting	9,900	23%	7,600	30%
	Digging	6,000	63%	5,000	75%
	Ventilation	4,700	75%	4,300	82%
	Dewatering	600	75%	600	83%
Materials Handling	**Diesel Equipment**	74,900	30%	50,000	45%
	Electric Equipment	NA			
	Conveyor (motor)	NA	85%		95%
	Load Haul Dump	NA			
	Pumps	NA	75%		83%
Beneficiation and Processing	**Crushing and Grinding**	59,800		50,400	
	Crushing	1,900	50%	1,200	80%
	Grinding	57,900	1%	49,200	1%
	Separations	4,300			
	Centrifuge	NA			
	Flotation	900	64%	700	79%
	Subtotal	162,148		120,017	
	Ancillary Operations	6,599		6,599	
	Total	**168,746**		**126,616**	

Table 4.5

Energy Requirements and Efficiencies of Equipment Types in Mineral Mining in Btu/yr (neglecting electricity losses)					
Mining area	**Equipment**	**Current Energy Requirements (Btu/ton)**	**Current Practice Efficiency**	**Best Practice Energy Requirement (Btu/ton)**	**Best Practice Efficiency**
Extraction	**Drilling**	5,000	22%	4,000	27%
	Blasting	400	23%	300	30%
	Digging	8,500	30%	5,600	45%
	Ventilation	3	75%	3	82%
	Dewatering	2,200	75%	2,000	83%
Materials Handling	**Diesel Equipment**	9,500	30%	6,300	45%
	Electric Equipment	271	75%	245	84%
	Conveyor (motor)	12	85%	11	95%
	Load Haul Dump	NA			
	Pumps	259	75%	234	83%
Beneficiation and Processing	**Crushing and Grinding**	2,700		1,780	
	Crushing		50%	1,537	80%
	Grinding	300	1%	240	
	Separations	1,300		100	
	Centrifuge	NA			
	Flotation	100	64%	100	79%
	Subtotal	30,000		20,400	
	Ancillary Operations	3,100		3,100	
	Total	**33,000**		**23,500**	

5 DESCRIPTION OF CASE STUDIES

When you were hammer you had no mercy. Now that you are anvil, be patient.

Quote

This chapter pretends to explain every point that compounds the developed case studies in order to analyze the different behaviors depending on the environment conditions such as temperature fluctuations and solar irradiance, working and cooling fluids and heating source.

The three case studies chosen forthat purpose are hypothetical mines situated in Lake Havasu City, at the borderline between the American states of Arizona and California (USA), the Russian city of Kurgan (close to Kazakhstan), and the Ombilin mine in the near of Padang, in the island of Sumatera (Indonesia). These mines would produce,respectively, granite,uranium and coal, whose energy and power demands will be defined for every case.

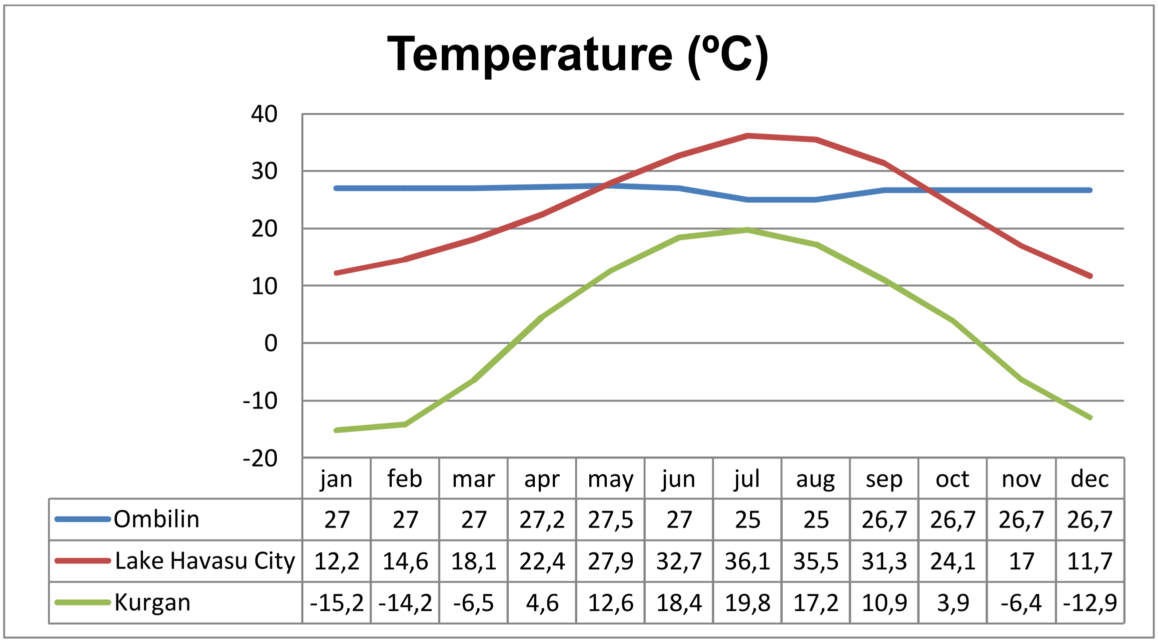
5.1 Mining Plant Definition

As described in the previous chapter, the first step of every case study is the analysis of every mine plant energy demand. The energy requirements vary hugely depending on the extracted material and the amount of production. For this purpose, similar amounts of production for different mines will be set.

There are basically two kind of energy demand: fuel and electricity. In this project we will consider the possibility of satisfice the electricity demand by the use of geothermal energy.

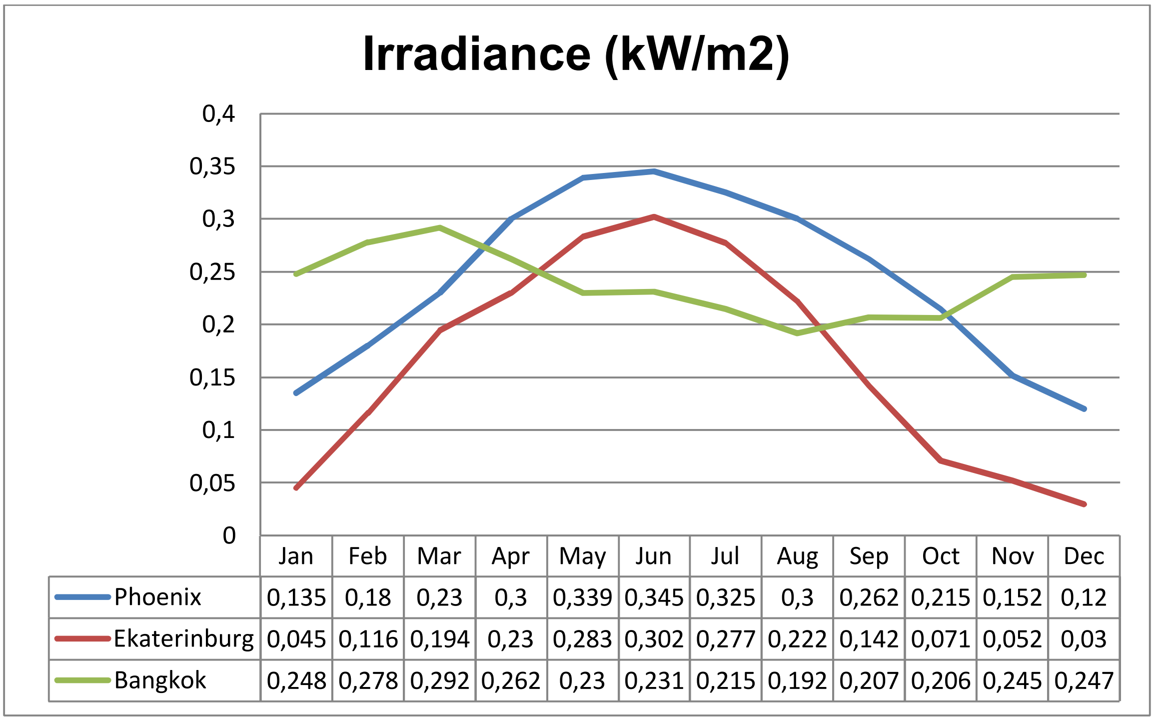
5.2 Climate conditions

First of all, every case study starts with a complete description of the geographical location and the climate conditions. To understand better the difference between those places and its influence in the results, it would be interesting to observe the next graphics comparating temperatures and irradiance:



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Ombilin	27	27	27	27,2	27,5	27	25	25	26,7	26,7	26,7	26,7
Lake Havasu City	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
Kurgan	-15,2	-14,2	-6,5	4,6	12,6	18,4	19,8	17,2	10,9	3,9	-6,4	-12,9

Table 5.1 Average Temperature (ºC) in the studied mines



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phoenix	0,135	0,18	0,23	0,3	0,339	0,345	0,325	0,3	0,262	0,215	0,152	0,12
Ekaterinburg	0,045	0,116	0,194	0,23	0,283	0,302	0,277	0,222	0,142	0,071	0,052	0,03
Bangkok	0,248	0,278	0,292	0,262	0,23	0,231	0,215	0,192	0,207	0,206	0,245	0,247

Table 5.2 Average Irradiance (kW/m^2) in the studied mines

Irradiance data were obtained by the use of the program SAM. Due to the difficulty of finding information about the solar power irradiance in the studied locations, alternative places in the near were selected.

5.3 Organic Rankine Cycle

First of all, every case study starts with a complete description of the geographical location and the climate conditions. To understand better the difference between those places and its influence in the results, it would be interesting to observe the next graphics comparing temperatures

5.3.1 The thermodynamics of Organic Rankine Cycle and working principles

The working principles for the ideal Organic Rankine Cycle are similar to the ideal Rankine Cycle. The condensate working fluid is pumped from the condenser where the pressure is low to the evaporator where the pressure is high. The process takes place at constant entropy. The high pressure liquid enters the evaporator and absorbs the thermal energy from heat source at constant pressure. In this process the refrigerant changes the phase from saturated liquid to saturated or superheated vapor. The external heat source can be waste heat from industry, geothermal heat, solar heat, biomass etc. The high pressure saturated or superheated vapor leaves the evaporator and expands through an expander at constant entropy to produce mechanical work. Under the expansion process, the pressure decreases to condenser pressure. After expansion process the working fluid leaves the expander and enters the condenser as unsaturated, saturated or superheated vapor depending on working conditions and the type of used working fluid. In the condenser, the working fluid condensates and changes phase to saturated or undercooled liquid with the help of a heat sink, and then the cycle is repeated.

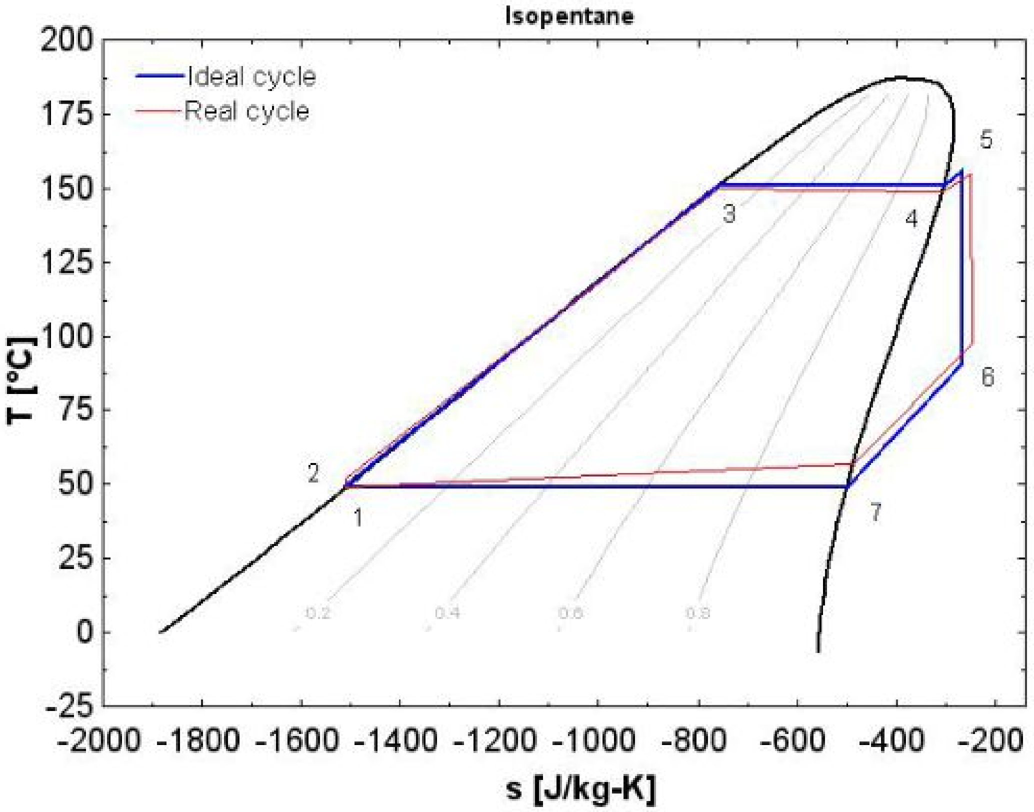


Figure 5.1 Graphic of an Organic Rankine Cycle (Isopentane)

In the real cycle the compression and expansion processes are not isentropic and there are always some losses in the pump and the expander. The heat addition and heat rejection processes are not isobaric and there are always pressure losses in the piping system. The irreversibility affects very much the performance of the thermodynamic system.

In a real cycle, there are two main sources for entropy generation and these sources are external and internal. The internal entropy generation occurs due to:

- Pressure drop because of friction in the system associated pipes
- Un-isentropic compression and expansion in the compressor or expander
- Internal transfer of energy over a finite temperature difference in the components.

And the external entropy generation occurs due to:

- The mechanical losses during work transfer

- Heat transfer over the finite temperature difference

5.3.2 System equations and theoretical analysis

The Organic Rankine Cycle has the same working principles and main components (evaporator, condenser, expander and pump) as the Steam Rankine Cycle. The main difference between the two cycles is the working fluid utilized.

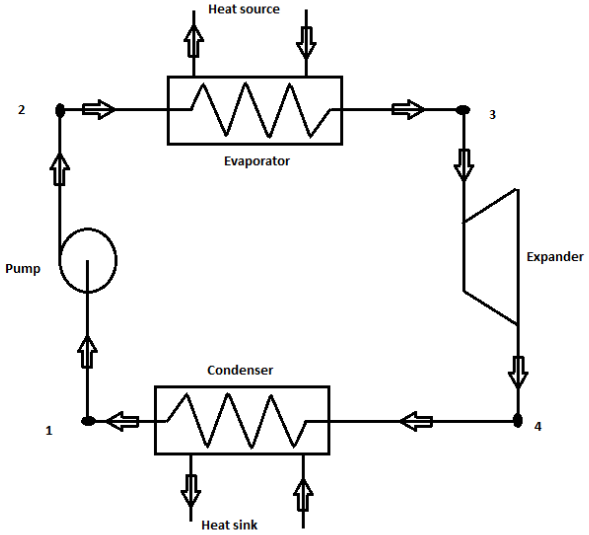


Figure 5.2 Scheme of the machinery required for an Organic Rankine Cycle

The working fluid passes through four main processes in order to complete one cycle. The following are the four processes for the ideal cycle.

Process (1 – 2) Compression

The working fluid leaves the condenser as saturated liquid and then it is pumped to the evaporator pressure at constant entropy. The process is ideal however the efficiency of energy transformation never reaches 100%. The state of the working fluid at pump inlet is indicated by point 1 and at pump outlet by point 2. The power absorbed by the pump is estimated by equation (1).

$$W_{1-2} = \dot{m}\,(h_2 - h_1) \quad (1)$$

Where W_{1-2} is the work consumption by pump, $\dot{m}$ is the mass flow rate, h_1 enthalpy at pump inlet and h_2 enthalpy at pump outlet.

The exergy destruction rate in the pump is given by equation (2)

$$\dot{I}_{1-2} = \dot{m}\,T_0[(s_2 - s_1)] \quad (2)$$

Where $\dot{I}_{1-2}$ is the exergy destruction rate in the pump, T_0 ambient temperature in K, s_1 entropy at pump inlet and s_2 entropy at pump outlet

Process (2-3) Heat addition

In this process heat is added to the working fluid at constant pressure, the process can be considered isobaric although the slight pressure drop in the evaporator pipes. The working fluid's state out of the evaporator is indicated by point 3 and the heat added to the working fluid can be calculated by equation (3).

$Q_{2-3}= \dot{m}\ (h_3-h_2)$ (3)

Where Q_{2-3} refers to the heat added to the working fluid and h_3 to the vapor enthalpy out of the evaporator and into the expander.

The temperature of the heat source decreases through the evaporator. Taking the arithmetic mean temperature (T_H) between inlet and outlet temperature, $T_H = (T_{in} - T_{out})/2$, the energy destruction in evaporator can be estimated by equation (4).

$\dot{I}_{2-3}= \dot{m}\ T_0[(s_3- s_2)\text{-}\ (h_3-h_2)/T_H]$ (4)

Where $\dot{I}_{2-3}$ is the exergy destruction rate in the evaporator and s_3 is the vapor entropy at evaporator outlet

Process (3-4) Expansion

This is an expansion process and the absorbed energy at the evaporator is converted to useful mechanical work by an expander or a turbine. The process is considered to be isentropic although the expander efficiency can never reach 100%. The state of the working fluid out of the expander is indicated by point 4 and the useful work out can be estimated by equation (5).

$W_{3-4}= \dot{m} *(h3-h4)$ (5)

Where W_{3-4} is the useful work produced by the turbine and $h4$ is the vapor enthalpy at turbine outlet

Equation (6) gives the exergy destruction rate in the expander.

$\dot{I}_{3-4}= \dot{m}\ T_0(s_4- s_3)$ (6)

$\dot{I}_{3-4}$ is the exergy destruction rate in turbine and s_4 is the vapor entropy at turbine outlet

Process (4-1) Heat rejection

In this process the heat is rejected in condenser in order to condensate the working fluid and re-circulates it in the cycle. The heat rejection process is considered to be isobaric despite pressure drops through the condenser due to friction losses in condenser pipes. The working fluid leaves the condenser as saturated or undercooled liquid. Point 1 refers to the working fluid at condenser outlet and pump inlet in T-S diagram. The amount of heat rejected can be estimated by equation (7).

$Q_{4-1}=\dot{m}(h4-h1)$ (7)

Where Q_{4-1} stands for the heat rejected heat in condenser

Since heat sink temperature increases continuously from condenser inlet to condenser outlet, the arithmetic mean temperature, $T_L = (T_{in} - T_{out})/2$ can be used to estimate the exergy destruction in the condenser. Equation (8) gives the exergy destruction in the condenser.

$\dot{I}_{4-1}= \dot{m}\ T_0[(s_1 - s_4)- (h_1-h_4)/T_L]$ (8)

Where $\dot{I}_{4-1}$ refers to the exergy destruction rate in condenser

The net thermal efficiency is defined as

$\eta_{thermal}= (W_{3-4} - W_{1-2})/Q_{2-3}$ (9)

The thermal efficiency is the ration of the Net Work Out to heat absorbed in the evaporator.

5.3.3 Heat Exchanger

Heat exchange is an important unit operation that contributes to efficiency and safety of many processes. Hereby performance of three different types of heat exchangers (tubular, plate, and shell & tube) will be evaluated. All these heat exchangers can be operated in both parallel- and counter-flow configurations. The heat exchange is performed between hot and cold water.

5.3.3.1 Theory

Overall Heat Transfer Coefficient U Consider energy balance in a differential segment of a single-pass heat exchanger. The rate of heat transfer in this segment is

$$dq(x)=U\Delta T(x)dA(x) \quad (1)$$

where U is the overall heat transfer coefficient, ΔT is the local temperature difference between the hot and cold fluids, and dA is the contact area in the differential segment. The overall heat transfer coefficient is inversely proportional to the total resistance Rtot to the heat flow. The latter is the sum of (1) resistance $R_{conv,h}$ to convective heat transfer from the hot fluid to the partition between the fluids, (2) resistance R_p to thermal conduction through the partition, and (3) resistance $R_{conv,c}$ to convective heat transfer from the partition to the cold fluid. Therefore

$$U=1/R_{Tot}=1/(R_{Conv,h} + R_P + R_{Conv,c}) \quad (2)$$

5.3.3.2 Relationships between Overall Heat Transfer Coefficient and the Inlet and Outlet Fluid Temperatures

Heat exchangers are usually analyzed using either the Logarithmic Mean Temperature Difference (LMTD) or the Effectiveness – Number of Transfer Units (ε-NTU) methods. The LMTD method is convenient for determining the overall heat transfer coefficient based on the measured inlet and outlet fluid temperatures. The ε-NTU method is more convenient for prediction of the outlet fluid temperatures if the heat transfer coefficient and the inlet temperatures are known.

5.3.3.3 Effectiveness-NTU Method

LMTD method is useful for determining the overall heat transfer coefficient U based on experimental values of the inlet and outlet temperatures and the fluid flow rates. However, this method is not very convenient for prediction of outlet temperatures if the inlet temperatures and U are known. In this case, one has to solve a nonlinear system of two equations and the overall energy balance) for two unknowns ($T_{h,o}$ and $T_{c,o}$). This solution requires application of an iterative approach.

A more convenient method for predicting the outlet temperatures is the effectivenessNTU method. This method can be derived from the LMTD method without introducing any additional assumptions. Therefore, the effectiveness-NTU and LMTD methods are equivalent. An advantage of the effectiveness-NTU method is its ability to predict the outlet temperatures without resorting to a numerical iterative solution of a system of nonlinear equations. The heat-exchanger effectiveness ε is defined as

$$\varepsilon=q/q_{max}$$

where q is the actual rate of heat transfer from the hot to cold fluid and q_{max} is the maximum possible rate of heat transfer for given inlet temperatures of the fluids,

$$q_{max}=C_{min}(T_{hi}-T_{ci})$$

Here, Cmin is the smaller of the two heat capacity rates C_c and C_h. If heat exchanger effectiveness is known, one can readily obtain q from these equations. After that, the outlet temperatures can be obtained from the energy balance. The efficiency ε depends on the heat exchanger geometry, flow pattern (parallel flow, counter-flow, cross-flow, etc.) and the number of transfer units

$$NTU=UA/\ C_{min}$$

Relationships between the effectiveness and NTU have been established for a large variety of heat exchanger configurations. Most of these relationships involve the ratio $C_r = C_{min}/C_{max}$ of the smaller and the larger of the heat capacity rates C_c and C_h. For example, for a single pass heat exchanger in the counter-flow regime

$$\varepsilon=[1-\exp(-NTU(1+C_r))]/\ [1-C_r*\exp(-NTU(1+C_r))]$$

5.3.4 Cost Factors

5.3.4.1 Installation cost

Installation costs are all initial costs excluding transmission and distribution that are incurred in the construction and commissioning of a power plant. The costs can be categorized into resource exploration, appraisal, production drilling and plant construction costs.

5.3.4.1.1 Exploration costs

The costs under this category include the cost of desk top data review, detailed surface study, infrastructure development and drilling of exploration wells. Depending on the whether in-house capacity or external consultants are used, the duration, the methodology used, remoteness of the resource, the detailed surface studies including the desk top may cost up to about 2 million US$. The infrastructure is a one off (fixed) cost that entails construction of access roads and water reticulation system. This cost will vary from project to project and is greatly influenced by the project's remoteness and availability of drilling water. It is common practice to drill 3 – 4 exploration wells; one as a discovery and two as confirmation wells.

5.3.4.1.2 Appraisal costs

Appraisal entails drilling additional wells and undertaking a feasibility study. It is typical to drill 6 – 9 appraisal wells. Thereafter, a bankable feasibility will be undertaken on the basis of which the prospect is approved for development. The feasibility study is mainly a desktop study that would include reservoir simulation and undertaking a preliminary design of proposed power plant. The feasibility study would cost about 2 million US$.

5.3.4.1.3 Production drilling costs

Production drilling entails drilling to provide adequate steam to operate a specific size of plant at full capacity and reinjection wells. The energy output from individual wells is highly variable, depending on the flow rate and the enthalpy (heat content) of the fluid, but is commonly in the range 5-10 MWe and rarely over 15 MWe per well (2010 Survey of World Energy).

Productivity is a affected by many variables including, well completion size, drilling fluids employed, permeability (primary and secondary), understanding of the field, the development phase, depth and the resource itself. Wells in high temperature fields are commonly 1.5-2.5 km deep and the production temperature 250- 340°C. Kenyan geothermal wells range between a depth of 900 to 3200 m. A typical well in Nevada costs about $10 million to drill.

5.3.4.1.4 Power plant construction

Rarely does one find cost of geothermal generation equipment stated alone. In addition, the cost of plants would vary even for plants of the same size because they are designed to match the resource characteristics in particular turbine inlet pressure. The price of generation equipment including installation may range between 1.5 million US$ to about 2.8 million US$.

5.3.4.2 Operation and maintenance cost

The operation and maintenance cost factors may be categorized as ordinary O & M costs which include staff, administrative and cost of spares, the plant inefficiency, reservoir management costs and cost of capital associated with increased working capital.

5.3.4.2.1 Ordinary O&M

The rate of operation and maintenance is fairly low for geothermal. The renewable energy cost of generation update (August 2009) indicates a figure of 0.0117 US$ per kWh.

5.3.4.2.2 Plant inefficiency cost

Power plants suffer failures and breakdown. They do not operate at design capacity over their entire life but with time the efficiency decreases and the plants require timeout for inspection, repairs, refurbishment, rehabilitation and overhauls. The timeout costs money for maintaining staff and depreciation. This cost is captured through the capacity factor. The renewable energy cost of generation update (August 2009) indicate capacity of 90% for binary plants and 94% for the flash steam plants.

5.3.4.2.3 Steam field management cost

The steam field requires close monitoring during steam production to forestall serious steam declines, cold flow invasion, scaling and other adverse effects. Management and remedial works may be undertaken including drilling make-up and additional re-injection wells, work-overs, tracer injections and injection of scale inhibitors. These costs will vary greatly from one project to another and from one field to another.

5.3.4.2.4 Working capital

Firms require funds in their normal day to day operations. Besides paying out debts that become due, firms need to establish inventories of most critical spares. Experience has shown that lead times for some key power plant parts can be in excess of half year and it is not unusual to receive parts a year after making an order. Capital retained for this purpose will cost the company money to secure. However, the cost of working capital is relatively small.

5.4 Comparison with other Technologies

The feasibility of a geothermal power project does not only depend on the technical issues previously introduced. Decision on the development of a geothermal project will also be dependent on the economic justification of the geothermal resources involved in the project. Table 4 proposes an overview of typical costs for various types of power plants:

- Geothermal:
    - Steam turbine plants: harnessing energy from geothermal fluids at temperature above 180°C.
    - Binary plant: the binary technology allows for production of electricity from low temperature resources that could otherwise not be used for such purpose, typically at reservoir temperatures below 180°C.

- Medium speed diesel: this type of power plant typically operates on heavy fuel.
- Steam turbines: typically operating on coal for the purpose of this paper.
- Combustion turbine typically operating on gas for the purpose of this paper.
- Nuclear.
- Wind: similarly to geothermal power plants, wind turbines are site specific.
- Hydro:
    - Large dam hydropower plants, designed to have a high capacity factor.
    - Other hydropower plants, with smaller dams and a lesser capacity factor.

Table 5.3 Typical costs for power plants and maintenance cost

Plant	**Investment cost MUSDMW**	**Annual operational and maintenance cost**		**Typical load factor**
		Fixed USD/MW	**Variable USD/MWh Gross**	
Geothermal, steam	3.60	43,000	4.3	90 - 95
Geothermal, binary	5.30	43,000	1.0	85 - 95
Large wind	2.00	35,000	2.0	35 - 40
Nuclear	4.05	90,000	15.0	80 - 90
Large hydro	2.80	15,000	1.0	80 - 90
GasTurbines	0.80	12,000	90.0	50 - 60
Coal	2.10	70,000	60.0	70 - 80
Diesel	1.50	60,000	120.0	30 - 40

Typical capacity, or load, factors are also indicated for each type of power plant in Table 4. The capacity factors indicated depend on availability of the source, for intermittent renewable sources of energy such as wind or hydropower, and on the fuel costs. Geothermal power plants are generally considered one of the power production means with the highest capacity factor as the energy may be available 24 hours a day almost all year round and may in some cases be above 95%.

It is possible to compare the economics of different energy sources by considering the various cost elements such as: investment cost, fuel cost, operation and maintenance costs, economic lifetime and efficiency. An Equity Research on “Alternative Energy” conducted by Credit Suisse in 2009 aimed at comparing Levelised Cost of Electricity for various sources of energy, see Figure 5.3. According to these estimates, geothermal plants are the least expensive form of power.

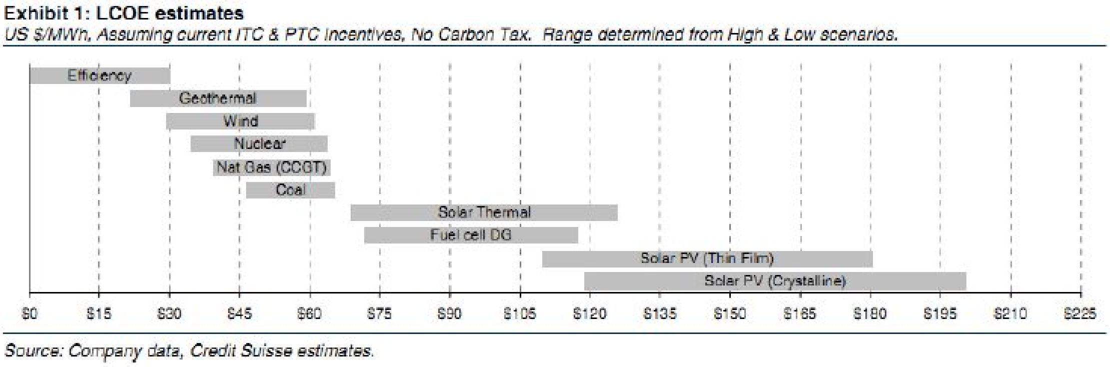


Figure 5.3 LCOE estimates forvarious sources of energy (CreditSuisse, 2009)

5.4.1 Exploration

Exploration is the initial development phase and seeks to locate a geothermal resource that can provide sufficient energy to run a power plant and produce electricity. This phase begins with various kinds of prospecting and field analysis and ends with the drilling of the first successful full-size commercial production well. Different technologies that aim to locate a productive geothermal reservoir are used at each exploration phase. The breakdown of exploration steps presented below, inspired by Nielson (1989), provides an order of magnitude for exploration costs based on a 100 MW development scenario. The original cost estimates for the three exploration phases detailed below (i.e. regional reconnaissance, district exploration, and prospect evaluation) have been inflated to represent current US Dollar values. Prior to investing any money on exploration activities, geothermal developers will make sure they control, or will be able to control, the land and mineral rights associated with the site. Costs related with these activities are typically lumped together as “lease acquisition costs”.

A. Regional reconnaissance.

Regional reconnaissance screens a region (1000's km^2) in order to narrow the focus and identify areas of potential interest. It involves geologic studies, analysis of available geophysical data, and geochemical surveys to identify more limited areas for detailed exploration. Assuming the development of a 100 MW power project, the cost of these activities was estimated to average $770,000 (Nielson 1989). This corresponds to $7.7 per kW installed. Regional reconnaissance costs are however heavily influenced by both the amount of resource information already available and by the accessibility of prospective areas. National government, international development institution or multilateral aid programs typically finance these activities. In the U.S., the USGS completed such surveys in the 1970's. Today, most developers tend to rely on the USGS data rather than funding this kind of activities of their own. The age and quality of the information currently available is becoming an issue.

B. District Exploration.

District exploration applies within more concise areas (100's km^2) and aims to site an initial narrow diameter hole or production well. Geophysical surveys and temperature gradient holes are the major components of this phase. According to the site characteristics and other exploration requirements, geophysical technologies may include gravity surveys, ground magnetic surveys, magnetotelluric surveys, electrical resistivity surveys and seismic surveys. These provide information about the subsurface rock formations and the probability of discovering a new geothermal reservoir. Encouraging results from prior exploration steps may lead to the drilling of the first deep exploration well. Drilling is the most expensive component of the district exploration phase but is the only means currently available to confirm the temperature and productive capacities of the subsurface resource. Either a production-sized well or a slim-hole is drilled. Slim-holes, especially cored holes, provide a great deal of information related to fractures, minerals, etc. Since slim holes are relatively shallow and do not always reach the resource, they do not allow detailed flow tests and are rarely useful as production or injection wells. Some developers therefore prefer not to use them and directly drill a full size production well. While the cost of drilling one full diameter production well may correspond to the cost of two slim holes, the well will be usable for precise flow rate tests and will be available for future energy production.

If the developer chooses to drill a slim hole, the average cost of the "district exploration" phase ranges from 1.5 to 3 million US$. (i.e. $22.5 per kW). This cost depends heavily on the geology of the resource area and the resource depth. Although it might be difficult and painful to abandon a million-dollar investment, exploration activities would only be continued at a particular site if information shows that there is a high probability of finding a productive geothermal reservoir.

C. Prospect Evaluation.

Prospect evaluation seeks to locate the best sites to drill production wells with high fluid temperatures and flow rates. Wells drilled during this phase are called "wildcats" and have an average success rate of 20-25%. Geophysical surveys help locate subsurface fractures that will be targeted by the drilling.

Once a resource is discovered, almost all activities consist of drilling production and injection wells, testing well flow rate, and reservoir engineering. This provides crucial information about the resource depth, temperature, and potential capacity. According to Nielson (1989), the "prospect" phase usually costs about $7.7 million (i.e. 77$/kW). The exploration phase typically ends with the drilling of the first successful production well. The cost value provided here is indicative and may vary greatly according to the number of unsuccessful wells and the size of the project.

Factors affecting the cost of exploration are closely related to site characteristics and location. Exploration for a "greenfield" geothermal project usually includes the district exploration phase, while expansion of existing plants may skip this phase and even present significant cost reduction in the prospect evaluation phase. Since the type of activities required to locate a new resource is independent of the project size, important economies of scale apply when exploration costs are spread out over a larger project. Current exploration activities in the U.S. typically concern 10 to 50 MW projects. Recent interviews with geothermal developers provided exploration cost estimates averaging $150/kW. Total exploration cost figures may thus range from the low $100/kW to $200+/kW according to the nature of the project (greenfield vs. expansion), the amount of information initially available, the suite of technologies involved in each exploration phase, and the size of the project and resulting economies of scale.

Since exploratory drilling is the most important cost component of the exploration phase, factors affecting drilling costs will strongly influence the resulting cost of the exploration phase. Specific attention is paid to those parameters in the "site development" section. (See below).

Other parameters affecting exploration costs are lease costs and timing, site remoteness, accessibility, topography as well as geologic engineering related to slope stability issues. If the cost of building new roads and other connection infrastructure are added to the exploration expenses, exploration costs may rise rapidly.

Exploration cost estimates found in the literature may be somewhat lower but are considered consistent with those provided above. The difference is justified by the current nature and size of exploration activities: current projects tend to be smaller, focus on more difficult areas than past projects and may use more advanced and thus more expensive exploration technologies. Some particularly low exploration cost figures (not included in the following table) may also be found but are thought to correspond to projects that do not require a full exploration program or contain unrealistic assumptions.

5.4.2 Confirmation

The confirmation phase mainly consists of drilling additional production wells and testing their flow rates until approximately 25% of the resource capacity needed by the project is confirmed. It also involves reservoir design and engineering and the drilling of some injection capacity to dispose of fluids from production well tests. In addition to confirming the energy potential of a resource, an important characteristic of this phase is linked to its financial component. Most lending institutions will require 25% of the total project capacity to be confirmed prior to lending any money to geothermal developers. This means that, similar to the exploration phase, all expenses incurred during the confirmation phase have to be funded with equity investment.

Drilling expenses usually account for eighty percent (80%) of total confirmation costs. Other activities and costs consist mainly of road and pad construction, well testing, reporting, regulatory compliance & permitting, and administration. Two major factors will affect total drilling costs: (1) the cost of drilling individual wells and, (2) the number of wells to drill. The cost of an individual well is mainly related to the depth and diameter of the well as well as the properties of the rock formation. The number of wells to drill is determined by the average well productivity and the size of the project. Well productivity directly depends on the resource temperature and the rock permeability. Compared to the exploration phase, the drilling success rate increases significantly during the confirmation phase and averages 60%. Such improvements are due to learning effects and are explained by a better understanding of the resource location and other site-specific characteristics. (A detailed analysis of factors influencing drilling cost is provided in the following section)

Confirmation cost estimates for commercially viable projects are considered to average 150 $/kW. This corresponds roughly to one-fourth of the total drilling costs but may be somewhat lower since confirmation does not require 25% of injection capacity to be drilled. Resulting confirmation costs may however vary widely according to the resource characteristics and drilling success rate.

Major factors affecting confirmation costs are related to drilling costs (see following section). Other parameters are the site's accessibility and the possible delays due to regulatory or permitting issues or accessibility of drilling rigs. Like the exploration phase, money involved in the confirmation phase is usually venture capital (equity) which requires a high rate of return and therefore affects the all in cost of the project. Any delay during or following this phase thus corresponds to an actual cost increase. The developer should thus make sure he will be able to obtain all permits required to start confirmation drilling.

5.4.3 Site Development

The site development phase covers all the remaining activities that bring a power plant on line. This includes power plant design and associated technological choices, drilling and well testing until all steam/brine requirements of the project are met, power plant construction and installation, and connection to the grid.

Once the resource characteristics are known, developers can relatively easily estimate the cost of putting the project online and thus approximate the minimal power price needed to make the project economically viable. This phase includes a series of technological choices that depend on the resource characteristics and location and might significantly affect the resulting cost of development.

5.4.3.1. Drilling

Drilling a geothermal well consists of a succession of steps of drilling and well casing construction until the top of the resource is reached. Once the well penetrates into the geothermal reservoir, the only additional casing that may be required would be an uncemented slotted liner to prevent rocks and debris from falling into the wellbore, however if the formation rock is competent then no additional casing is required. The productivity of the well will be influenced by its length in the permeable rock as well as the number of productive fractures it crosses.

Drilling costs are highly dependent upon resource characteristics. Other economic parameters may however also influence the total cost of drilling. All the parameters listed below affect the cost of drilling, whatever the phase of development.

A. RESOURCE AND BRINE CHARACTERISTICS:

Factors influencing the cost of drilling and completing one well:

The depth of the resource is one of the major parameters influencing the cost of drilling a geothermal well. Along with the rock formation (nature, structure and hardness), which determines the drilling speed, these parameters influence the initial well diameter, the number of casing strings needed and, thereby, the time required to drill the well. According to the variability of these parameters, the drilling of a geothermal well may last from 25 to over 90 days, with a reasonable average of 45 days. Deeper wells also require larger and thus more expensive drilling rigs.

The pressure of the geothermal resource and rock formations above it will influence both the drilling process and the strength of the well casing. High pressure may result in well blow-out. In addition to being dangerous for the drilling crew, well blow-out may be very expensive and can threaten the economic viability of the project. In order to prevent this, the developer must install a stronger and heavier casing along with a highly specialized blow-out prevention system. This may involve the drilling of a larger, and thus more expensive, well diameter, the handling of a specialized well casing and the use of special and better quality "blow-out prevention" equipment.

When the geological formation above the resource has an internal pressure less than hydrostatic and is permeable, loss of circulation fluid may become problematic. In such cases, the drilling process may require more frequent casing stages or other specific measures (e.g. use of lower density drilling fluids) that significantly increase drilling costs. Each additional casing layer results in additional work (casing construction and well head completion), delays the drilling process (drilling activities are on hold during these casing and wellhead completion activities), and results in a narrower well diameter (which will affect the brine flow and thereby the well productivity). In some cases compressed air, aerated mud or water as well as foam can be utilized as a drilling media rather than drilling mud. Compressed air or similar systems increase the cost of drilling for both the equipment that compresses the air and the system to handle the exhausted air and cuttings discharged from the well.

Loss of circulation fluid in a productive zone of the resource has a major effect on drilling costs. If the drill bit enters a highly permeable zone (e.g. a open fracture) in which formation pressure doesn't compensate for the pressure of the column of drilling fluids, this fluid may flow into the resource rock formation (i.e. loss of circulation fluid). If the developer wants to pursue the drilling to enhance the productivity of the well, that zone must be temporarily plugged with specific material (e.g. cotton seed hulls). This decision is however difficult to make since the productive zone may remain permanently plugged.

The total number of casing strings is determined by both the depth and the type of geologic structures drilled through and determines the resulting productive diameter of the well, which, in turn, influences the overall well productivity through frictional losses. Once the resource characteristics are known, the developer may target a certain well diameter at a certain depth. For self-flowing wells, this aims to minimize frictional losses, while in the case of pumped resources it permits the pump to be installed at sufficient depth. As brine rises in the well, the pressure decreases but temperature stays approximately constant, so at some particular depth the brine will begin to boil and steam will form. Since two-phase flows (i.e. water & steam) squander much more energy in frictional losses than single-phase flows, the developer may want to reduce frictional losses above the "boiling point" depth by employing a larger well diameter. For pumped resources, the developer must install the pumps at sufficient depth to avoid two-phase flow. This usually means that a 13 3 /8 diameter well completion is needed down to a level below the brine "boiling point" depth in order to accommodate the downhole pump. Since the cost of the well is directly proportional to its diameter, such diameter requirements may significantly affect the resulting cost of the well.

The chemistry of the brine is another important factor that determines the nature of the materials used in the well casing process. A corrosive geothermal fluid may require the use of resistant pipes and cement. Adding a titanium liner to protect the casing may significantly increase the cost of a well. Current cost estimates for titanium pipes average $1000 per foot (i.e. 2.4 M$ for a 2400 feet deep casing). This kind of requirement is rare, and in the U.S., limited to the Salton Sea geothermal resource.

Statistical analyses of historical drilling costs data show that the depth of the well is the major parameter explaining its overall cost. GeothemEx (2004) built the following empirical function to estimate drilling cost:

$$\text{Drilling cost (in US\$)} = 240{,}785 + 64 \text{ x (depth in m)} + 0.0017716 \text{ x (depth in m)}^2$$

Factors influencing the number of wells to drill:

Rock permeability and resource temperature and pressure are the major parameters influencing the well flow rate. These factors will also determine the well productivity and thus the number of wells needed to supply the power plant's energy requirements.

In the U.S., flow rates of commercial wells vary greatly (from pumped resources, to low and high natural flow rates), and temperatures of commercially viable resources vary from slightly below 250°F to over 500°F. Since well productivity is directly related to both these parameters, the resulting productivity of a geothermal well varies even more (1-2 MW to 25-50 MW/well) but average values range 3-5 MW.

$$\textit{Well productivity (MW)} = \textit{resource temperature (°F)} / 50 - 3.5$$

Downhole pumps are intolerant of high temperatures and their use is therefore limited to low or medium temperature resources, which, in most cases, use binary power systems. On the other hand, high temperature resources with reasonable rock permeability are characterized with self-discharging wells. Their natural discharge rate increases as the temperature of the resource rises. Another major factor affecting the well's natural flow rate is the rock permeability of the geologic structure. This characteristic determines the ability of the geothermal fluid to flow through a porous or fractured media. The resource productivity may vary widely from place to place within the reservoir, and may also change with time.

Well productivity decline is a common phenomenon in geothermal power projects. It justifies the drilling of at least one additional productive well above the estimated brine/energy requirements of the power plant during the initial drilling phase. The impact of productivity decline on make-up well drilling costs is addressed in the O&M cost section. Although make-up drilling costs are considered as depreciable costs rather than expenses and thus appear as capital costs in accounting books, this paper considers them as O&M costs that help maintain power production to an optimal level during the entire lifetime of the power plant.

5.6 Component Cost Estimation

The key components affected by the choice of working fluid are those illustrated previously—the working-fluid pump, the expander and the heat exchangers. The costs of these components are added to give an estimate of the plant cost. Although this sum does not give the total installation cost, it is through this amount that the effects of working-fluid choice on plant costs are manifested directly.

Other factors that contribute to the plant installation costs would be similar for the various working fluids, considered especially as the fluids considered in this work are of the same chemical class; other factors such as flammability and corrosiveness can increase investment costs when comparing working fluids from different chemical classes.

Generally, there are uncertainties inherent in the estimation of costs of process equipment and plants (and also in the estimation of heat-transfer coefficients, albeit to a lesser degree), with preliminary cost estimation techniques being accurate up to ±25%. While these uncertainties do exist, the qualitative information derived from using a particular costing technique for comparison of plants/systems of different sizes will not be influenced to a large degree by such uncertainties. Thus, it is important to use a single and consistent source of information for the comparison of the ORC systems employing different working fluids.

Various techniques are available for estimating the installation/capital costs of process equipment and units. Data for such techniques are usually obtained from surveys of equipment manufacturers during a particular time period. An example is the capital equipment-costing (CAPCOST) program which contains the capital costs of a large variety of process equipment, benchmarked in the year 2001.

Another technique available is the C-value method, used in combination with the ESDU 92013 chart, produced in 1994, for estimating the cost of different types of heat exchangers. Similar to the CAPCOST program, logarithmic correlations are presented for a wide range of process equipment in Seider et al.; the data used for these correlations were gathered in the year 2006. Generally, conversions from the publication years (1994, 2001 or 2006) to the current year can be carried out using

the Chemical Engineering Plant Cost Index (CEPCI).

In this work, we employ the correlations provided by Seider et al. due to its more recent date of production, thereby minimizing variations introduced by year-to-year conversions with the CEPCI.

Component-base costs (C_B, indexed in year 2006; £1 ≡ €1.47, $1.84) are calculated using logarithmic correlations of component size factors (S) according to Seider et al.:

$$C_B = F*\exp[C_0 + C_1 \ln S + C_2(\ln S)^2] .$$

The component size factors are presented in the next table. Also provided are the cost coefficients (C_0, C_1, C_2, converted to SI units). The correlation for the pump motor (with W_{pump} re-expressed in units of hp) base cost contains more terms and is given by:

$$C_B = \exp[5.83 + 0.134*\ln W_{pump} + 0.0533(\ln W_{pump})^2 + 0.0286(\ln W_{pump})^3 - 0.00355(\ln W_{pump})^4]$$

Table 5.4 Component cost coefficients used to calculate C_B

Component	S	F	C_0	C_1	C_2
Expander	W (kW)	1,0	6,5106	0,81	0
Heaters/coolers	A (m^2)	1,0	10,106	-0,4429	0,0901
Evaporator/Condenser	A (m^2)	1,0	9,5638	0,532	-0,0002

Finally, the cost is depending on some factors such as the design of heat exchanger, the material of manufacturing and the work pressure. This last factor will be calculated by the next values:

$$C_{HX}=C_B F_M(F_D+F_P)$$

Table 5.5 Guthrie Material and pressure factors for Heat Exchangers: $F_M (F_P + F_D)$

Design Type	**F_D**		**Vessel Pressure (psig)**					
Kettle reboiler	1,35							
Floating head	1,00		**Up to**	150	300	400	800	1000
U tube	0,85		**F_P**	0,00	0,10	0,25	0,52	0,55
Fixed tube sheet	0,80							
Shell/Tube Materials, F_M								
Area (ft^2)	CS/CS	CS/Brass	CS/SS	SS/SS	CS/Monel	Monel/Monel	CS/Ti	Ti/Ti
Up to 100	1,00	1,05	1,54	2,50	2,00	3,20	4,10	10,28
100 to 500	1,00	1,10	1,78	3,10	2,30	3,50	5,20	10,60
500 to1000	1,00	1,15	2,25	3,26	2,50	3,65	6,15	10,75
1000to 5000	1,00	1,30	2,81	3,75	3,10	4,25	8,95	13,05

6 GRANITE MINE IN LAKE HAVASU CITY

Do not go where the path may lead, go instead where there is no path
and leave a trail

Ralph Waldo Emerson

This mine is an open pit mine producing 5,000 tons ore and 5,000 tons waste per day. Rock characteristics for both ore and waste are typical of those of granite or porphyritic material. Operating conditions, wage scales, and unit prices are typical for western U.S. mining operations. This mine will be located close to Lake Havasu City, in Arizona, U.S.

Figure 6.1 Granite Mining

Table 6.1 Granite Mining Plant Model

Production		**Equipment**		
Mine Type	Surface Mine	Hydraulic Shovels (d)	1 x	3.4 m^3
Stripping Ratio	1:1	Front-end Loaders (d)	1 x	3.8 m^3
Ore Production	5,000 tons/day	Rear-dump Trucks (d)	6 x	41.0 tons
Waste Production	5,000 tons/day	Rotary Drills (d)	2 x	20.00 cm
Haul Distance-Ore	1,532 m	Bulldozers	3 x	60 kW
Haul Distance-Waste	1,310 m	Graders	1 x	115 kW
Total Resource	18,720,000 tons	Water Tankers	1 x	9,500 l
Hours per Shift	10 hours/shift	Service/Tire Trucks (d)	3 x	1,800 kg
Shifts per Day	2 shifts/day	Bulk Trucks (d)	1 x	450 kg/min
Days per Year	312 days/year	Light Plants	4 x	8.9 kW
Bench Height-Ore	4.60 m	Pumps	2 x	14.9 kW
Bench Height-Waste	6.72 m	Pickup Trucks (d)	5 x	680 kg
Powder Factor-Ore	0.33			
Powder Factor-Waste	0.29			

ENERGY REQUIREMENTS	
Diesel Fuel (d)	4,751 l/day
Electricity	639 kWh/day
Max Power Demand	360,4 kW

6.1 Mine Location

Lake Havasu City is located at 34°29′24″N 114°18′32″W. According to the United States Census Bureau, the city has a total area of 112 km^2, of which, 111 km^2 of it is land and 0.10 km^2 of it (0.07%) is water.

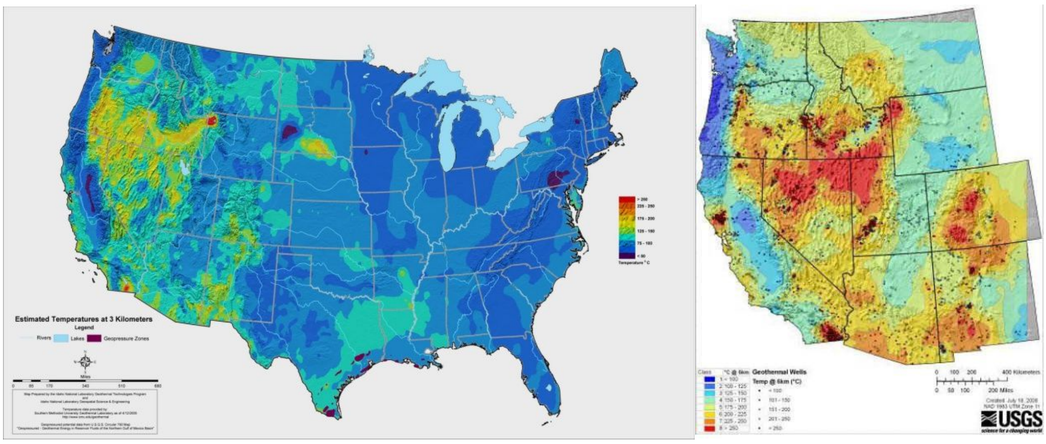


Figure 6.2 U.S.A. Geothermal Sources Map

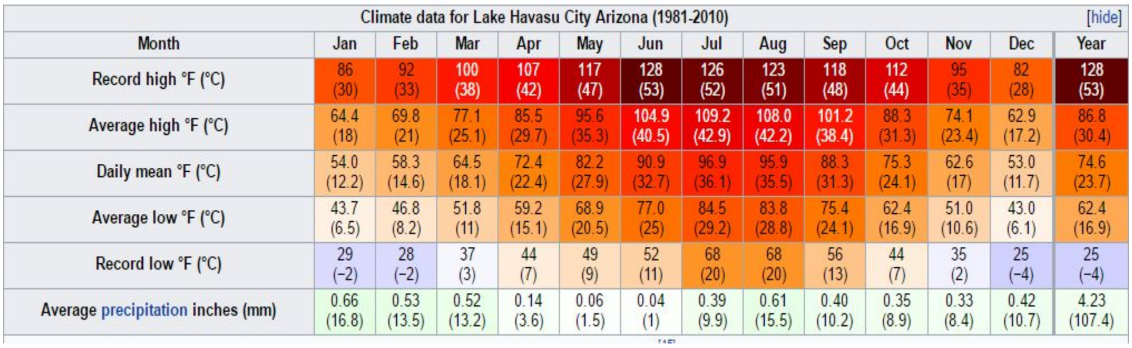
According to the mapsabove, geothermal water temperature ranges are between 125-150ºC at 3 km depth, and about 225-250ºC after 6 km. Advantages and disadvantages will be analized after by compulsory calculations.

6.2 Climate conditions

Lake Havasu City has a hot desert climate. In the winter months, daytime highs usually range from 60 °F (16 °C) to 70 °F (21 °C). Lows in winter average between 40 °F to 50 °F (4 °C-10 °C); temperatures do occasionally dip below 40 °F (4 °C). The city has extremely hot summers, with highs normally remaining between 100 °F and 115 °F (38 °C - 46 °C). Highs are known to exceed 125 °F (52 °C) during the summer months. Overnight low temperatures stay between 80 °F to 90 °F (27 °C - 32 °C) for the months of July and August.

The highest overnight low temperature (record high minimum) ever recorded in Lake Havasu City was 98 °F (37 °C) on July 22, 2003.

Mean annual precipitation is 3.84 inches. The annual mean temperature is 74.6 °F (23.7 °C).



Climate data for Lake Havasu City Arizona (1981-2010) [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	86 (30)	92 (33)	100 (38)	107 (42)	117 (47)	128 (53)	126 (52)	123 (51)	118 (48)	112 (44)	95 (35)	82 (28)	128 (53)
Average high °F (°C)	64.4 (18)	69.8 (21)	77.1 (25.1)	85.5 (29.7)	95.6 (35.3)	104.9 (40.5)	109.2 (42.9)	108.0 (42.2)	101.2 (38.4)	88.3 (31.3)	74.1 (23.4)	62.9 (17.2)	86.8 (30.4)
Daily mean °F (°C)	54.0 (12.2)	58.3 (14.6)	64.5 (18.1)	72.4 (22.4)	82.2 (27.9)	90.9 (32.7)	96.9 (36.1)	95.9 (35.5)	88.3 (31.3)	75.3 (24.1)	62.6 (17)	53.0 (11.7)	74.6 (23.7)
Average low °F (°C)	43.7 (6.5)	46.8 (8.2)	51.8 (11)	59.2 (15.1)	68.9 (20.5)	77.0 (25)	84.5 (29.2)	83.8 (28.8)	75.4 (24.1)	62.4 (16.9)	51.0 (10.6)	43.0 (6.1)	62.4 (16.9)
Record low °F (°C)	29 (−2)	28 (−2)	37 (3)	44 (7)	49 (9)	52 (11)	68 (20)	68 (20)	56 (13)	44 (7)	35 (2)	25 (−4)	25 (−4)
Average precipitation inches (mm)	0.66 (16.8)	0.53 (13.5)	0.52 (13.2)	0.14 (3.6)	0.06 (1.5)	0.04 (1)	0.39 (9.9)	0.61 (15.5)	0.40 (10.2)	0.35 (8.9)	0.33 (8.4)	0.42 (10.7)	4.23 (107.4)

Table 6.2 Climate data for Lake Havasu City Arizona

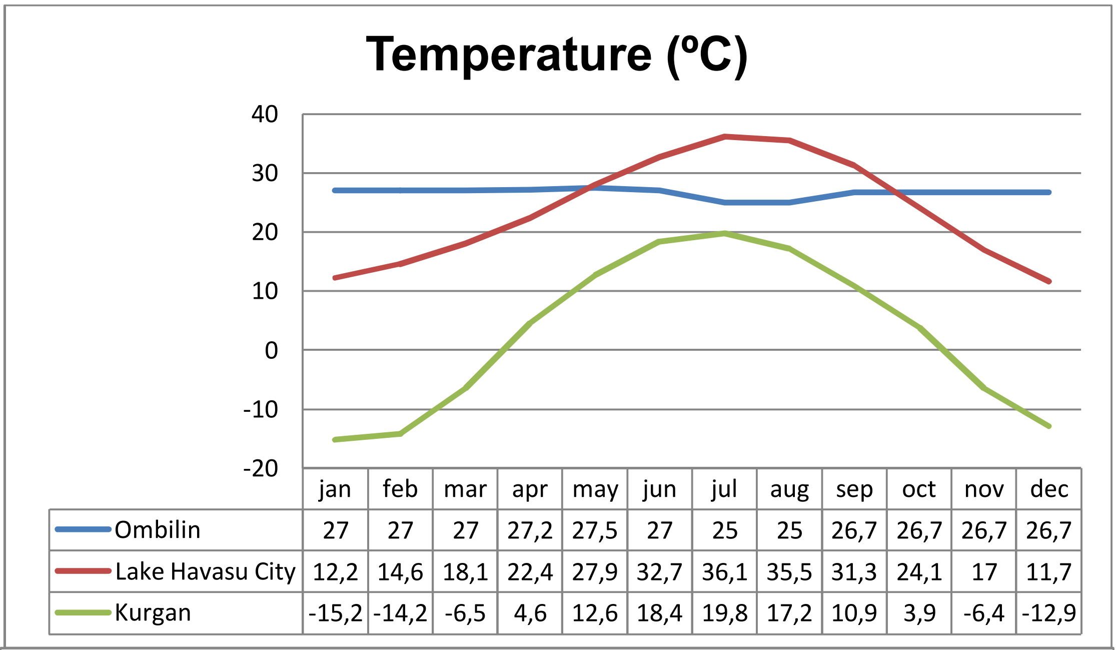
Lake Havasu City holds the all-time record high temperature in Arizona history with 128 °F recorded on June 29, 1994. This temperature is also the highest for a town or city in the Western Hemisphere. On December 31, 2014, snow fell on Lake Havasu City.

The next tables will show the data of solar radiation obtained in the city of Lake Havasu, AZ.

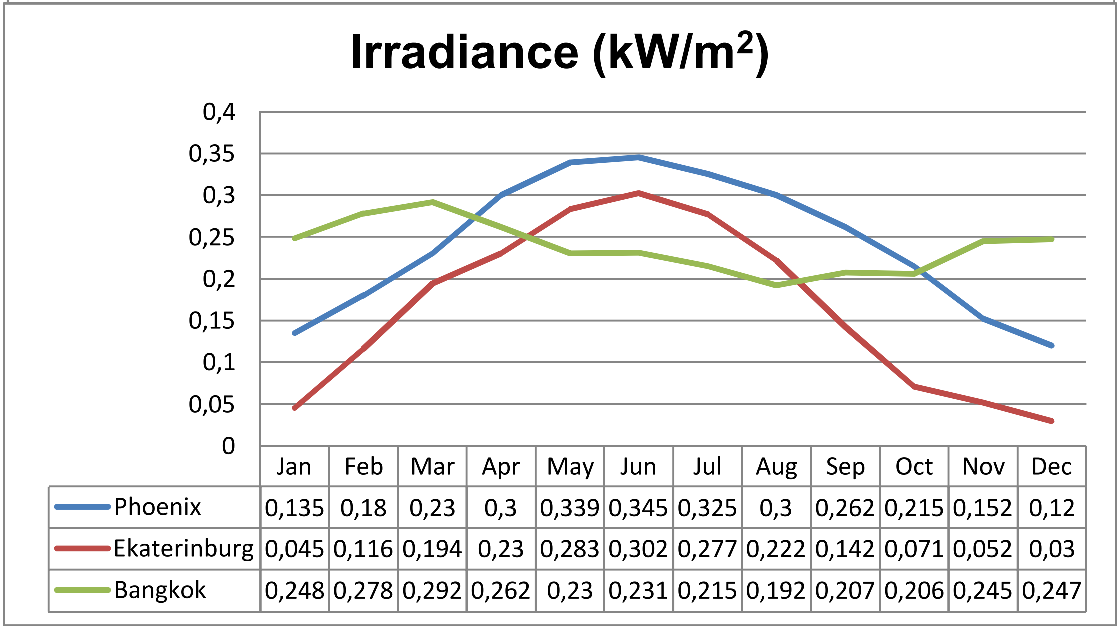
Table 6.3 Average Daily Solar Global Radiation

	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
kWh/m^2	3,1	4	5,5	6,9	7,6	7,9	7	6,2	5,8	4,6	3,5	2,9

The 2 graphics attached below represent both temperature and radiation (kW/m^2) from close cities taken by the SAM program comparing this mine with the location of the other case studies of this project, in order to observe the differences between them:



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Ombilin	27	27	27	27,2	27,5	27	25	25	26,7	26,7	26,7	26,7
Lake Havasu City	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
Kurgan	-15,2	-14,2	-6,5	4,6	12,6	18,4	19,8	17,2	10,9	3,9	-6,4	-12,9



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phoenix	0,135	0,18	0,23	0,3	0,339	0,345	0,325	0,3	0,262	0,215	0,152	0,12
Ekaterinburg	0,045	0,116	0,194	0,23	0,283	0,302	0,277	0,222	0,142	0,071	0,052	0,03
Bangkok	0,248	0,278	0,292	0,262	0,23	0,231	0,215	0,192	0,207	0,206	0,245	0,247

Finally, due to the proximity of the Havasu Lake, it would be in addition another case of study the possibility of using its water as cooling fluid. This aspect will be studied after, taking in consideration possible environment damages in order to avoid them.

6.3 Fluid Selection

The choice of the optimal working fluid depends basically on the heat source and the heat sink temperature. For any heat temperature level there are a number of candidates which show a good match between heat source and heat sink temperatures and cycles boundary conditions. The choice the right working fluid is not an easy process. The fluid selection process is a trade-off between thermodynamic specifications, safety, environmental and economy aspects.

Simulation assumptions

Following are the assumption for this scenario

- The cycle is considered to work at steady state
- Pressure drop in heat exchangers is neglected
- Isentropic efficiency for pump and expander is assumed to be 0.8
- Min Ambient temperature T_{Min} = 0 ºC
- Max Ambient temperature T_{Max} = 45 ºC
- Heat sinks temperature T_{Sink} = T_{Amb} -10 ºC
- The Evaporating temperature is depending on the thermodynamical properties of every fluid. It will be considered the value of T_{Crit} -10 ºC
- Heat source temperature dependant on the source depth. T_{1km} = 100 ºC, T_{1km} = 150 ºC, T_{1km} = 220 ºC

The evaporation temperatures are too high in this scenario and much higher than the critical temperature for many working fluids. For this reason, many working fluid with low critical temperature can´t be used in this scenario.

FLUID	T_{NBP}	T_{crit}	P_{crit}	efficiency$_{min}$	T_{efmin}	efficiency$_{max}$	T_{efmax}
R11	23,558	197,81	4407,6	0,15180	40	0,2014	0
R245fa	14,99	153,85	3651	0,12270	45	0,1849	0
R236ea	6,05	139,14	3502	0,11470	45	0,1741	0
Cis-butene	3,57	162,45	4225,5	0,14240	45	0,2046	0
R114	3,45	154,55	3257	0,10950	45	0,1684	0
Trans-butene	0,73	155,31	4027	0,13570	45	0,1980	0
Butane	-0,65	151,85	3800	0,12910	45	0,1909	0
R236fa	-1,55	124,75	3200	0,10030	45	0,1625	0
RC318	-6,15	115,05	2780	0,08544	45	0,1445	0
Butene	-6,46	145,99	4005	0,12540	45	0,1888	0
Isobutene	-7,15	233,81	4010	0,13610	45	0,2009	0
R142b	-9,25	136,95	4060	0,11670	45	0,1810	0
Sulfurdioxide	-10,15	157,35	7090	0,14520	45	0,2088	0
R124	-12,15	122,15	3062	0,09886	45	0,1636	0
R152a	-14,17	113,11	4517	0,09110	45	0,1598	0
R134a	-26,15	100,85	4059	0,07430	45	0,1437	0
R1234yf	-29,65	94,55	3380	0,06454	45	0,1342	0
R12	-29,95	111,85	414	0,01213	45	0,0261	0
Ammonia	-33,45	132,1	11333	0,11860	45	0,1868	0
R161	-37,75	102,05	5090	0,07729	45	0,1480	0
R22	-40,95	95,95	4990	0,06875	45	0,1412	0
Propane	-42,15	96,55	4247	0,06770	45	0,1388	0
Propylene	-47,75	90,95	4560	0,06061	45	0,1335	0
Carbonylsulfide	-50,31	105,47	6370	0,08221	45	0,1543	0
Hydrogensulfide	-60,45	99,8	9000	0,07548	45	0,1493	0

Table 6.4 Working fluids behavior, Lake Havasu City

With these results obtained from the described operations in an Organic Rankine Cycle (ORC), 9 working fluids were selected for a better analysis, according to environment conditions:

6.4 Organic Rankine Cycle ORC

The Organic Rankine Cycle has the same working principles and main components (evaporator, condenser, expander and pump) as the Steam Rankine Cycle. At the same time, there are some major differences between the two cycles. The differences are mainly related to the used working fluid in the cycle, the working fluid's thermo-physical properties, the heat source temperature and the cycle architecture. Organic Rankine Cycle can extract energy and generate power from much lower heat source temperature than traditional Rankine cycle.

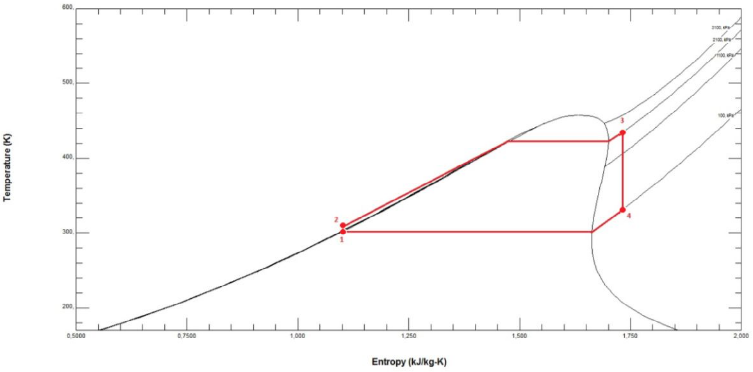


Figure 6.3 Organic Rankine Cycle (ORC)

From the analisys of different fluids values such as temperatures (ºC), pressures (kPa), mass heat and work exchanges (kW/kg) and process efficiency are obtained for the next step moduling heat exchangers and condensers.

T_{source}=100ºC

R22	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	14,04	16,45	20	24,35	29,91	34,75	38,22	37,62	33,38	26,11	18,93	13,53
P_{max} (kPa)	4044	4044	4044	4044	4044	4044	4111	4111	4111	4111	4110	4041
v_4 (l/kg)	27,26	25,47	23,1	20,55	17,75	15,67	14,08	14,29	15,93	19,27	23,4	27,66
Q_b (kW/kg)	193,3	190,4	186,1	180,9	174	168	160,2	161	166,4	175,4	184,2	194
Q_c (kW/kg)	162,2	160,9	158,6	155,7	151,7	148	142,2	142,7	146,1	151,1	156,5	162,8
W_{net} (kW/kg)	23,5	22,41	20,86	19,01	16,75	14,85	13,32	13,54	15,12	17,97	20,96	23,74
η(%)	12,16	11,77	11,2	10,51	9,622	8,844	8,315	8,412	9,088	10,24	11,38	12,24

Propane	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	13,9	16,33	19,87	24,21	29,77	34,6	38,02	37,42	33,2	25,93	18,75	13,39
P_{max} (kPa)	3462	3472	3487	3504	3525	3525	3536	3536	3536	3510	3482	3460
v_4 (l/kg)	63,85	59,68	54,13	48,09	41,42	36,65	33,51	34,02	37,84	45,91	55,81	64,77
Q_b (kW/kg)	395,2	388	377,4	364,1	346,8	333,5	322,8	324,5	336,2	358,8	380,7	396,7
Q_c (kW/kg)	333,2	328,9	322,5	314,2	302,9	294,5	287,1	288,2	295,9	310,8	324,5	334,1
W_{net} (kW/kg)	47,16	44,83	41,51	37,58	32,8	29,03	26,37	26,82	30	36,07	42,54	47,66
η(%)	11,93	11,55	11	10,32	9,457	8,703	8,17	8,264	8,923	10,05	11,17	12,01

Hydrogensulfide	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	14,95	17,4	20,96	25,33	35,75	39,2	38,59	38,59	34,35	27,05	19,85	14,44
P_{max} (kPa)	7479	7497	7507	7507	7507	7507	7507	7507	7507	7507	7507	7476
v_4 (l/kg)	30,92	29,07	26,67	24,08	21,22	19,05	17,68	17,92	19,66	23,15	27,38	31,32
Q_b (kW/kg)	398,3	392,1	383,9	374,6	362,4	351,7	344	345,3	354,8	370,8	386,3	399,6
Q_c (kW/kg)	329,8	326,5	322,4	317,8	311,6	305,8	301,5	302,3	307,5	315,9	323,5	330,4
W_{net} (kW/kg)	51,51	49,17	45,95	42,19	37,56	33,68	31,02	31,48	34,8	40,74	46,93	52
η(%)	12,93	12,54	11,97	11,27	10,36	9,577	9,018	9,117	9,807	10,99	12,15	13,01

T_{source}=150ºC

Butene	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	13,44	15,85	19,36	23,69	29,22	34,05	37,47	36,87	32,64	25,4	18,26	12,93
Tmax	136	136	136	136	136	136	136	136	136	136	136	136
P_{max} (kPa)	3192	3200	3211	3223	3238	3251	3259	3257	3247	3228	3208	3190
v_4 (l/kg)	253,8	234	208	180,3	150,6	129	115,8	118	134,9	170,5	215,7	258,1
Q_b (kW/kg)	493,6	487,6	478,9	468,1	454,2	442	433,3	434,8	445,6	463,8	481,6	494,8
Q_c (kW/kg)	385,1	382,5	378,6	373,5	366,8	360,6	356	356,8	362,4	371,5	379,8	385,7
W_{net} (kW/kg)	84,51	81,81	77,98	73,38	67,68	62,9	59,64	60,21	64,29	71,6	79,18	85,08
η(%)	17,12	16,78	16,28	15,68	14,9	14,23	13,76	13,85	14,43	15,44	16,44	17,19

R142b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	13,4	15,82	19,35	23,7	29,26	34,11	37,54	36,94	32,69	25,42	18,24	12,89
Tmax	127	127	127	127	127	127	127	127	127	127	127	127
P_{max} (kPa)	3156	3167	3183	3202	3226	3246	3260	3258	3240	3209	3117	3154
v_4 (l/kg)	98.02	90,69	81,22	71,14	60,29	52,39	47,5	48,3	54,55	67,52	84,1	99,63
Q_b (kW/kg)	265,6	262,1	257	250,6	242,4	235,1	229,9	230,9	237,3	248,1	258,6	266,3
Q_c (kW/kg)	209,9	208,3	205,8	202,6	198,3	194,3	191,3	191,9	195,5	201,3	206,6	210,3
W_{net} (kW/kg)	43,37	41,88	39,78	37,26	34,14	31,51	29,71	30,02	32,27	36,27	40,44	43,68
η(%)	16,33	15,98	15,48	14,87	14,08	13,4	12,92	13	13,6	14,62	15,64	16,4

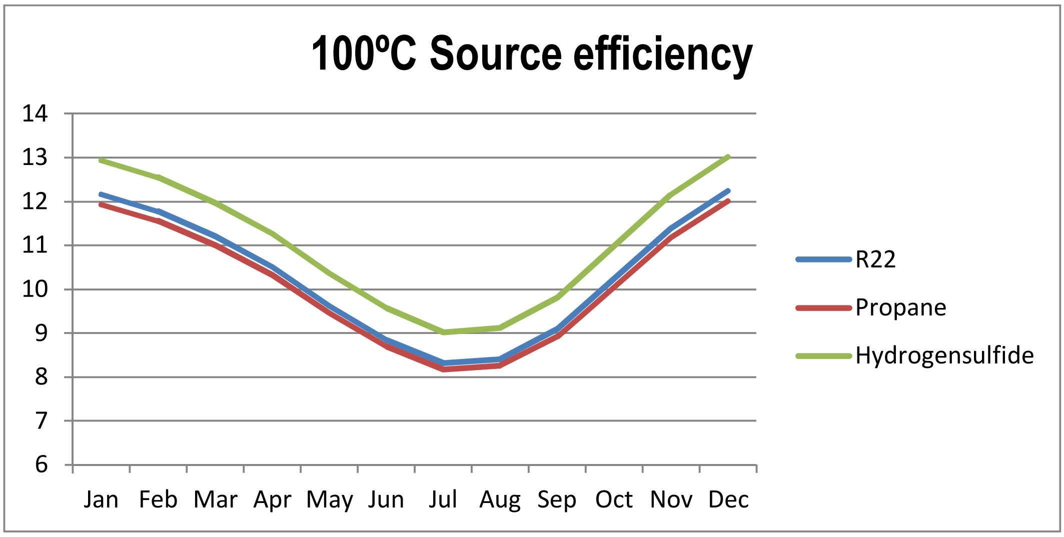
Ammonia	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	13,99	16,43	19,99	24,37	29,98	34,87	38,34	37,73	33,45	26,1	18,87	13,48
Tmax	122,1	122,1	122,1	122,1	122,1	122,1	122,1	122,1	122,1	122,1	122,1	122,1
P_{max} (kPa)	8859	8888	8931	8984	9049	9105	9143	9136	9088	9004	8919	8853
v_4 (l/kg)	14,02	12,99	11,64	10,21	8,673	7,553	6,864	6,98	7,862	9,702	12,04	14,24
Q_b (kW/kg)	1137	1123	1102	1076	1043	1014	999,3	997	1023	1066	1108	1140
Q_c (kW/kg)	890,4	884,4	875,2	863,5	847,5	832,8	821,9	823,9	837,2	858,6	878,1	891,6
W_{net} (kW/kg)	191,1	184,7	175,4	164,3	150,6	139,1	131,1	132,5	142,4	160	178,3	192,5
η(%)	16,81	16,45	15,92	15,27	14,44	13,71	13,2	13,29	13,93	15,01	16,09	16,89

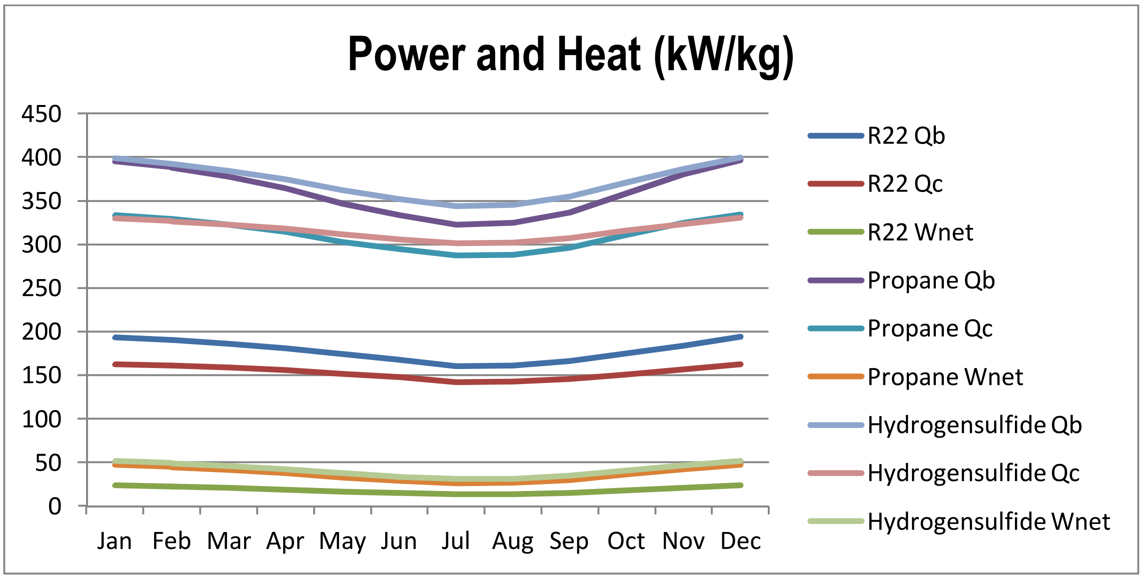
T_{source}=220ºC

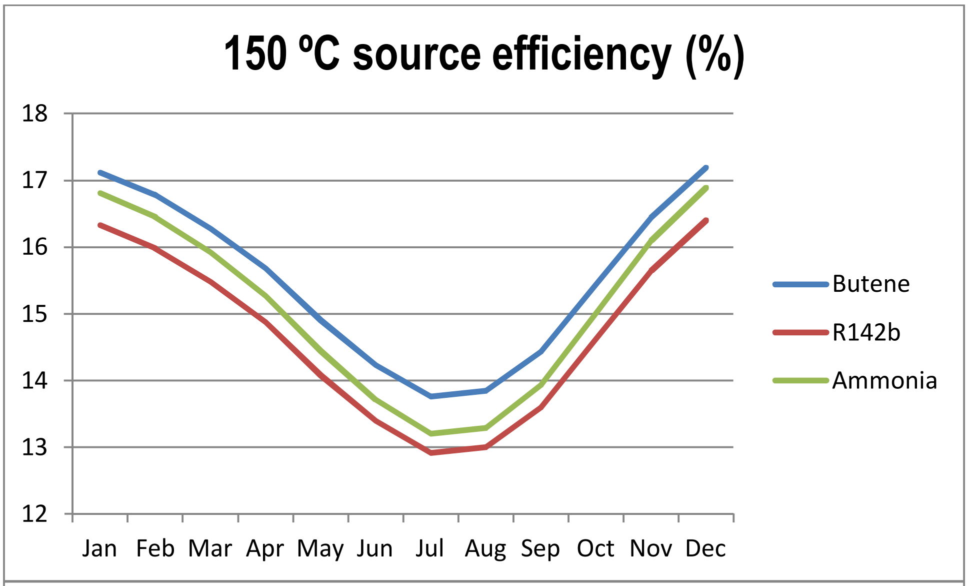
R11	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
P_{max} (kPa)	3344	3355	3372	3393	3419	3442	3457	3454	3435	3401	3367	3341
v_4 (l/kg)	252,9	232,4	205,9	178,2	149,1	128,2	115,6	117,7	133,9	168,5	213,8	257,5
Q_b (kW/kg)	254,3	252	248,5	244,3	238,9	234,2	230,8	231,4	235,6	242,7	249,6	254,8
Q_c (kW/kg)	183,6	182,9	181,8	180,3	178,4	176,6	175,3	175,5	177,1	179,8	182,1	183,7
W_{net} (kW/kg)	55,57	54,28	52,42	50,19	47,4	45,03	43,39	43,68	45,71	49,32	53	55,85
η(%)	21,85	21,54	21,09	20,54	19,84	19,23	18,8	18,87	19,41	20,32	21,24	21,92

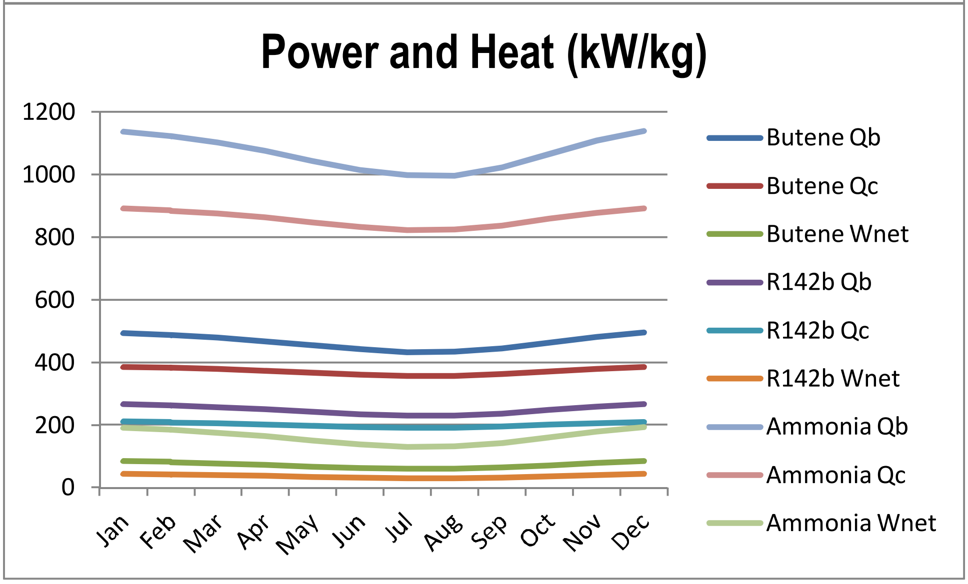
Cis-butene	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	13,51	15,92	19,43	23,75	29,27	34,08	37,49	36,89	32,68	25,45	18,33	13,01
P_{max} (kPa)	3313	3324	3339	3356	3376	3393	3404	3402	3388	3362	3334	3311
v_4 (l/kg)	346,9	320,2	285,3	248	207,9	178,7	160,6	163,7	186,7	234,8	295,8	352,6
Q_b (kW/kg)	544	538,1	529,3	518,6	504,9	492,8	484,2	485,8	496,3	514,4	532,1	545,3
Q_c (kW/kg)	413,8	411,4	408	403,5	397,5	391,9	387,9	388,6	393,6	401,7	409,1	414,3
W_{net} (kW/kg)	101,9	99,04	94,82	89,83	83,63	78,4	74,77	75,41	79,9	87,87	96,14	102,5
η(%)	18,74	18,41	17,91	17,32	16,57	15,91	15,44	15,52	16,1	17,08	18,07	18,81

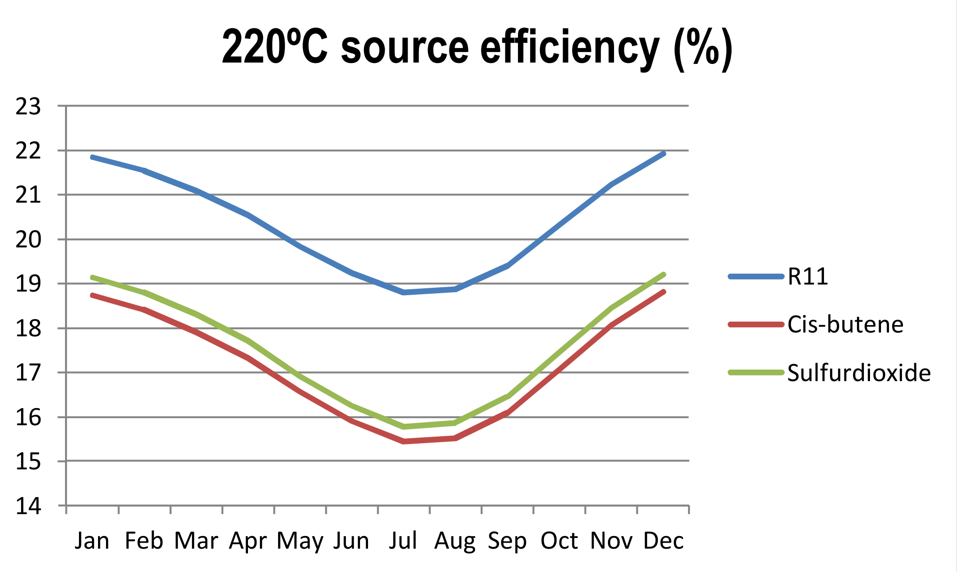
Sulfurdioxide	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{amb} (^{0}C)	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
T2 (ºC)	13,84	16,28	19,84	24,21	29,8	34,68	38,14	37,53	33,26	25,94	18,72	13,34
P_{max} (kPa)	6100	6121	6151	6187	6231	6269	6296	6291	6258	6200	6141	6069
v_4 (l/kg)	107,1	98,75	87,91	76,51	64,44	55,73	50,42	51,31	58,11	72,51	91,15	109
Q_b (kW/kg)	372,6	368,7	362,8	355,6	346,4	338,3	332,5	333,5	340,7	352,8	364,7	373,5
Q_c (kW/kg)	281,1	279,7	277,4	274,6	270,7	267,2	264,5	265	268,2	273,4	278,2	281,4
W_{net} (kW/kg)	71,33	69,31	66,42	62,94	58,63	54,97	52,44	52,89	56,02	61,59	67,32	71,75
η(%)	19,14	18,8	18,31	17,7	16,92	16,25	15,77	15,86	16,45	17,46	18,46	19,21

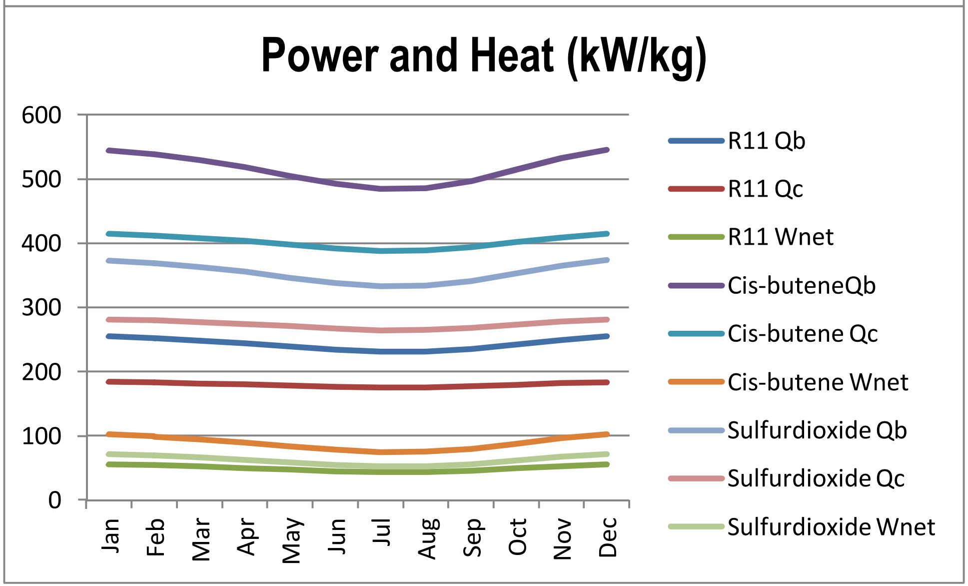



Power and Heat (kW/kg)
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
R22 Qb
R22 Qc
R22 Wnet
Propane Qb
Propane Qc
Propane Wnet
Hydrogensulfide Qb
Hydrogensulfide Qc
Hydrogensulfide Wnet


150 ºC source efficiency (%)
18
17
16
15
14
13
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Butene
R142b
Ammonia


Power and Heat (kW/kg)
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Butene Qb
Butene Qc
Butene Wnet
R142b Qb
R142b Qc
R142b Wnet
Ammonia Qb
Ammonia Qc
Ammonia Wnet


220ºC source efficiency (%)
23
22
21
20
19
18
17
16
15
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
R11
Cis-butene
Sulfurdioxide


Power and Heat (kW/kg)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
R11 Qb
R11 Qc
R11 Wnet
Cis-buteneQb
Cis-butene Qc
Cis-butene Wnet
Sulfurdioxide Qb
Sulfurdioxide Qc
Sulfurdioxide Wnet

6.5 Heat Exchanger

The next tables show the different behavior of the chosen fluids in contact with the geothermal water source through heat exchangers, calculated according to the ε-NTU system explaint in the 5º chapter. The most important data obtained from this analysis are the different temperature values, mass of working and cooling fluids and the parasit power demand.

The mass ofworking fluid was calculated taking in consideration the maximum power demand of the mine and the mass net work value calculated by the Rankine cycle (W_m)

100 ºC source:

R22

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
37,6	0,8367	4,947	15,34	5,122	4044	1489	14,04	85,95	100	28,08	23,5	60,67	3,956
38,36	0,832	5,222	16,08	4,95	4044	1519	16,45	85,95	100	30,49	22,41	64,03	3,982
39,51	0,8246	5,667	17,28	4,698	4044	1565	20	85,95	100	34,03	20,86	69,49	4,022
41,05	0,8145	6,301	18,96	4,388	4044	1625	24,35	85,95	100	38,38	19,01	77,27	4,076
43,19	0,7998	7,286	21,52	3,992	4044	1710	29,91	85,95	100	43,95	16,75	89,35	4,152
45,35	0,785	8,367	24,27	3,648	4044	1796	34,75	85,95	100	48,78	14,85	102,6	4,228
47,7	0,7728	9,44	27,06	3,4	4111	1889	38,22	85,95	100	52,25	13,32	115,8	4,278
47,4	0,7751	9,262	26,62	3,444	4111	1877	37,62	85,95	100	51,65	13,54	113,6	4,267
46,08	0,7957	8,093	23,84	3,833	4111	1797	33,38	85,95	100	46,99	15,12	99,24	4,164
42,35	0,8101	6,692	20,06	4,263	4111	1677	26,11	85,95	100	40,14	17,97	82,06	4,092
39,78	0,8269	5,614	17,19	4,775	4110	1575	18,93	85,95	100	32,96	20,96	68,84	4,004
37,43	0,8377	4,891	15,18	5,158	4041	1482	13,53	85,95	100	27,57	23,74	59,98	3,951

Propane

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
43,53	0,844	5,427	7,642	5,406	3462	1650	13,9	86,55	100	27,33	47,16	66,54	8,707
44,54	0,8394	5,745	8,039	5,225	3472	1688	16,33	86,55	100	29,76	44,83	70,45	8,764
46,13	0,8323	6,265	8,682	4,961	3487	1749	19,87	86,55	100	33,31	41,51	76,83	8,849
48,26	0,8228	7,007	9,59	4,639	3504	1829	24,21	86,55	100	37,64	37,58	85,93	8,96
51,25	0,8087	8,169	10,99	4,225	3525	1943	29,77	86,55	100	43,21	32,8	100,2	9,117
53,92	0,7946	9,387	12,41	3,866	3525	2044	34,6	86,55	100	48,03	29,03	115,1	9,272
56,17	0,7833	10,46	13,67	3,612	3536	2129	38,02	86,55	100	51,45	26,37	128,3	9,389
55,78	0,7854	10,26	13,44	3,657	3536	2114	37,42	86,55	100	50,85	26,82	125,9	9,367
53,29	0,7989	9,034	12,01	3,971	3536	2020	33,2	86,55	100	46,63	30	110,8	9,222
49,15	0,8187	7,339	9,992	4,511	3510	1863	25,93	86,55	100	39,36	36,07	89,99	9,007
45,63	0,8346	6,095	8,472	5,045	3482	1730	18,75	86,55	100	32,18	42,54	74,74	8,821
43,31	0,8449	5,363	7,562	5,444	3460	1642	13,39	86,55	100	26,82	47,66	65,76	8,696

Hydrogensulfide

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
43,91	0,8802	4,031	6,997	7,344	7479	1262	14,95	89,8	100	25,14	51,51	49,43	7,064
44,82	0,8767	4,252	7,33	7,104	7497	1288	17,4	89,8	100	27,59	49,17	52,14	7,114
46,11	0,8711	4,601	7,843	6,753	7507	1326	20,96	89,8	100	31,15	45,95	56,42	7,194
47,75	0,8636	5,086	8,542	6,325	7507	1373	25,33	89,8	100	35,52	42,19	62,37	7,301
46,9	0,8415	5,954	9,595	5,304	7507	1348	35,75	89,8	100	45,94	37,56	73,01	7,609
49,78	0,8325	6,746	10,7	4,967	7507	1431	39,2	89,8	100	49,38	33,68	82,72	7,73
54,53	0,8341	7,303	11,62	5,025	7507	1567	38,59	89,8	100	48,78	31,02	89,56	7,708
53,73	0,8341	7,197	11,45	5,025	7507	1544	38,59	89,8	100	48,78	31,48	88,25	7,708
51,61	0,8448	6,387	10,36	5,44	7507	1484	34,35	89,8	100	44,54	34,8	78,33	7,563
48,44	0,8604	5,3	8,846	6,157	7507	1392	27,05	89,8	100	37,24	40,74	64,99	7,347
45,71	0,8729	4,489	7,68	6,863	7507	1314	19,85	89,8	100	30,04	46,93	55,05	7,168
43,73	0,8809	3,987	6,931	7,393	7476	1257	14,44	89,8	100	24,63	52	48,89	7,054

150 ºC source:

Butene

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
34,35	0,8976	2,631	4,265	8,761	3192	1355	13,44	136	150	27,42	84,51	96,77	22,69
34,92	0,8958	2,727	4,405	8,589	3200	1378	15,85	136	150	29,83	81,81	100,3	22,77
35,76	0,893	2,876	4,622	8,337	3211	1411	19,36	136	150	33,34	77,98	105,8	22,89
36,86	0,8893	3,076	4,911	8,027	3223	1454	23,69	136	150	37,68	73,38	113,2	23,04
38,36	0,8842	3,365	5,325	7,633	3238	1514	29,22	136	150	43,2	67,68	123,8	23,24
39,75	0,8794	3,649	5,73	7,287	3251	1569	34,05	136	150	48,04	62,9	134,2	23,43
40,78	0,8758	7,995	6,043	7,044	3259	1609	37,47	136	150	51,45	59,64	294,1	48,67
40,59	0,8764	7,908	5,986	7,086	3257	1602	36,87	136	150	50,85	60,21	290,9	48,6
39,33	0,8809	3,562	5,606	7,389	3247	1552	32,64	136	150	46,62	64,29	131	23,37
37,31	0,8878	3,161	5,034	7,906	3228	1472	25,4	136	150	39,38	71,6	116,3	23,1
35,49	0,8938	2,828	4,552	8,416	3208	1400	18,26	136	150	32,24	79,18	104	22,85
34,23	0,898	2,611	4,236	8,796	3190	1351	12,93	136	150	26,92	85,08	96,06	22,68

R142b

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
21,04	0,8318	2,853	8,31	4,943	3156	1364	13,4	127	150	36,38	43,37	104,9	12,63
21,4	0,8288	2,964	8,606	4,837	3167	1387	15,82	127	150	38,8	41,88	109	12,67
21,94	0,8242	3,135	9,06	4,684	3183	1422	19,35	127	150	42,32	39,78	115,3	12,73
22,63	0,8181	3,368	9,673	4,495	3202	1467	23,7	127	150	46,67	37,26	123,9	12,81
23,58	0,8097	7,661	10,56	4,253	3226	1529	29,26	127	150	52,24	34,14	281,8	26,7
24,49	0,8017	8,394	11,44	4,042	3246	1588	34,11	127	150	57,09	31,51	308,8	27
25,17	0,7957	8,974	12,13	3,893	3260	1632	37,54	127	150	60,52	29,71	330,1	27,21
25,05	0,7968	8,869	12,01	3,919	3258	1624	36,94	127	150	59,92	30,02	326,3	27,18
24,22	0,8042	8,169	11,17	4,104	3240	1570	32,69	127	150	55,66	32,27	300,5	26,91
23,36	0,8224	3,441	9,937	4,542	3209	1486	25,42	127	150	47,54	36,27	126,6	12,74
21,78	0,8257	3,082	8,912	4,733	3117	1412	18,24	127	150	41,21	40,44	113,4	12,72
20,97	0,8324	2,83	8,251	4,965	3154	1359	12,89	127	150	35,87	43,68	104,1	12,62

Ammonia

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
13,43	0,7951	2,318	1,886	3,878	8859	1056	13,99	122,1	150	41,86	191,1	85,29	45,22
13,64	0,7913	2,408	1,951	3,791	8888	1073	16,43	122,1	150	44,3	184,7	88,6	45,41
13,97	0,7856	2,552	2,055	3,663	8931	1099	19,99	122,1	150	47,86	175,4	93,86	45,68
14,4	0,7782	5,674	2,194	3,506	8984	1132	24,37	122,1	150	52,24	164,3	208,7	95,16
14,98	0,7678	6,284	2,393	3,305	9049	1178	29,98	122,1	150	57,85	150,6	231,2	96,6
15,54	0,758	6,897	2,591	3,13	9105	1222	34,87	122,1	150	62,74	139,1	253,7	97,92
15,96	0,7504	7,393	2,749	3,005	9143	1255	38,34	122,1	150	66,21	131,1	272	98,93
15,88	0,7518	7,301	2,72	3,027	9136	1249	37,73	122,1	150	65,6	132,5	268,6	98,74
15,37	0,7609	6,71	2,531	3,18	9088	1209	33,45	122,1	150	61,32	142,4	246,9	97,54
14,58	0,7751	5,853	2,253	3,444	9004	1146	26,1	122,1	150	53,97	160	215,3	95,6
15,45	0,8294	2,38	2,021	4,345	8919	1090	18,87	122,1	150	41,23	178,3	87,57	43,32
13,38	0,7959	2,3	1,872	3,896	8853	1052	13,48	122,1	150	41,35	192,5	84,6	45,19

220 ºC source:

R11

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
11,73	0,8453	3,039	6,486	5,46	3344	1064	12,2	187,8	220	44,35	55,57	223,6	34,48
11,87	0,8435	3,12	6,64	5,385	3355	1077	14,6	187,8	220	46,75	54,28	229,6	34,57
12,08	0,8408	3,244	6,875	5,277	3372	1096	18,1	187,8	220	50,25	52,42	238,7	34,71
12,35	0,8373	3,405	7,181	5,143	3393	1121	22,4	187,8	220	54,55	50,19	250,6	34,89
12,72	0,8326	3,63	7,603	4,971	3419	1154	27,9	187,8	220	60,06	47,4	267,1	35,13
13,05	0,8283	3,845	8,004	4,822	3442	1184	32,7	187,8	220	64,85	45,03	282,9	35,34
13,3	0,8252	4,008	8,306	4,717	3457	1207	36,1	187,8	220	68,25	43,39	294,9	35,5
13,26	0,8257	3,978	8,251	4,735	3454	1203	35,5	187,8	220	67,65	43,68	292,7	35,47
12,95	0,8296	3,781	7,884	4,866	3435	1175	31,3	187,8	220	63,46	45,71	278,2	35,28
14,26	0,8755	3,31	7,307	6,103	3401	1131	24,1	187,8	220	48,48	49,32	243,5	33,33
12,01	0,8416	3,204	6,8	5,31	3367	1090	17	187,8	220	49,15	53	235,8	34,67
11,7	0,8456	3,022	6,453	5,475	3341	1061	11,7	187,8	220	43,86	55,85	222,4	34,46

Cis-butene

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
6,575	0,6732	4,546	3,537	2,059	3313	1252	13,51	152,5	220	80,99	101,9	334,5	94,57
6,671	0,6694	4,695	3,639	2,023	3324	1270	15,92	152,5	220	83,39	99,04	345,4	94,93
6,824	0,6636	4,931	3,801	1,971	3339	1299	19,43	152,5	220	86,91	94,82	362,8	95,46
7,015	0,6562	5,242	4,012	1,907	3356	1336	23,75	152,5	220	91,23	89,83	385,7	96,13
7,275	0,6462	5,682	4,309	1,825	3376	1385	29,27	152,5	220	96,75	83,63	418	97,01
7,516	0,6371	6,11	4,597	1,754	3393	1431	34,08	152,5	220	101,6	78,4	449,5	97,79
7,697	0,6303	6,445	4,82	1,704	3404	1465	37,49	152,5	220	105	74,77	474,2	98,38
7,664	0,6315	6,383	4,779	1,713	3402	1459	36,89	152,5	220	104,4	75,41	469,6	98,26
7,444	0,6398	5,981	4,511	1,775	3388	1417	32,68	152,5	220	100,2	79,9	440,1	97,57
7,096	0,6531	5,374	4,102	1,882	3362	1351	25,45	152,5	220	92,93	87,87	395,4	96,39
6,775	0,6654	4,855	3,749	1,988	3334	1290	18,33	152,5	220	85,8	96,14	357,2	95,29
6,555	0,674	4,516	3,516	2,066	3311	1248	13,01	152,5	220	80,49	102,5	332,3	94,5

Sulfurdioxide

A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm	wp	wpm
4,946	0,648	3,829	5,053	1,84	6100	1013	13,84	147,4	220	86,42	71,33	281,7	55,76
5,013	0,6438	3,954	5,2	1,806	6121	1026	16,28	147,4	220	88,85	69,31	290,9	55,95
5,113	0,6374	4,147	5,426	1,757	6151	1047	19,84	147,4	220	92,41	66,42	305,1	56,24
5,243	0,6293	4,405	5,726	1,697	6187	1074	24,21	147,4	220	96,78	62,94	324,1	56,6
5,418	0,6184	4,771	6,147	1,62	6231	1109	29,8	147,4	220	102,4	58,63	351	57,1
5,582	0,6084	5,129	6,556	1,553	6269	1143	34,68	147,4	220	107,2	54,97	377,4	57,56
5,704	0,6009	5,409	6,873	1,505	6296	1168	38,14	147,4	220	110,7	52,44	398	57,9
5,681	0,6023	5,357	6,814	1,513	6291	1163	37,53	147,4	220	110,1	52,89	394,2	57,84
5,534	0,6114	5,021	6,433	1,572	6258	1133	33,26	147,4	220	105,8	56,02	369,4	57,42
5,296	0,6261	4,514	5,852	1,673	6200	1084	25,94	147,4	220	98,5	61,59	332,1	56,75
5,082	0,6395	4,085	5,354	1,773	6141	1040	18,72	147,4	220	91,28	67,32	300,6	56,14
4,933	0,6488	3,805	5,023	1,847	6069	1010	13,34	147,4	220	85,92	71,75	280	55,74

6.6 Condenser

The next tables show the different behavior of the chosen fluids in contact with condensers of diverse sizes, according to the ε-NTU system explaint in the 5º chapter. The most important data obtained from this analysis are the different temperature values, mass of working and cooling fluids and the parasit power demand.

Because of the proximity to the lake, cooling fluid is considered free to obtain, so the most important fact to choose will be to reduce the size (and the cost) of the condenser.

R22 Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	4,373	0,5	123,9	15,98	0,637	727,4	162,2	2592	2,2	7,2	12,2	23,5	15,19
feb	4,618	0,5	129,1	16,79	0,6361	780,5	160,9	2701	4,6	9,6	14,6	22,41	15,83
mar	3,504	0,5	137,1	18,08	0,6535	862,9	158,6	2868	8,1	13,1	18,1	20,86	16,81
apr	3,965	0,5	148,3	19,91	0,6515	972,9	155,7	3101	12,4	17,4	22,4	19,01	18,18
may	4,694	0,5	164,8	22,72	0,6486	1128	151,7	3447	17,9	22,9	27,9	16,75	20,21
jun	5,514	0,5	182,4	25,78	0,6457	1278	148	3815	22,7	27,7	32,7	14,85	22,37
jul	6,329	0,5	196,3	28,86	0,6422	1393	142,2	4104	26,1	31,1	36,1	13,32	24,07
aug	6,191	0,5	193,6	28,37	0,6427	1372	142,7	4048	25,5	30,5	35,5	13,54	23,74
sep	5,341	0,5	176,5	25,27	0,6456	1233	146,1	3692	21,3	26,3	31,3	15,12	21,64
oct	4,241	0,5	152,4	21,1	0,6497	1019	151,1	3188	14,1	19,1	24,1	17,97	18,69
nov	3,457	0,5	134,5	17,98	0,6533	836,3	156,5	2814	7	12	17	20,96	16,5
dec	4,323	0,5	123	15,82	0,6372	716,7	162,8	2575	1,7	6,7	11,7	23,74	15,09
jan	7,56	0,7	87,43	15,79	1,114	727,4	162,2	2562	2,2	9,2	12,2	23,5	10,72
feb	7,98	0,7	91,09	16,58	1,113	780,5	160,9	2668	4,6	11,6	14,6	22,41	11,17
mar	6,036	0,7	96,66	17,85	1,141	862,9	158,6	2830	8,1	15,1	18,1	20,86	11,85
apr	6,825	0,7	104,4	19,63	1,138	972,9	155,7	3057	12,4	19,4	22,4	19,01	12,8
may	8,071	0,7	115,9	22,36	1,133	1128	151,7	3393	17,9	24,9	27,9	16,75	14,21
jun	9,468	0,7	128	25,33	1,128	1278	148	3748	22,7	29,7	32,7	14,85	15,7
jul	10,86	0,7	137,6	28,32	1,123	1393	142,2	4028	26,1	33,1	36,1	13,32	16,87
aug	10,62	0,7	135,7	27,85	1,124	1372	142,7	3974	25,5	32,5	35,5	13,54	16,64
sep	9,177	0,7	123,9	24,84	1,128	1233	146,1	3629	21,3	28,3	31,3	15,12	15,2
oct	7,299	0,7	107,3	20,79	1,135	1019	151,1	3141	14,1	21,1	24,1	17,97	13,15
nov	5,957	0,7	94,86	17,75	1,141	836,3	156,5	2778	7	14	17	20,96	11,63
dec	7,475	0,7	86,84	15,63	1,115	716,7	162,8	2545	1,7	8,7	11,7	23,74	10,65
jan	14,64	0,9	67,55	15,69	2,173	727,4	162,2	2545	2,2	11,2	12,2	23,5	8,284
feb	15,46	0,9	70,36	16,47	2,171	780,5	160,9	2650	4,6	13,6	14,6	22,41	8,628
mar	11,62	0,9	74,63	17,72	2,212	862,9	158,6	2810	8,1	17,1	18,1	20,86	9,152
apr	13,14	0,9	80,56	19,48	2,207	972,9	155,7	3033	12,4	21,4	22,4	19,01	9,878
may	15,54	0,9	89,33	22,17	2,2	1128	151,7	3363	17,9	26,9	27,9	16,75	10,95
jun	18,23	0,9	98,61	25,08	2,193	1278	148	3712	22,7	31,7	32,7	14,85	12,09
jul	20,91	0,9	105,9	28,03	2,185	1393	142,2	3986	26,1	35,1	36,1	13,32	12,98
aug	20,46	0,9	104,5	27,56	2,186	1372	142,7	3933	25,5	34,5	35,5	13,54	12,81
sep	17,67	0,9	95,51	24,61	2,193	1233	146,1	3596	21,3	30,3	31,3	15,12	11,71
oct	14,05	0,9	82,76	20,62	2,203	1019	151,1	3116	14,1	23,1	24,1	17,97	10,15
nov	11,47	0,9	73,26	17,62	2,211	836,3	156,5	2758	7	16	17	20,96	8,983
dec	14,48	0,9	67,1	15,53	2,174	716,7	162,8	2528	1,7	10,7	11,7	23,74	8,228

Propane Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	3,515	0,5	126,9	7,972	0,65	677,3	333,2	2656	2,2	7,2	12,2	47,16	15,57
feb	3,75	0,5	132,1	8,401	0,6488	723,7	328,9	2763	4,6	9,6	14,6	44,83	16,2
mar	4,137	0,5	140,3	9,097	0,6469	795,5	322,5	2934	8,1	13,1	18,1	41,51	17,2
apr	4,694	0,5	151,5	10,08	0,6444	890,7	314,2	3169	12,4	17,4	22,4	37,58	18,58
may	5,577	0,5	168,2	11,62	0,6407	1024	302,9	3519	17,9	22,9	27,9	32,8	20,63
jun	8,215	0,5	185,9	13,2	0,6209	1153	294,5	3887	22,7	27,7	32,7	29,03	22,79
jul	7,371	0,5	200,4	14,6	0,6343	1250	287,1	4191	26,1	31,1	36,1	26,37	24,58
aug	9,003	0,5	197,6	14,34	0,6183	1233	288,2	4133	25,5	30,5	35,5	26,82	24,23
sep	6,247	0,5	180,4	12,75	0,6381	1114	295,9	3773	21,3	26,3	31,3	30	22,12
oct	6,381	0,5	156,4	10,52	0,6271	930,6	310,8	3271	14,1	19,1	24,1	36,07	19,18
nov	4,01	0,5	137,6	8,869	0,6475	772,4	324,5	2878	7	12	17	42,54	16,87
dec	3,468	0,5	125,9	7,886	0,6502	667,9	334,1	2635	1,7	6,7	11,7	47,66	15,44
jan	6,065	0,7	89,56	7,875	1,135	677,3	333,2	2624	2,2	9,2	12,2	47,16	10,98
feb	6,468	0,7	93,14	8,294	1,133	723,7	328,9	2728	4,6	11,6	14,6	44,83	11,42
mar	7,131	0,7	98,84	8,974	1,13	795,5	322,5	2894	8,1	15,1	18,1	41,51	12,12
apr	8,086	0,7	106,6	9,938	1,126	890,7	314,2	3123	12,4	19,4	22,4	37,58	13,08
may	9,595	0,7	118,2	11,43	1,12	1024	302,9	3462	17,9	24,9	27,9	32,8	14,5
jun	14,15	0,7	130,4	12,97	1,089	1153	294,5	3818	22,7	29,7	32,7	29,03	15,99
jul	12,65	0,7	140,4	14,32	1,11	1250	287,1	4111	26,1	33,1	36,1	26,37	17,22
aug	15,49	0,7	138,5	14,07	1,085	1233	288,2	4055	25,5	32,5	35,5	26,82	16,98
sep	10,74	0,7	126,6	12,53	1,116	1114	295,9	3708	21,3	28,3	31,3	30	15,53
oct	11,01	0,7	110	10,37	1,099	930,6	310,8	3222	14,1	21,1	24,1	36,07	13,49
nov	6,913	0,7	96,98	8,752	1,131	772,4	324,5	2840	7	14	17	42,54	11,89
dec	5,984	0,7	88,83	7,79	1,136	667,9	334,1	2603	1,7	8,7	11,7	47,66	10,89
jan	11,69	0,9	69,19	7,822	2,203	677,3	333,2	2606	2,2	11,2	12,2	47,16	8,484
feb	12,47	0,9	71,94	8,236	2,201	723,7	328,9	2709	4,6	13,6	14,6	44,83	8,821
mar	13,75	0,9	76,3	8,908	2,196	795,5	322,5	2873	8,1	17,1	18,1	41,51	9,357
apr	15,6	0,9	82,28	9,859	2,19	890,7	314,2	3098	12,4	21,4	22,4	37,58	10,09
may	18,52	0,9	91,14	11,33	2,182	1024	302,9	3431	17,9	26,9	27,9	32,8	11,18
jun	27,48	0,9	100,4	12,84	2,135	1153	294,5	3781	22,7	31,7	32,7	29,03	12,32
jul	24,44	0,9	108,1	14,17	2,167	1250	287,1	4068	26,1	35,1	36,1	26,37	13,25
aug	30,1	0,9	106,6	13,93	2,129	1233	288,2	4013	25,5	34,5	35,5	26,82	13,07
sep	20,73	0,9	97,56	12,41	2,176	1114	295,9	3673	21,3	30,3	31,3	30	11,96
oct	21,37	0,9	84,87	10,28	2,15	930,6	310,8	3195	14,1	23,1	24,1	36,07	10,41
nov	13,33	0,9	74,88	8,688	2,198	772,4	324,5	2819	7	16	17	42,54	9,182
dec	11,54	0,9	68,63	7,738	2,204	667,9	334,1	2585	1,7	10,7	11,7	47,66	8,416

Hydrogensulfide Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	2,214	0,5	114,6	7,269	0,6637	1453	329,8	2397	2,2	7,2	12,2	51,51	14,05
feb	3,784	0,5	119	7,627	0,643	1549	326,5	2490	4,6	9,6	14,6	49,17	14,6
mar	2,514	0,5	126,1	8,18	0,6627	1596	322,4	2637	8,1	13,1	18,1	45,95	15,46
apr	4,52	0,5	135,8	8,937	0,6404	1891	317,8	2840	12,4	17,4	22,4	42,19	16,65
may	3,362	0,5	150,3	10,09	0,6587	2153	311,6	3143	17,9	22,9	27,9	37,56	18,43
jun	5,901	0,5	165,3	11,3	0,6362	2423	305,8	3456	22,7	27,7	32,7	33,68	20,26
jul	6,513	0,5	177,6	12,32	0,6345	2620	301,5	3715	26,1	31,1	36,1	31,02	21,78
aug	4,279	0,5	175,4	12,13	0,6554	2584	302,3	3667	25,5	30,5	35,5	31,48	21,5
sep	5,675	0,5	160,6	10,92	0,6369	2345	307,5	3359	21,3	26,3	31,3	34,8	19,69
oct	3,021	0,5	140	9,268	0,66	1972	315,9	2928	14,1	19,1	24,1	40,74	17,16
nov	3,992	0,5	123,8	8,003	0,6422	1649	323,5	2589	7	12	17	46,93	15,18
dec	3,55	0,5	113,6	7,199	0,644	1434	330,4	2378	1,7	6,7	11,7	52	13,94
jan	3,818	0,7	80,93	7,189	1,157	1453	329,8	2371	2,2	9,2	12,2	51,51	9,924
feb	6,539	0,7	84,05	7,539	1,124	1549	326,5	2462	4,6	11,6	14,6	49,17	10,31
mar	4,33	0,7	88,97	8,081	1,156	1596	322,4	2605	8,1	15,1	18,1	45,95	10,91
apr	7,802	0,7	95,73	8,821	1,12	1891	317,8	2803	12,4	19,4	22,4	42,19	11,74
may	5,78	0,7	105,8	9,941	1,149	2153	311,6	3098	17,9	24,9	27,9	37,56	12,97
jun	10,16	0,7	116,2	11,12	1,113	2423	305,8	3402	22,7	29,7	32,7	33,68	14,25
jul	11,21	0,7	124,7	12,11	1,11	2620	301,5	3652	26,1	33,1	36,1	31,02	15,29
aug	7,343	0,7	123,2	11,93	1,144	2584	302,3	3606	25,5	32,5	35,5	31,48	15,1
sep	9,777	0,7	112,9	10,75	1,114	2345	307,5	3307	21,3	28,3	31,3	34,8	13,85
oct	5,199	0,7	98,64	9,143	1,151	1972	315,9	2888	14,1	21,1	24,1	40,74	12,1
nov	6,897	0,7	87,36	7,908	1,123	1649	323,5	2558	7	14	17	46,93	10,71
dec	6,137	0,7	80,29	7,12	1,126	1434	330,4	2352	1,7	8,7	11,7	52	9,845
jan	7,329	0,9	62,56	7,146	2,235	1453	329,8	2357	2,2	11,2	12,2	51,51	7,672
feb	12,64	0,9	64,96	7,492	2,187	1549	326,5	2446	4,6	13,6	14,6	49,17	7,965
mar	8,31	0,9	68,74	8,027	2,233	1596	322,4	2588	8,1	17,1	18,1	45,95	8,429
apr	15,08	0,9	73,92	8,757	2,181	1891	317,8	2783	12,4	21,4	22,4	42,19	9,065
may	11,1	0,9	81,62	9,862	2,224	2153	311,6	3073	17,9	26,9	27,9	37,56	10,01
jun	19,65	0,9	89,57	11,03	2,171	2423	305,8	3372	22,7	31,7	32,7	33,68	10,98
jul	21,67	0,9	96,1	12	2,167	2620	301,5	3617	26,1	35,1	36,1	31,02	11,78
aug	14,09	0,9	94,91	11,82	2,216	2584	302,3	3573	25,5	34,5	35,5	31,48	11,64
sep	18,9	0,9	87,1	10,66	2,173	2345	307,5	3279	21,3	30,3	31,3	34,8	10,68
oct	9,98	0,9	76,15	9,076	2,227	1972	315,9	2867	14,1	23,1	24,1	40,74	9,338
nov	13,33	0,9	67,5	7,856	2,185	1649	323,5	2541	7	16	17	46,93	8,277
dec	11,86	0,9	62,07	7,077	2,189	1434	330,4	2338	1,7	10,7	11,7	52	7,611

Butene Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	1,632	0,5	80,63	4,382	0,6622	197,4	385,1	1687	2,2	7,2	12,2	84,51	9,887
feb	1,702	0,5	82,82	4,529	0,6617	213,8	382,5	1733	4,6	9,6	14,6	81,81	10,16
mar	1,811	0,5	86,11	4,757	0,6609	239,4	378,6	1801	8,1	13,1	18,1	77,98	10,56
apr	1,958	0,5	90,41	5,062	0,6599	274	373,5	1891	12,4	17,4	22,4	73,38	11,09
may	2,172	0,5	96,45	5,5	0,6585	323,9	366,8	2017	17,9	22,9	27,9	67,68	11,83
jun	2,347	0,5	102,2	5,929	0,6578	327,7	360,6	2138	22,7	27,7	32,7	62,9	12,54
jul	2,552	0,5	106,6	6,262	0,6562	410,1	356	2229	26,1	31,1	36,1	59,64	13,07
aug	2,521	0,5	105,8	6,201	0,6564	403,3	356,8	2213	25,5	30,5	35,5	60,21	12,97
sep	2,319	0,5	100,5	5,797	0,6576	357,7	362,4	2101	21,3	26,3	31,3	64,29	12,32
oct	2,021	0,5	92,21	5,191	0,6595	288,7	371,5	1929	14,1	19,1	24,1	71,6	11,31
nov	1,776	0,5	85,04	4,683	0,6612	231	379,8	1779	7	12	17	79,18	10,43
dec	1,618	0,5	80,19	4,352	0,6623	194,1	385,7	1678	1,7	6,7	11,7	85,08	9,834
jan	2,824	0,7	57,14	4,348	1,155	197,4	385,1	1674	2,2	9,2	12,2	84,51	7,007
feb	2,945	0,7	58,68	4,493	1,154	213,8	382,5	1719	4,6	11,6	14,6	81,81	7,196
mar	3,133	0,7	61	4,718	1,153	239,4	378,6	1786	8,1	15,1	18,1	77,98	7,48
apr	3,386	0,7	64,01	5,018	1,151	274	373,5	1874	12,4	19,4	22,4	73,38	7,85
may	3,754	0,7	68,25	5,449	1,149	323,9	366,8	1999	17,9	24,9	27,9	67,68	8,37
jun	4,055	0,7	72,3	5,871	1,148	327,7	360,6	2117	22,7	29,7	32,7	62,9	8,866
jul	4,407	0,7	75,36	6,198	1,145	410,1	356	2206	26,1	33,1	36,1	59,64	9,241
aug	4,355	0,7	74,8	6,138	1,145	403,3	356,8	2190	25,5	32,5	35,5	60,21	9,172
sep	4,008	0,7	71,06	5,741	1,147	357,7	362,4	2081	21,3	28,3	31,3	64,29	8,714
oct	3,494	0,7	65,28	5,145	1,15	288,7	371,5	1911	14,1	21,1	24,1	71,6	8,005
nov	3,072	0,7	60,25	4,645	1,153	231	379,8	1764	7	14	17	79,18	7,388
dec	2,8	0,7	56,84	4,318	1,155	194,1	385,7	1665	1,7	8,7	11,7	85,08	6,97
jan	5,435	0,9	44,25	4,329	2,232	197,4	385,1	1667	2,2	11,2	12,2	84,51	5,427
feb	5,667	0,9	45,44	4,473	2,23	213,8	382,5	1711	4,6	13,6	14,6	81,81	5,572
mar	6,029	0,9	47,22	4,696	2,229	239,4	378,6	1778	8,1	17,1	18,1	77,98	5,791
apr	6,518	0,9	49,55	4,994	2,226	274	373,5	1865	12,4	21,4	22,4	73,38	6,076
may	7,227	0,9	52,81	5,421	2,223	323,9	366,8	1988	17,9	26,9	27,9	67,68	6,476
jun	7,805	0,9	55,93	5,839	2,221	327,7	360,6	2105	22,7	31,7	32,7	62,9	6,858
jul	8,487	0,9	58,28	6,163	2,218	410,1	356	2194	26,1	35,1	36,1	59,64	7,147
aug	8,385	0,9	57,85	6,104	2,218	403,3	356,8	2178	25,5	34,5	35,5	60,21	7,094
sep	7,716	0,9	54,97	5,711	2,221	357,7	362,4	2070	21,3	30,3	31,3	64,29	6,741
oct	6,726	0,9	50,52	5,12	2,225	288,7	371,5	1902	14,1	23,1	24,1	71,6	6,195
nov	5,911	0,9	46,64	4,624	2,229	231	379,8	1756	7	16	17	79,18	5,72
dec	5,388	0,9	44,02	4,299	2,232	194,1	385,7	1658	1,7	10,7	11,7	85,08	5,398

R142b Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	2,514	0,5	85,78	8,552	0,6473	223,2	209,9	1795	2,2	7,2	12,2	43,37	10,52
feb	2,615	0,5	88,26	8,864	0,6467	242,1	208,3	1846	4,6	9,6	14,6	41,88	10,82
mar	2,771	0,5	91,93	9,343	0,6458	271,5	205,8	1923	8,1	13,1	18,1	39,78	11,27
apr	2,984	0,5	96,78	9,991	0,6446	311,3	202,6	2024	12,4	17,4	22,4	37,26	11,87
may	3,294	0,5	103,6	10,93	0,643	368,6	198,3	2167	17,9	22,9	27,9	34,14	12,71
jun	3,605	0,5	110,2	11,87	0,6414	424,9	194,3	2306	22,7	27,7	32,7	31,51	13,52
jul	3,853	0,5	115,3	12,61	0,6402	468,6	191,3	2412	26,1	31,1	36,1	29,71	14,14
aug	3,808	0,5	114,4	12,47	0,6405	460,8	191,9	2394	25,5	30,5	35,5	30,02	14,03
sep	3,51	0,5	108,2	11,58	0,6419	407,9	195,5	2264	21,3	26,3	31,3	32,27	13,27
oct	3,076	0,5	98,85	10,27	0,6442	328,4	201,3	2068	14,1	19,1	24,1	36,27	12,12
nov	2,72	0,5	90,75	9,187	0,6461	261,9	206,6	1898	7	12	17	40,44	11,13
dec	2,493	0,5	85,31	8,49	0,6474	219,4	210,3	1786	1,7	6,7	11,7	43,68	10,46
jan	4,355	0,7	60,77	8,482	1,131	223,2	209,9	1780	2,2	9,2	12,2	43,37	7,451
feb	4,53	0,7	62,51	8,789	1,13	242,1	208,3	1831	4,6	11,6	14,6	41,88	7,665
mar	4,8	0,7	65,08	9,26	1,129	271,5	205,8	1906	8,1	15,1	18,1	39,78	7,981
apr	5,167	0,7	68,49	9,898	1,127	311,3	202,6	2005	12,4	19,4	22,4	37,26	8,398
may	5,701	0,7	73,27	10,82	1,124	368,6	198,3	2146	17,9	24,9	27,9	34,14	8,985
jun	6,237	0,7	77,91	11,74	1,122	424,9	194,3	2281	22,7	29,7	32,7	31,51	9,554
jul	6,663	0,7	81,46	12,47	1,12	468,6	191,3	2385	26,1	33,1	36,1	29,71	9,988
aug	6,586	0,7	80,85	12,34	1,12	460,8	191,9	2367	25,5	32,5	35,5	30,02	9,914
sep	6,073	0,7	76,51	11,46	1,122	407,9	195,5	2240	21,3	28,3	31,3	32,27	9,382
oct	5,326	0,7	69,94	10,17	1,126	328,4	201,3	2048	14,1	21,1	24,1	36,27	8,576
nov	4,712	0,7	64,25	9,107	1,129	261,9	206,6	1881	7	14	17	40,44	7,879
dec	4,321	0,7	60,44	8,421	1,131	219,4	210,3	1771	1,7	8,7	11,7	43,68	7,411
jan	8,422	0,9	47,05	8,443	2,197	223,2	209,9	1772	2,2	11,2	12,2	43,37	5,769
feb	8,761	0,9	48,39	8,747	2,196	242,1	208,3	1822	4,6	13,6	14,6	41,88	5,933
mar	9,285	0,9	50,37	9,215	2,194	271,5	205,8	1896	8,1	17,1	18,1	39,78	6,177
apr	9,996	0,9	52,99	9,847	2,191	311,3	202,6	1995	12,4	21,4	22,4	37,26	6,498
may	11,03	0,9	56,68	10,76	2,187	368,6	198,3	2134	17,9	26,9	27,9	34,14	6,95
jun	12,07	0,9	60,24	11,67	2,183	424,9	194,3	2268	22,7	31,7	32,7	31,51	7,387
jul	12,9	0,9	62,97	12,39	2,181	468,6	191,3	2370	26,1	35,1	36,1	29,71	7,721
aug	12,75	0,9	62,5	12,26	2,181	460,8	191,9	2353	25,5	34,5	35,5	30,02	7,664
sep	11,75	0,9	59,16	11,39	2,185	407,9	195,5	2227	21,3	30,3	31,3	32,27	7,255
oct	10,3	0,9	54,11	10,12	2,19	328,4	201,3	2037	14,1	23,1	24,1	36,27	6,635
nov	9,114	0,9	49,73	9,063	2,194	261,9	206,6	1872	7	16	17	40,44	6,098
dec	8,355	0,9	46,79	8,382	2,197	219,4	210,3	1763	1,7	10,7	11,7	43,68	5,738

Ammonia Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	1,325	0,5	82,49	1,939	0,6688	663,4	890,4	1726	2,2	7,2	12,2	191,1	10,12
feb	2,187	0,5	84,87	2,008	0,6532	719,2	884,4	1776	4,6	9,6	14,6	184,7	10,41
mar	1,499	0,5	88,57	2,117	0,6675	806,8	875,2	1852	8,1	13,1	18,1	175,4	10,86
apr	1,647	0,5	93,44	2,263	0,6664	925,5	863,5	1954	12,4	17,4	22,4	164,3	11,46
may	1,867	0,5	100,3	2,475	0,6648	1096	847,5	2097	17,9	22,9	27,9	150,6	12,3
jun	3	0,5	106,9	2,685	0,6493	1264	832,8	2236	22,7	27,7	32,7	139,1	13,11
jul	3,207	0,5	112,2	2,854	0,6484	1394	821,9	2346	26,1	31,1	36,1	131,1	13,75
aug	2,246	0,5	111,2	2,823	0,6623	1370	823,9	2326	25,5	30,5	35,5	132,5	13,64
sep	2,024	0,5	104,9	2,621	0,6637	1213	837,2	2195	21,3	26,3	31,3	142,4	12,87
oct	2,565	0,5	95,47	2,326	0,6513	976	858,6	1997	14,1	19,1	24,1	160	11,71
nov	2,274	0,5	87,38	2,081	0,6527	778,5	878,1	1828	7	12	17	178,3	10,72
dec	1,311	0,5	81,98	1,924	0,669	652,2	891,6	1716	1,7	6,7	11,7	192,5	10,05
jan	2,29	0,7	58,46	1,923	1,165	663,4	890,4	1713	2,2	9,2	12,2	191,1	7,168
feb	3,788	0,7	60,13	1,991	1,14	719,2	884,4	1761	4,6	11,6	14,6	184,7	7,373
mar	2,59	0,7	62,72	2,099	1,163	806,8	875,2	1837	8,1	15,1	18,1	175,4	7,692
apr	2,845	0,7	66,14	2,243	1,161	925,5	863,5	1937	12,4	19,4	22,4	164,3	8,111
may	3,224	0,7	70,93	2,451	1,159	1096	847,5	2077	17,9	24,9	27,9	150,6	8,698
jun	5,187	0,7	75,59	2,658	1,134	1264	832,8	2213	22,7	29,7	32,7	139,1	9,269
jul	5,543	0,7	79,25	2,823	1,133	1394	821,9	2320	26,1	33,1	36,1	131,1	9,718
aug	3,874	0,7	78,59	2,793	1,155	1370	823,9	2301	25,5	32,5	35,5	132,5	9,637
sep	3,494	0,7	74,19	2,595	1,157	1213	837,2	2172	21,3	28,3	31,3	142,4	9,097
oct	4,438	0,7	67,57	2,304	1,137	976	858,6	1978	14,1	21,1	24,1	160	8,285
nov	3,938	0,7	61,89	2,064	1,14	778,5	878,1	1812	7	14	17	178,3	7,589
dec	2,266	0,7	58,1	1,909	1,166	652,2	891,6	1702	1,7	8,7	11,7	192,5	7,124
jan	4,395	0,9	45,27	1,915	2,247	663,4	890,4	1705	2,2	11,2	12,2	191,1	5,551
feb	7,31	0,9	46,55	1,982	2,211	719,2	884,4	1753	4,6	13,6	14,6	184,7	5,709
mar	4,972	0,9	48,56	2,089	2,244	806,8	875,2	1828	8,1	17,1	18,1	175,4	5,954
apr	5,462	0,9	51,19	2,232	2,241	925,5	863,5	1927	12,4	21,4	22,4	164,3	6,277
may	6,191	0,9	54,88	2,438	2,238	1096	847,5	2066	17,9	26,9	27,9	150,6	6,729
jun	10,01	0,9	58,46	2,642	2,202	1264	832,8	2201	22,7	31,7	32,7	139,1	7,168
jul	10,7	0,9	61,27	2,806	2,2	1394	821,9	2307	26,1	35,1	36,1	131,1	7,514
aug	7,442	0,9	60,76	2,776	2,232	1370	823,9	2287	25,5	34,5	35,5	132,5	7,451
sep	6,711	0,9	57,38	2,58	2,235	1213	837,2	2160	21,3	30,3	31,3	142,4	7,036
oct	8,566	0,9	52,29	2,293	2,206	976	858,6	1968	14,1	23,1	24,1	160	6,411
nov	7,599	0,9	47,91	2,054	2,21	778,5	878,1	1804	7	16	17	178,3	5,875
dec	4,35	0,9	44,99	1,901	2,247	652,2	891,6	1695	1,7	10,7	11,7	192,5	5,517

R11 Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	1,643	0,5	69,13	8,192	0,6565	137,2	176,6	1447	2,2	7,2	12,2	45,03	8,477
feb	1,708	0,5	71,29	8,508	0,6562	153,2	175,3	1491	4,6	9,6	14,6	43,39	8,742
mar	1,699	0,5	70,9	8,45	0,6561	150,3	175,5	1483	8,1	13,1	18,1	43,68	8,694
apr	1,626	0,5	68,31	8,068	0,6564	130,9	177,1	1429	12,4	17,4	22,4	45,71	8,377
may	1,045	0,5	64,19	7,467	0,6685	102,3	179,8	1343	17,9	22,9	27,9	49,32	7,871
jun	0,9683	0,5	60,42	6,94	0,6689	79,13	182,1	1264	22,7	27,7	32,7	53	7,409
jul	0,9173	0,5	57,8	6,58	0,6691	64,69	183,7	1209	26,1	31,1	36,1	55,85	7,087
aug	0,9217	0,5	58,06	6,614	0,6691	65,96	183,6	1214	25,5	30,5	35,5	55,57	7,12
sep	0,9417	0,5	59,23	6,773	0,6691	72,31	182,9	1239	21,3	26,3	31,3	54,28	7,263
oct	0,9718	0,5	61	7,018	0,669	82,42	181,8	1276	14,1	19,1	24,1	52,42	7,48
nov	1,476	0,5	63,23	7,335	0,6572	96,33	180,3	1323	7	12	17	50,19	7,754
dec	1,56	0,5	66,27	7,775	0,6569	116,7	178,4	1387	1,7	6,7	11,7	47,4	8,127
jan	2,848	0,7	49,05	8,137	1,146	137,2	176,6	1437	2,2	9,2	12,2	45,03	6,015
feb	2,959	0,7	50,57	8,449	1,145	153,2	175,3	1481	4,6	11,6	14,6	43,39	6,201
mar	2,945	0,7	50,3	8,392	1,145	150,3	175,5	1473	8,1	15,1	18,1	43,68	6,168
apr	2,819	0,7	48,47	8,015	1,145	130,9	177,1	1419	12,4	19,4	22,4	45,71	5,944
may	1,809	0,7	45,57	7,421	1,165	102,3	179,8	1334	17,9	24,9	27,9	49,32	5,587
jun	1,677	0,7	42,91	6,899	1,165	79,13	182,1	1256	22,7	29,7	32,7	53	5,262
jul	1,589	0,7	41,05	6,543	1,166	64,69	183,7	1202	26,1	33,1	36,1	55,85	5,034
aug	1,632	0,7	39,65	6,573	1,163	137,2	176,6	1161	25,5	32,5	35,5	55,57	4,862
sep	2,377	0,7	40,3	6,731	1,145	153,2	175,3	1180	21,3	28,3	31,3	54,28	4,941
oct	2,454	0,7	41,79	6,973	1,145	150,3	175,5	1224	14,1	21,1	24,1	52,42	5,125
nov	2,557	0,7	44,08	7,288	1,146	130,9	177,1	1291	7	14	17	50,19	5,405
dec	2,706	0,7	47,41	7,726	1,147	102,3	179,8	1389	1,7	8,7	11,7	47,4	5,814
jan	5,503	0,9	39,21	8,11	2,221	79,13	182,1	1477	2,2	11,2	12,2	45,03	4,808
feb	3,851	0,9	41,09	8,422	2,249	64,69	183,7	1547	4,6	13,6	14,6	43,39	5,038
mar	3,842	0,9	40,8	8,365	2,249	65,96	183,6	1536	8,1	17,1	18,1	43,68	5,003
apr	3,695	0,9	38,81	7,989	2,248	72,31	182,9	1461	12,4	21,4	22,4	45,71	4,759
may	3,453	0,9	35,72	7,396	2,247	82,42	181,8	1345	17,9	26,9	27,9	49,32	4,38
jun	3,241	0,9	32,93	6,876	2,246	96,33	180,3	1240	22,7	31,7	32,7	53	4,038
jul	3,103	0,9	30,9	6,521	2,245	116,7	178,4	1163	26,1	35,1	36,1	55,85	3,79
aug	3,139	0,9	30,74	6,553	2,244	137,2	176,6	1157	25,5	34,5	35,5	55,57	3,77
sep	4,59	0,9	31,25	6,71	2,217	153,2	175,3	1176	21,3	30,3	31,3	54,28	3,831
oct	4,737	0,9	32,4	6,951	2,217	150,3	175,5	1220	14,1	23,1	24,1	52,42	3,973
nov	4,935	0,9	34,17	7,264	2,218	130,9	177,1	1286	7	16	17	50,19	4,19
dec	5,22	0,9	36,74	7,698	2,22	102,3	179,8	1384	1,7	10,7	11,7	47,4	4,506

Cis-butene Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	1,839	0,5	71,64	3,623	0,6533	138,5	413,8	1499	2,2	7,2	12,2	101,9	8,785
feb	1,901	0,5	73,35	3,73	0,6529	150,5	411,4	1534	4,6	9,6	14,6	99,04	8,994
mar	1,998	0,5	76,06	3,899	0,6523	170	408	1591	8,1	13,1	18,1	94,82	9,327
apr	2,127	0,5	79,49	4,121	0,6515	196,2	403,5	1663	12,4	17,4	22,4	89,83	9,748
may	1,649	0,5	84,25	4,433	0,6633	234,1	397,5	1762	17,9	22,9	27,9	83,63	10,33
jun	1,794	0,5	88,74	4,736	0,6622	271,7	391,9	1856	22,7	27,7	32,7	78,4	10,88
jul	1,907	0,5	92,21	4,971	0,6615	301,2	387,9	1928	26,1	31,1	36,1	74,77	11,31
aug	1,886	0,5	91,57	4,928	0,6616	295,8	388,6	1915	25,5	30,5	35,5	75,41	11,23
sep	1,75	0,5	87,41	4,645	0,6625	260,3	393,6	1828	21,3	26,3	31,3	79,9	10,72
oct	2,181	0,5	80,94	4,214	0,6512	207,5	401,7	1693	14,1	19,1	24,1	87,87	9,926
nov	1,967	0,5	75,2	3,845	0,6525	163,7	409,1	1573	7	12	17	96,14	9,221
dec	1,827	0,5	71,29	3,601	0,6534	136	414,3	1492	1,7	6,7	11,7	102,5	8,742
jan	3,189	0,7	50,82	3,598	1,141	138,5	413,8	1489	2,2	9,2	12,2	101,9	6,231
feb	3,295	0,7	52,02	3,703	1,14	150,5	411,4	1524	4,6	11,6	14,6	99,04	6,379
mar	3,463	0,7	53,93	3,871	1,139	170	408	1579	8,1	15,1	18,1	94,82	6,613
apr	3,685	0,7	56,35	4,089	1,138	196,2	403,5	1650	12,4	19,4	22,4	89,83	6,909
may	2,852	0,7	59,69	4,397	1,156	234,1	397,5	1748	17,9	24,9	27,9	83,63	7,319
jun	3,101	0,7	62,84	4,695	1,155	271,7	391,9	1840	22,7	29,7	32,7	78,4	7,706
jul	3,297	0,7	65,28	4,927	1,154	301,2	387,9	1911	26,1	33,1	36,1	74,77	8,005
aug	3,261	0,7	64,83	4,885	1,154	295,8	388,6	1898	25,5	32,5	35,5	75,41	7,95
sep	3,026	0,7	61,91	4,606	1,155	260,3	393,6	1813	21,3	28,3	31,3	79,9	7,592
oct	3,78	0,7	57,37	4,182	1,137	207,5	401,7	1680	14,1	21,1	24,1	87,87	7,034
nov	3,409	0,7	53,32	3,817	1,139	163,7	409,1	1561	7	14	17	96,14	6,539
dec	3,167	0,7	50,57	3,577	1,141	136	414,3	1482	1,7	8,7	11,7	102,5	6,201
jan	6,158	0,9	39,37	3,584	2,211	138,5	413,8	1483	2,2	11,2	12,2	101,9	4,828
feb	6,363	0,9	40,3	3,689	2,21	150,5	411,4	1518	4,6	13,6	14,6	99,04	4,942
mar	6,689	0,9	41,78	3,855	2,209	170	408	1573	8,1	17,1	18,1	94,82	5,123
apr	7,118	0,9	43,64	4,072	2,207	196,2	403,5	1643	12,4	21,4	22,4	89,83	5,351
may	5,485	0,9	46,22	4,377	2,234	234,1	397,5	1740	17,9	26,9	27,9	83,63	5,667
jun	5,964	0,9	48,65	4,673	2,232	271,7	391,9	1831	22,7	31,7	32,7	78,4	5,965
jul	6,342	0,9	50,52	4,903	2,23	301,2	387,9	1902	26,1	35,1	36,1	74,77	6,195
aug	6,272	0,9	50,18	4,861	2,23	295,8	388,6	1889	25,5	34,5	35,5	75,41	6,153
sep	5,819	0,9	47,93	4,584	2,232	260,3	393,6	1804	21,3	30,3	31,3	79,9	5,877
oct	7,3	0,9	44,42	4,164	2,206	207,5	401,7	1672	14,1	23,1	24,1	87,87	5,448
nov	6,584	0,9	41,31	3,801	2,209	163,7	409,1	1555	7	16	17	96,14	5,065
dec	6,116	0,9	39,18	3,563	2,211	136	414,3	1476	1,7	10,7	11,7	102,5	4,805

Sulfurdioxide Condenser

month	A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	0,918	0,5	69,47	5,172	0,6733	250,2	281,1	1454	2,2	7,2	12,2	71,33	8,519
feb	1,713	0,5	71,21	5,326	0,656	273,2	279,7	1490	4,6	9,6	14,6	69,31	8,732
mar	1,793	0,5	73,77	5,562	0,6556	309,6	277,4	1543	8,1	13,1	18,1	66,42	9,046
apr	1,9	0,5	77,15	5,876	0,655	359,3	274,6	1614	12,4	17,4	22,4	62,94	9,461
may	2,052	0,5	81,77	6,318	0,6543	431,6	270,7	1710	17,9	22,9	27,9	58,63	10,03
jun	1,304	0,5	86,22	6,749	0,6703	503,4	267,2	1803	22,7	27,7	32,7	54,97	10,57
jul	1,389	0,5	89,57	7,082	0,6697	559,6	264,5	1873	26,1	31,1	36,1	52,44	10,98
aug	2,296	0,5	88,96	7,02	0,6531	549,4	265	1860	25,5	30,5	35,5	52,89	10,91
sep	2,156	0,5	84,88	6,619	0,6538	481,6	268,2	1775	21,3	26,3	31,3	56,02	10,41
oct	1,119	0,5	78,53	6,008	0,6717	380,5	273,4	1643	14,1	19,1	24,1	61,59	9,63
nov	0,9924	0,5	72,97	5,486	0,6727	297,7	278,2	1526	7	12	17	67,32	8,948
dec	0,9107	0,5	69,12	5,141	0,6734	245,6	281,4	1447	1,7	6,7	11,7	71,75	8,476
jan	1,588	0,7	49,29	5,137	1,172	250,2	281,1	1444	2,2	9,2	12,2	71,33	6,044
feb	2,969	0,7	50,51	5,289	1,145	273,2	279,7	1479	4,6	11,6	14,6	69,31	6,194
mar	3,107	0,7	52,32	5,523	1,144	309,6	277,4	1532	8,1	15,1	18,1	66,42	6,416
apr	3,292	0,7	54,7	5,833	1,143	359,3	274,6	1602	12,4	19,4	22,4	62,94	6,707
may	3,554	0,7	57,95	6,268	1,142	431,6	270,7	1697	17,9	24,9	27,9	58,63	7,106
jun	2,252	0,7	61,07	6,693	1,168	503,4	267,2	1788	22,7	29,7	32,7	54,97	7,489
jul	2,399	0,7	63,43	7,021	1,167	559,6	264,5	1857	26,1	33,1	36,1	52,44	7,778
aug	3,975	0,7	63	6,96	1,14	549,4	265	1844	25,5	32,5	35,5	52,89	7,725
sep	3,734	0,7	60,13	6,565	1,141	481,6	268,2	1761	21,3	28,3	31,3	56,02	7,374
oct	1,934	0,7	55,67	5,962	1,17	380,5	273,4	1630	14,1	21,1	24,1	61,59	6,827
nov	1,716	0,7	51,76	5,448	1,171	297,7	278,2	1516	7	14	17	67,32	6,347
dec	1,575	0,7	49,04	5,107	1,173	245,6	281,4	1437	1,7	8,7	11,7	71,75	6,014
jan	3,045	0,9	38,19	5,118	2,257	250,2	281,1	1439	2,2	11,2	12,2	71,33	4,684
feb	5,729	0,9	39,14	5,269	2,217	273,2	279,7	1474	4,6	13,6	14,6	69,31	4,799
mar	5,995	0,9	40,53	5,501	2,216	309,6	277,4	1526	8,1	17,1	18,1	66,42	4,97
apr	6,352	0,9	42,37	5,809	2,215	359,3	274,6	1595	12,4	21,4	22,4	62,94	5,195
may	6,857	0,9	44,87	6,241	2,213	431,6	270,7	1689	17,9	26,9	27,9	58,63	5,503
jun	4,32	0,9	47,28	6,662	2,25	503,4	267,2	1780	22,7	31,7	32,7	54,97	5,798
jul	4,601	0,9	49,1	6,987	2,249	559,6	264,5	1848	26,1	35,1	36,1	52,44	6,02
aug	7,67	0,9	48,76	6,927	2,21	549,4	265	1836	25,5	34,5	35,5	52,89	5,98
sep	7,204	0,9	46,56	6,535	2,212	481,6	268,2	1753	21,3	30,3	31,3	56,02	5,709
oct	3,709	0,9	43,12	5,937	2,253	380,5	273,4	1623	14,1	23,1	24,1	61,59	5,287
nov	3,292	0,9	40,1	5,427	2,256	297,7	278,2	1510	7	16	17	67,32	4,917
dec	3,021	0,9	38,01	5,088	2,257	245,6	281,4	1432	1,7	10,7	11,7	71,75	4,66

6.7 Cost Estimations

With equations and estimations explaint in chapter 5, we analyze the costs of different parts. After that, we obtain the values of NPV and IRR in order to establish the best option and its viability:

BOILER									
	depth (m)	T_{src} (ºC)	A_b (m^2)	P_{max} (kPa)	C_B($)	F	C_{HX}($)	Drilling Cost($)	n_w
R22	1000	100	48	4111	31302,93	3,08	96413,02	306556,60	1
propane	1000	100	56,2	3536	32659,04	3,08	100589,84	306556,60	1
hydrogensulfide	1000	100	55	7507	32461,44	3,17	102902,77	306556,60	1
butene	3000	150	41	3259	30138,51	2,44	73537,96	448729,40	1
R142b	3000	150	25,2	3260	27577,75	2,44	67289,71	448729,40	1
ammonia	3000	150	16	9143	26381,20	2,53	66744,44	448729,40	1
R11	6000	220	14,5	3457	26257,23	2,44	64067,64	688562,60	1
cis-butene	6000	220	8	3404	26486,23	2,11	55885,95	688562,60	1
sulfurdioxide	6000	220	5,8	6296	27326,85	2,16	59026,00	688562,60	1

CONDENSER							TURBINE AND PUMPS		
	T_{mx} (ºC)	A_c (m^2)	P_{max} (kPa)	C_B($)	F	C_{HX}($)	C_T($)	C_{Pc}($)	C_{Pwf}($)
R22	40	6,4	1393	27013,22	1,46	39439,30	145853,32	3389,18	14585,33
propane	40	9,0	1250	26307,23	1,46	38408,56	145853,32	3450,93	14585,33
hydrogensulfide	40	6,6	2620	26925,56	1,69	45504,20	145853,32	3110,81	14585,33
butene	40	2,6	330	32042,90	1,31	41976,20	145853,32	2057,27	14585,33
R142b	40	3,9	470	29140,30	1,31	38173,80	145853,32	2185,33	14585,33
ammonia	40	3,3	1394	30194,36	1,46	44083,77	145853,32	2138,82	14585,33
R11	40	1,7	160	36538,41	1,31	47865,32	145853,32	1541,88	14585,33
cis-butene	40	2,2	310	33609,69	1,31	44028,70	145853,32	1845,99	14585,33
sulfurdioxide	40	2,3	560	33169,16	1,31	43451,60	145853,32	1807,46	14585,33

R22	606236,75
propane	609444,58
hydrogensulfide	618513,03
butene	726739,48
R142b	716816,89
ammonia	722135,08
R11	962476,09
cis-butene	950761,89
sulfurdioxide	953286,31

Average Cost kWh in Arizona: 11.29¢
Cost per year: 0,1129 $/kWh * 639 kWh/day * 365 days/year = 26332,232 $/year

$$\text{NPV}(i,N) = \sum_{1}^{N} \frac{Rt}{(1+i)^t} - I_0$$

27 years	i=1%
32 years	i=2%
40 years	i=3%

7 OMBILIN MINE

Dimana ada kemauan,di situ ada jalan

Indonesian quote

The **Ombilin Coal Mine** (formerly **PT Tambang Batubara Ombilin** (**TBO**)) is a coal mine near Sawahlunto, West Sumatra, Indonesia. It is located approximately 70 km northeast of Padang. By 2008, the mine had estimated reserves about 90.3 million tons of coking coal, of which 43 million tons was mineable. The mine is owned by PT Tambang Batubara Bukit Asam (PTBA) and operated by the China National Technology Import-Export Corporation (CNTIC). The mine produces about 500,000 tons of coal per year.

Coal was discovered in this area by Dutch engineer WH. De Gereve in 1868. Mining started at the open-pit mine in 1892 after the construction of a railway. In the pre-independence period, coal production peaked in 1930, at more than 620,000 tons a year. In 1942–1945, the mine was controlled by Japan. In 1945–1958, the mine was managed by the directorate of mining and in 1958–1968, by the bureau of state mining companies. In 1968, it became the Ombilin production unit of the state coal mining company. Production peaked in 1976 at 1,201,846 tons per year.

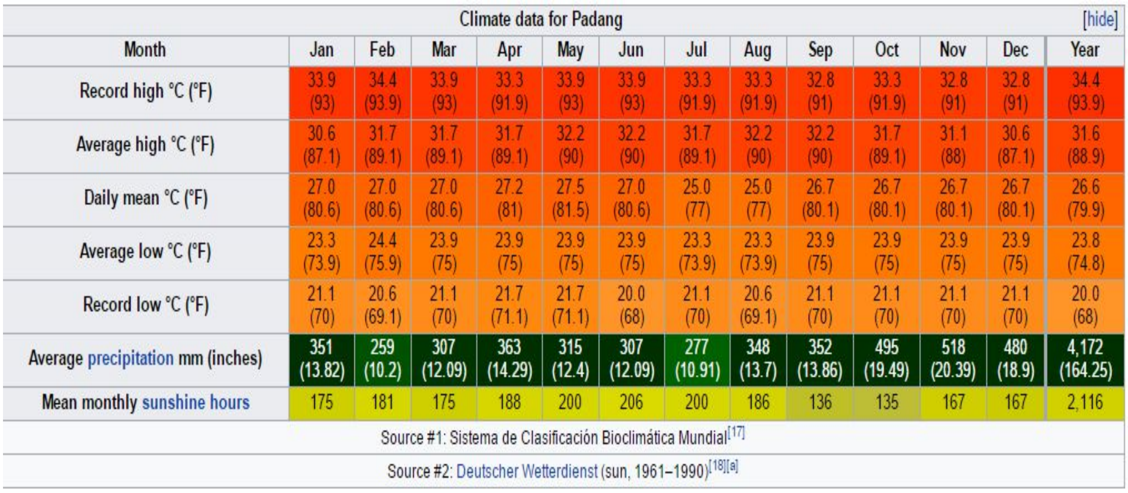
Until 2002 it operated as an open-pit mine. After that, only underground mine continues operating. In recent times, CNTIC has invested $100 million to the mine.

On 2011, the region continues to bring benefits to its constituents through reforestation of the former mining location and its conversion into a tourist destination. A well maintenance pit with sufficient lighting and air supply from blower attract local and foreign tourists mainly from Malaysia and Singapore. Seeing the pit cost Rp.30,000 (US$3.5) per person.

Figure 7.1 Ombilin Mine Map

7.1 Climate

Padang (70 km from the mine) features a tropical rainforest climate under Köppen's climate classification. Padang is one of Indonesia's wettest cities, with frequent rainfall throughout the course of the year. The city averages roughly 4300 mm of rain per year. Padang's driest month is February, where 250 mm of precipitation on average is observed. The city temperatures are relatively constant throughout the year, with an average of 26 ºC.



Climate data for Padang													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	33.9 (93)	34.4 (93.9)	33.9 (93)	33.3 (91.9)	33.9 (93)	33.9 (93)	33.3 (91.9)	33.3 (91.9)	32.8 (91)	33.3 (91.9)	32.8 (91)	32.8 (91)	34.4 (93.9)
Average high °C (°F)	30.6 (87.1)	31.7 (89.1)	31.7 (89.1)	31.7 (89.1)	32.2 (90)	32.2 (90)	31.7 (89.1)	32.2 (90)	32.2 (90)	31.7 (89.1)	31.1 (88)	30.6 (87.1)	31.6 (88.9)
Daily mean °C (°F)	27.0 (80.6)	27.0 (80.6)	27.0 (80.6)	27.2 (81)	27.5 (81.5)	27.0 (80.6)	25.0 (77)	25.0 (77)	26.7 (80.1)	26.7 (80.1)	26.7 (80.1)	26.7 (80.1)	26.6 (79.9)
Average low °C (°F)	23.3 (73.9)	24.4 (75.9)	23.9 (75)	23.9 (75)	23.9 (75)	23.9 (75)	23.3 (73.9)	23.3 (73.9)	23.9 (75)	23.9 (75)	23.9 (75)	23.9 (75)	23.8 (74.8)
Record low °C (°F)	21.1 (70)	20.6 (69.1)	21.1 (70)	21.7 (71.1)	21.7 (71.1)	20.0 (68)	21.1 (70)	20.6 (69.1)	21.1 (70)	21.1 (70)	21.1 (70)	21.1 (70)	20.0 (68)
Average precipitation mm (inches)	351 (13.82)	259 (10.2)	307 (12.09)	363 (14.29)	315 (12.4)	307 (12.09)	277 (10.91)	348 (13.7)	352 (13.86)	495 (19.49)	518 (20.39)	480 (18.9)	4,172 (164.25)
Mean monthly sunshine hours	175	181	175	188	200	206	200	186	136	135	167	167	2,116
Source #1: Sistema de Clasificación Bioclimática Mundial[17]													
Source #2: Deutscher Wetterdienst (sun, 1961–1990)[18][a]													

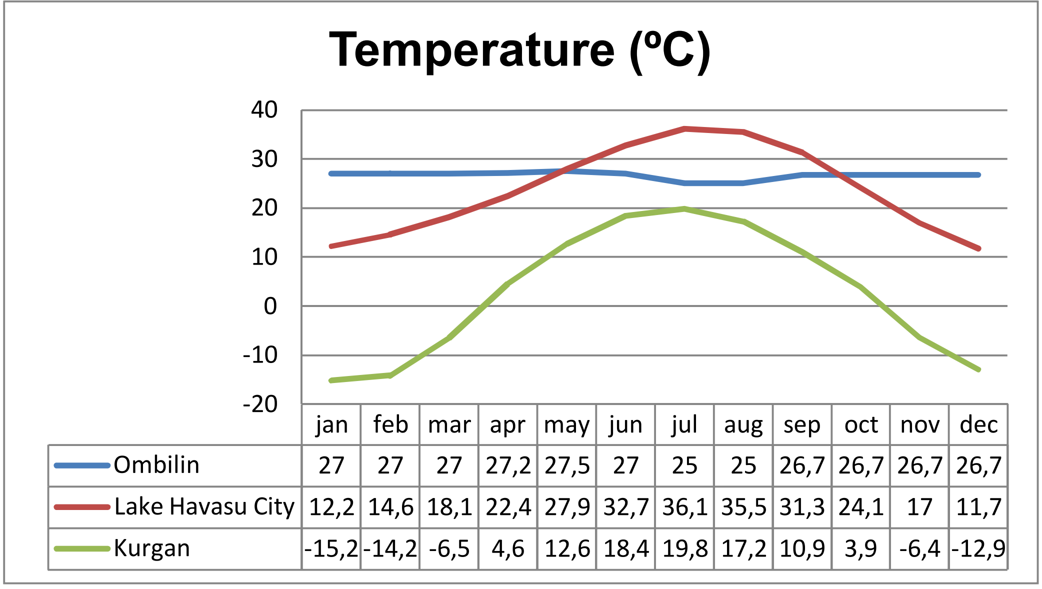
Table 7.1 Climate data forPadang

Geographic information system (GIS) is a system that captures, stores, analyzes, manages, and presents data that are linked to locations. In the simplest terms, GIS is the merging of cartography, statistical analysis, and database technology. GIS takes the number from databases and puts the information in the map as features. By mapping where and how things move over a period of time, the insight of profile can be gained. The process of combining and transforming information from different layers is sometimes called map "algebra" insofar as it involves adding and subtracting information. If, for example, we wanted to consider the effects of widening a road, we could begin with the road layer, widen a road to its new width to produce a new map, and overlay this new map on layers representing land use. The ability to separate information in layers, and then combine it with other layers of information is the reason why GIS hold such great potential as research and decision-making tools. This section reviews implementation of GIS technology to administrative solar energy resources. GIS models have been successfully used in performing solar radiation mapping in several countries. The renewable energy sources (RES) have some special "geographical qualities" for their treatment with GIS. So far, the solar radiation map over Indonesia has not developed yet. Based on the necessity, this work aims to study solar irradiation estimation in Indonesia with the ANN model and to present the estimated result as solar mapping over Indonesia using GIS technology

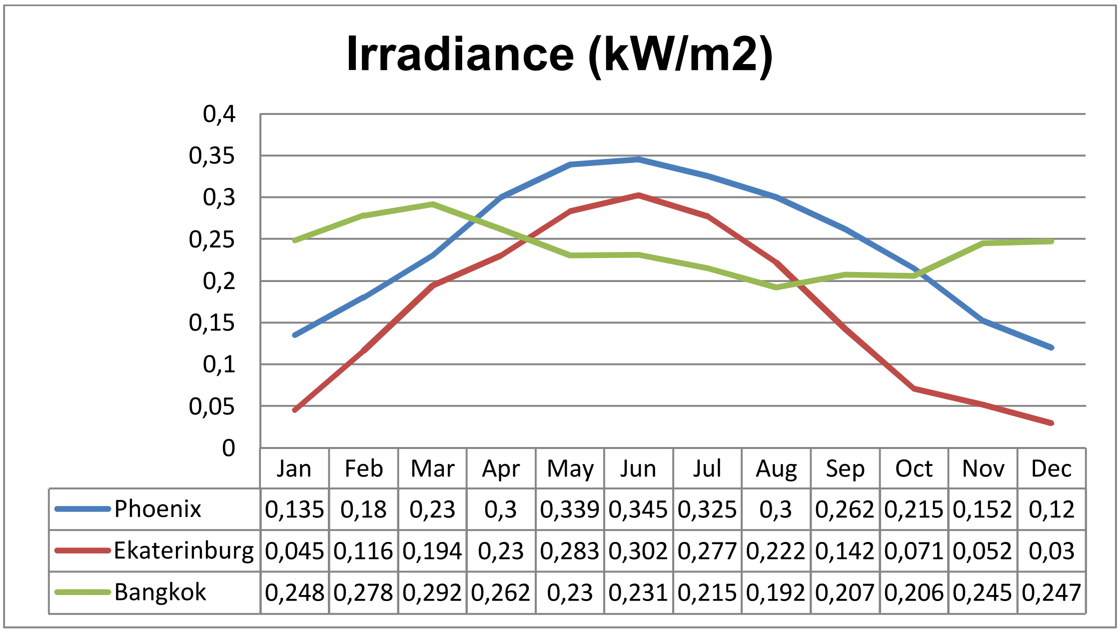
Table 7.2 Average Daily Solar Global Radiation

	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
kWh/m^2	4,89	4,82	4,82	4,93	4,94	4,87	4,94	4,78	4,69	4,57	4,54	4,34

The 2 graphics attached below represent both temperature and radiation (kW/m^2) comparing this mine with the location of the other case studies of this project, in order to observe the differences between them:



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Ombilin	27	27	27	27,2	27,5	27	25	25	26,7	26,7	26,7	26,7
Lake Havasu City	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
Kurgan	-15,2	-14,2	-6,5	4,6	12,6	18,4	19,8	17,2	10,9	3,9	-6,4	-12,9



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phoenix	0,135	0,18	0,23	0,3	0,339	0,345	0,325	0,3	0,262	0,215	0,152	0,12
Ekaterinburg	0,045	0,116	0,194	0,23	0,283	0,302	0,277	0,222	0,142	0,071	0,052	0,03
Bangkok	0,248	0,278	0,292	0,262	0,23	0,231	0,215	0,192	0,207	0,206	0,245	0,247

Finally, due to the geographic location in the Sumatera island, it would be in addition another case of study the possibility of using sea water as cooling fluid. This aspect will be studied after, taking in consideration possible environment damages in order to avoid them.

7.2 Geothermal Energy in Indonesia

Indonesia is geologically located at the confluence of three major tectonic plates, the Eurasian Plate, Indo-Australian and the Pacific, this geological conditions make a real contribution to the availability of geothermal energy in Indonesia. Observed from the appearance of geothermal energy in the surface per unit area, Indonesia fourth ranks in the world, even from high temperature variables, Indonesia second ranks. Making Indonesia has the largest geothermal potential in the world to save 40% of the world's geothermal resources. Manifestations of geothermal energy in Indonesia is not less than 252 locations spread across Sumatra, Java, Nusa Tenggara, Bali, Sulawesi to the Moluccas.

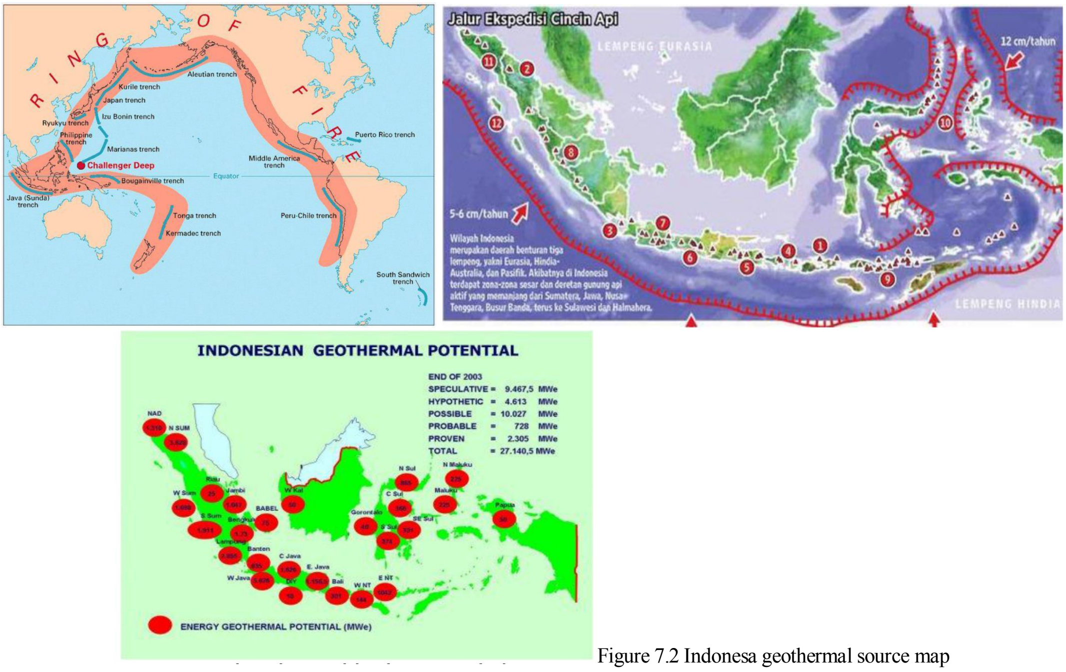


Figure 7.2 Indonesa geothermal source map

7.3 Coal Mine Energy Consumption

For the purpose of finding the values of energy demand in a coal mine, the example of Moolarben Coal Project will be considered.

The Moolarben Coal Project (MCP) has a staged implementation: where construction will commence in the first quarter of 2009 with the development of open cut coal mining and a coal preparation plant (CPP), and then beginning open cut coal production during 2010 and underground coal development 2011.

The projected energy use from these activities is shown in Table and Figure below. The figures are based on information supplied by the Moolarben Coal Mines (MCM) management team. This information included a schedule of equipment to be used in the operation, and estimates of energy use based on the experience at the Ashton Mine.

It is noted that the projected unit cost of both electricity and diesel will vary depending on the supplier agreements reached by MCM, market prices, and other influences, and are used throughout this document as indicators only.

7.3.1 Development of Energy Key Performance Indicators

Key Performance Indicators (KPIs) are applicable at an industry level, enterprise level, and an operational level. Key Performance Indicators can be developed for the mining activities which are either:

a) Externally focused, and provide the ultimate measures of performance against higher level objectives; or

b) Internally focused, which are diagnostic and are useful in formulating and measuring the performance of control strategies.

MCM will be required to identify a range of indicators to provide information for reporting purposes, and to assist in the management of energy efficiency of their operations. A number of KPIs may be required to understand the energy efficiency of various operations undertaken by MCM. For example, separate KPIs may be determined for the operation of the open cut pits, underground mining, and coal preparation plant.

For the purposes of energy management, the KPIs developed may be based on the Run of Mine (ROM) tons to give an intensity measure, or based on production tons (i.e. saleable product) to give an efficiency measure.

Intensity Measures are useful for determining the intensity of the mining process. They include energy consumed by the mining operation, but exclude the energy associated with processing, waste and wash plant.

-Efficiency Measures – used to determine the efficiency of the entire operation including all aspects of mining and processing.

Based on the projected annual energy consumption for MCM, it is possible to estimate the value of the intensity KPI for energy consumption per unit of production. The calculated KPIs are shown in the next table .

Table 7.3 Estimate of KPIs for Moolarben Coal Mine

Operation	Tons ROM Coal/year	GJ/year	KPI: GJ/ton ROM Coal
Open cut - GJ/ton	8000000	1508680	0,189
Underground - GJ/ton	4000000	267750	0,067
TOTAL	**12000000**	**1776430**	**0,148**

These estimated figures compare favorably to the KPI for energy consumption at Ashton Mine (based on consumption data from Ashton Mine) which is illustrated in Figure A2. The chart shows the actual overall energy per ton of saleable coal achieved by Ashton for the 2006 and 2007 financial years. It is estimated that the saleable coal from the MCP open cut and underground operations will be about 80% of the ROM coal figure, giving a KPI of approximately 0.185 GJ/ton saleable coal.

7.3.2 Diesel

MCM intends to use a fleet of diesel powered vehicles for open-cut mining operations. The fleet consists of vehicles and equipment designed to remove overburden, and for coal excavation and transport requirements.

At full production, the expected fleet consists of approximately 70 vehicles, including 4 x 600 ton excavators, 16 x 240 ton overburden removal trucks, and 8 x 240 ton coal trucks. The major diesel users are shown in the next figure.

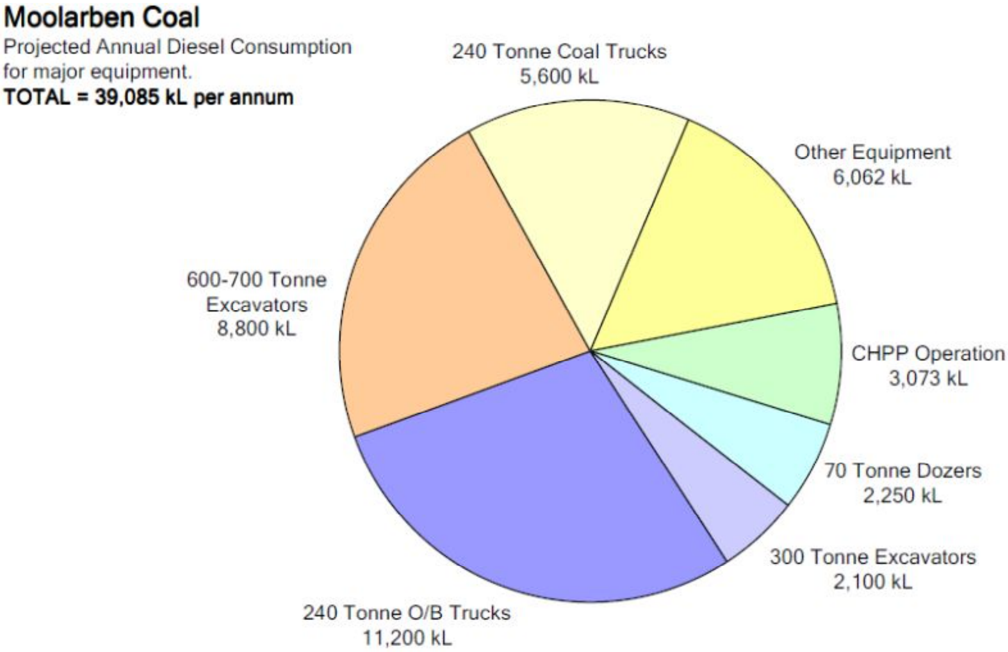


Figure 7.3 Moolarben Coal Projected Annual Design Consumption for major equipment

7.3.3. Electrical Energy

7.3.3.1 Major Plant Items

The next figure shows the expected consumption of electricity according to the maximum demand rating of the proposed equipment.

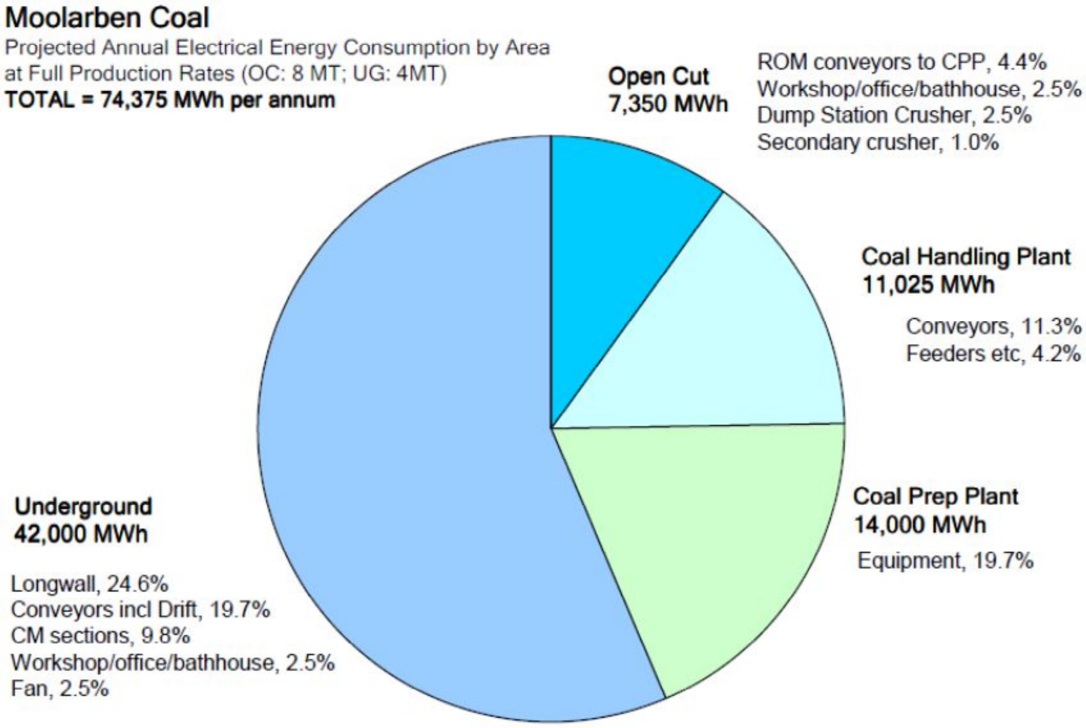


Figure 7.4 Moolarben Coal Projected Annual Electricity Consumption by Area at Full Production Rates

Finally, the daily energy demand for our case of study for 1000 tons/day, and using the same correlation of maximum power demand as in the granite mine case, is going to be the next:

Table 7.4 Energy Use

Electricity (kWh/day)	6.198
Diesel Fuel(L/day)	58,68
Power (kW)	3495,7

7.4 Fluid Selection

The choice of the optimal working fluid depends basically on the heat source and the heat sink temperature. For any heat temperature level there are a number of candidates which show a good match between heat source and heat sink temperatures and cycles boundary conditions. The choice the right working fluid is not an easy process. The fluid selection process is a trade-off between thermodynamic specifications, safety, environmental and economy aspects.

Simulation assumptions
Following are the assumption for this scenario

- The cycle is considered to work at steady state
- Pressure drop in heat exchangers is neglected
- Isentropic efficiency for pump and expander is assumed to be 0.8
- Min Ambient temperature $T_{Min} = 20$ ºC
- Max Ambient temperature $T_{Max} = 35$ ºC
- Heat sinks temperature $T_{Sink} = T_{Amb} -10$ ºC
- The Evaporating temperature is depending on the thermodynamical properties of every fluid. It will be considered the value of $T_{Crit} -10$ ºC
- Heat source temperature dependant on the source depth. $T_{1km} = 100$ ºC, $T_{1km} = 150$ ºC, $T_{1km} = 220$ ºC

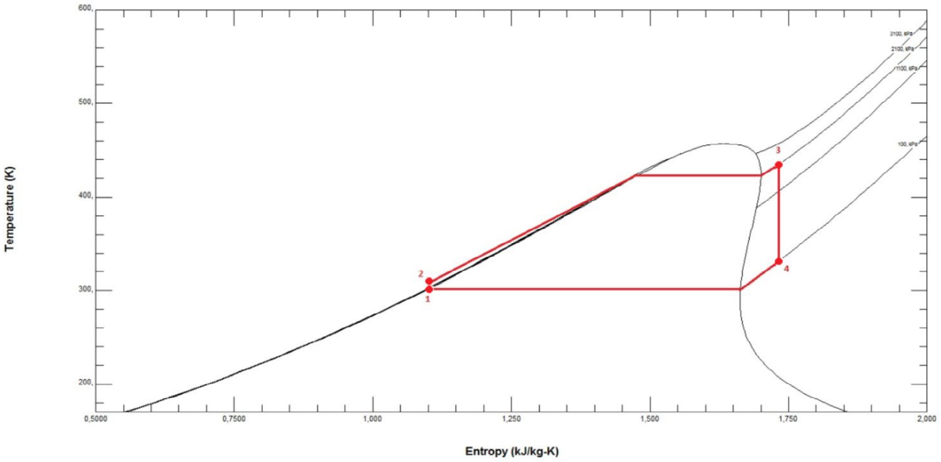
The evaporation temperatures are too high in this scenario and much higher than the critical temperature for many working fluids. For this reason, many working fluid with low critical temperature can´t be used in this scenario.

FLUID	T_{NBP}	T_{crit}	P_{crit}	efficiency$_{min}$	T_{efmin}	efficiency$_{max}$	T_{efmax}
R11	23,558	197,81	4407,6	0,18940	35	0,2085	20
R245fa	14,99	153,85	3651	0,14410	35	0,1639	20
R236ea	6,05	139,14	3502	0,12770	35	0,1473	20
Cis-butene	3,57	162,45	4225,5	0,15590	35	0,1765	20
R114	3,45	154,55	3257	0,13630	35	0,1554	20
Trans-butene	0,73	155,31	4027	0,14940	35	0,1701	20
Butane	-0,65	151,85	3800	0,14250	35	0,1628	20
R236fa	-1,55	124,75	3200	0,11400	35	0,1346	20
RC318	-6,15	115,05	2780	0,09843	35	0,1179	20
Butene	-6,46	145,99	4005	0,13910	35	0,1601	20
Isobutene	-7,15	233,81	4010	0,14980	35	0,1710	20
R142b	-9,25	136,95	4060	0,13070	35	0,1521	20
Sulfurdioxide	-10,15	157,35	7090	0,15930	35	0,1804	20
R124	-12,15	122,15	3062	0,11310	35	0,1346	20
R152a	-14,17	113,11	4517	0,10620	35	0,1290	20
R134a	-26,15	100,85	4059	0,08968	35	0,1127	20
R1234yf	-29,65	94,55	3380	0,07996	35	0,1031	20
R12	-29,95	111,85	4140	0,10280	35	0,1256	20
Ammonia	-33,45	132,1	11333	0,13370	35	0,1563	20
R161	-37,75	102,05	5090	0,09289	35	0,1165	20
R22	-40,95	95,95	4990	0,08439	35	0,1090	20
Propane	-42,15	96,55	4247	0,08343	35	0,1070	20
Propylene	-47,75	90,95	4560	0,07690	35	0,1011	20
Carbonylsulfide	-50,31	105,47	6370	0,09817	35	0,1222	20
Hydrogensulfide	-60,45	99,8	9000	0,09199	35	0,1166	20

With these results obtained from the described operations in an Organic Rankine Cycle (ORC), 9 working fluids were selected for a better analysis, according to environment conditions:

7.5 Organic Rankine Cycle (ORC)

The Organic Rankine Cycle has the same working principles and main components (evaporator, condenser, expander and pump) as the Steam Rankine Cycle. At the same time, there are some major differences between the two cycles. The differences are mainly related to the used working fluid in the cycle, the working fluid's thermo-physical properties, the heat source temperature and the cycle architecture. Organic Rankine Cycle can extract energy and generate power from much lower heat source temperature than traditional Rankine cycle.



From the analisys of different fluids values such as temperatures (ºC), pressures (kPa), mass heat and work exchanges (kW/kg) and process efficiency are obtained for the next step moduling heat exchangers and condensers.

T_{source}=100ºC

R22											
month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,09778	1102	4111	171,8	149,4	27	29,04	85,95	27	0,01783	16,8
feb	0,09778	1102	4111	171,8	149,4	27	29,04	85,95	27	0,01783	16,8
mar	0,09778	1102	4111	171,8	149,4	27	29,04	85,95	27	0,01783	16,8
apr	0,09746	1108	4111	171,5	149,2	27,2	29,24	85,95	27,2	0,01774	16,72
may	0,09698	1116	4111	171,2	149	27,5	29,55	85,95	27,5	0,0176	16,6
jun	0,09778	1102	4111	171,8	149,4	27	29,04	85,95	27	0,01783	16,8
jul	0,101	1044	4103	174,7	151,2	25	27,02	85,95	25	0,01885	17,64
aug	0,101	1044	4103	174,7	151,2	25	27,02	85,95	25	0,01885	17,64
sep	0,09826	1093	4103	172,6	150	26,7	28,73	85,95	26,7	0,01802	16,96
oct	0,09826	1093	4103	172,6	150	26,7	28,73	85,95	26,7	0,01802	16,96
nov	0,09826	1093	4103	172,6	150	26,7	28,73	85,95	26,7	0,01802	16,96
dec	0,09826	1093	4103	172,6	150	26,7	28,73	85,95	26,7	0,01802	16,96
Propane											
month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,09533	1002	3472	349,3	304,9	27	28,82	85,55	27	0,04245	33,3
feb	0,09533	1002	3472	349,3	304,9	27	28,82	85,55	27	0,04245	33,3
mar	0,09533	1002	3472	349,3	304,9	27	28,82	85,55	27	0,04245	33,3
apr	0,09502	1007	3472	348,8	304,5	27,2	29,03	85,55	27,2	0,04223	33,14
may	0,09455	1014	3472	348	304	27,5	29,33	85,55	27,5	0,0419	32,9
jun	0,09533	1002	3472	349,3	304,9	27	28,82	85,55	27	0,04245	33,3
jul	0,09849	952,2	3472	354,8	308,2	25	26,81	85,55	25	0,0447	34,94
aug	0,09849	952,2	3472	354,8	308,2	25	26,81	85,55	25	0,0447	34,94
sep	0,09581	994,1	3472	350,1	305,4	26,7	28,52	85,55	26,7	0,04278	33,55
oct	0,09581	994,1	3472	350,1	305,4	26,7	28,52	85,55	26,7	0,04278	33,55
nov	0,09581	994,1	3472	350,1	305,4	26,7	28,52	85,55	26,7	0,04278	33,55
dec	0,09581	994,1	3472	350,1	305,4	26,7	28,52	85,55	26,7	0,04278	33,55
Hydrogensulfide											

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1051	2117	7507	364,4	312,6	27	29,99	89,8	27	0,02166	38,31
feb	0,1051	2117	7507	364,4	312,6	27	29,99	89,8	27	0,02166	38,31
mar	0,1051	2117	7507	364,4	312,6	27	29,99	89,8	27	0,02166	38,31
apr	0,1048	2127	7507	363,9	312,4	27,2	30,2	89,8	27,2	0,02156	38,14
may	0,1043	2142	7507	363,3	312	27,5	30,5	89,8	27,5	0,02141	37,89
jun	0,1051	2117	7507	364,4	312,6	27	29,99	89,8	27	0,02166	38,31
jul	0,1084	2016	7507	368,8	314,9	25	27,97	89,8	25	0,02267	39,98
aug	0,1084	2016	7507	368,8	314,9	25	27,97	89,8	25	0,02267	39,98
sep	0,1056	2101	7507	365,1	312,9	26,7	29,69	89,8	26,7	0,02181	38,56
oct	0,1056	2101	7507	365,1	312,9	26,7	29,69	89,8	26,7	0,02181	38,56
nov	0,1056	2101	7507	365,1	312,9	26,7	29,69	89,8	26,7	0,02181	38,56
dec	0,1056	2101	7507	365,1	312,9	26,7	29,69	89,8	26,7	0,02181	38,56

T_{source}=150ºC

Butene

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1502	315,5	3236	456,4	367,9	27	28,31	136	27	0,155	68,58
feb	0,1502	315,5	3236	456,4	367,9	27	28,31	136	27	0,155	68,58
mar	0,1502	315,5	3236	456,4	367,9	27	28,31	136	27	0,155	68,58
apr	0,15	317,3	3236	456	367,7	27,2	28,51	136	27,2	0,1541	68,38
may	0,1496	320,1	3237	455,2	367,3	27,5	28,82	136	27,5	0,1525	68,08
jun	0,1502	315,5	3237	456,4	367,9	27	28,31	136	27	0,1548	68,57
jul	0,1531	296,8	3231	461,5	370,4	25	26,3	136	25	0,1655	70,66
aug	0,1531	296,8	3231	461,5	370,4	25	26,3	136	25	0,1655	70,66
sep	0,1507	312,7	3235	457,2	368,3	26,7	28,01	136	26,7	0,1566	68,88
oct	0,1507	312,7	3235	457,2	368,3	26,7	28,01	136	26,7	0,1566	68,88
nov	0,1507	312,7	3235	457,2	368,3	26,7	28,01	136	26,7	0,1566	68,88
dec	0,1507	312,7	3235	457,2	368,3	26,7	28,01	136	26,7	0,1566	68,88

R142b

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1421	358,8	3219	243,9	199,1	27	28,35	127	27	0,06196	34,65
feb	0,1421	358,8	3219	243,9	199,1	27	28,35	127	27	0,06196	34,65
mar	0,1421	358,8	3219	243,9	199,1	27	28,35	127	27	0,06196	34,65
apr	0,1418	360,9	3220	243,5	198,9	27,2	28,55	127	27,2	0,06159	34,54
may	0,1414	364,2	3225	242,9	198,5	27,5	28,85	127	27,5	0,061	34,35
jun	0,1421	358,8	3217	243,9	199,2	27	28,34	127	27	0,06198	34,67
jul	0,1449	337,7	3210	246,9	200,7	25	26,32	127	25	0,06574	35,77
aug	0,1449	337,7	3215	246,6	200,5	25	26,33	127	25	0,06568	35,74
sep	0,1425	355,5	3220	244,2	199,2	26,7	28,04	127	26,7	0,06249	34,81
oct	0,1425	355,5	3220	244,2	199,2	26,7	28,04	127	26,7	0,06249	34,81
nov	0,1425	355,5	3220	244,2	199,2	26,7	28,04	127	26,7	0,06249	34,81
dec	0,1425	355,5	3220	244,2	199,2	26,7	28,04	127	26,7	0,06249	34,81

Ammonia

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1457	1067	9039	1049	850,2	27	29,06	122,1	27	0,08905	152,8
feb	0,1457	1067	9039	1049	850,2	27	29,06	122,1	27	0,08905	152,8
mar	0,1457	1067	9039	1049	850,2	27	29,06	122,1	27	0,08905	152,8
apr	0,1454	1073	9041	1048	849,6	27,2	29,26	122,1	27,2	0,08853	152,4
may	0,145	1083	9045	1046	848,7	27,5	29,57	122,1	27,5	0,08776	151,6
jun	0,1457	1067	9039	1049	850,2	27	29,06	122,1	27	0,08905	152,8
jul	0,1488	1003	9015	1061	856,1	25	27,02	122,1	25	0,09446	157,8
aug	0,1488	1003	9015	1061	856,1	25	27,02	122,1	25	0,09446	157,8
sep	0,1462	1057	9035	1051	851,1	26,7	28,75	122,1	26,7	0,08984	153,6
oct	0,1462	1057	9035	1051	851,1	26,7	28,75	122,1	26,7	0,08984	153,6
nov	0,1462	1057	9035	1051	851,1	26,7	28,75	122,1	26,7	0,08984	153,6
dec	0,1462	1057	9035	1051	851,1	26,7	28,75	122,1	26,7	0,08984	153,6

T_{source}=220ºC

R11

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1995	113,2	3415	239,8	178,7	27	27	187,8	27	0,1534	47,85
feb	0,1995	113,2	3415	239,8	178,7	27	27	187,8	27	0,1534	47,85
mar	0,1995	113,2	3415	239,8	178,7	27	27	187,8	27	0,1534	47,85
apr	0,1993	114	3416	239,6	178,7	27,2	27,2	187,8	27,2	0,1524	47,75
may	0,1989	115,1	3417	239,3	178,5	27,5	27,5	187,8	27,5	0,151	47,6
jun	0,1995	113,2	3415	239,8	178,7	27	27	187,8	27	0,1534	47,85
jul	0,2021	105,6	3406	241,8	179,4	25	25	187,8	25	0,1636	48,86
aug	0,2021	105,6	3406	241,8	179,4	25	25	187,8	25	0,1636	48,86
sep	0,1999	112	3413	240,1	178,8	26,7	26,7	187,8	26,7	0,1549	48
oct	0,1999	112	3413	240,1	178,8	26,7	26,7	187,8	26,7	0,1549	48
nov	0,1999	112	3413	240,1	178,8	26,7	26,7	187,8	26,7	0,1549	48
dec	0,1999	112	3413	240,1	178,8	26,7	26,7	187,8	26,7	0,1549	48

Cis-butene

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1669	227,5	3373	507,1	398,4	27	28,36	152,5	27	0,2139	84,63
feb	0,1669	227,5	3373	507,1	398,4	27	28,36	152,5	27	0,2139	84,63
mar	0,1669	227,5	3373	507,1	398,4	27	28,36	152,5	27	0,2139	84,63
apr	0,1666	229	3374	506,6	398,2	27,2	28,56	152,5	27,2	0,2126	84,41
may	0,1662	231,2	3375	505,9	397,9	27,5	28,87	152,5	27,5	0,2106	84,08
jun	0,1669	227,5	3373	507,1	398,4	27	28,36	152,5	27	0,2139	84,63
jul	0,1696	213,5	3373	511,6	400,2	25	26,36	152,5	25	0,2261	86,77
aug	0,1696	213,5	3373	511,6	400,2	25	26,36	152,5	25	0,2261	86,77
sep	0,1673	225,4	3372	507,9	398,8	26,7	28,06	152,5	26,7	0,2159	84,97
oct	0,1673	225,4	3372	507,9	398,8	26,7	28,06	152,5	26,7	0,2159	84,97
nov	0,1673	225,4	3372	507,9	398,8	26,7	28,06	152,5	26,7	0,2159	84,97
dec	0,1673	225,4	3372	507,9	398,8	26,7	28,06	152,5	26,7	0,2159	84,97

Sulfurdioxide

month	efficiency	P_1	P_2	Q_B	Q_C	T_1	T_2	T_3	T_e	v_4	W_{net}
jan	0,1705	419	6224	347,9	271,4	27	28,88	147,4	27	0,06624	59,32
feb	0,1705	419	6224	347,9	271,4	27	28,88	147,4	27	0,06624	59,32
mar	0,1705	419	6224	347,9	271,4	27	28,88	147,4	27	0,06624	59,32
apr	0,1702	421,8	6226	347,6	271,2	27,2	29,09	147,4	27,2	0,06583	59,16
may	0,1698	426	6228	347,1	271	27,5	29,39	147,4	27,5	0,06523	58,93
jun	0,1705	419	6224	347,9	271,4	27	28,88	147,4	27	0,06624	59,32
jul	0,1733	392,2	6208	351,3	272,8	25	26,85	147,4	25	0,07049	60,88
aug	0,1733	392,2	6208	351,3	272,8	25	26,85	147,4	25	0,07049	60,88
sep	0,1709	414,9	6222	348,4	271,6	26,7	28,58	147,4	26,7	0,06686	59,55
oct	0,1709	414,9	6222	348,4	271,6	26,7	28,58	147,4	26,7	0,06686	59,55
nov	0,1709	414,9	6222	348,4	271,6	26,7	28,58	147,4	26,7	0,06686	59,55
dec	0,1709	414,9	6222	348,4	271,6	26,7	28,58	147,4	26,7	0,06686	59,55

7.6 Heat Exchanger

The next tables show the different behavior of the chosen fluids in contact with the geothermal water source through heat exchangers, calculated according to the ε-NTU system explaint in the 5º chapter. The most important data obtained from this analysis are the different temperature values, mass of working and cooling fluids and the parasit power demand.

The mass ofworking fluid was calculated taking in consideration the maximum power demand of the mine and the mass net work value calculated by the Rankine cycle (W_m)

100 ºC source:

R22

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	422,1	0,8022	70,11	208,1	4,054	4111	16714	29,04	85,95	100	43,07	16,8
feb	422,1	0,8022	70,11	208,1	4,054	4111	16714	29,04	85,95	100	43,07	16,8
mar	422,1	0,8022	70,11	208,1	4,054	4111	16714	29,04	85,95	100	43,07	16,8
apr	422,9	0,8017	70,5	209,1	4,04	4111	16747	29,24	85,95	100	43,27	16,72
may	424,1	0,8008	71,08	210,6	4,018	4111	16794	29,55	85,95	100	43,58	16,6
jun	422,1	0,8022	70,11	208,1	4,054	4111	16714	29,04	85,95	100	43,07	16,8
jul	443,6	0,8332	64,32	198,2	4,645	4103	16373	27,02	85,95	100	39,19	17,64
aug	413,5	0,8077	66,34	198,2	4,198	4103	16373	27,02	85,95	100	41,05	17,64
sep	420	0,8031	69,4	206,1	4,076	4103	16632	28,73	85,95	100	42,77	16,96
oct	420	0,8031	69,4	206,1	4,076	4103	16632	28,73	85,95	100	42,77	16,96
nov	420	0,8031	69,4	206,1	4,076	4103	16632	28,73	85,95	100	42,77	16,96
dec	420	0,8031	69,4	206,1	4,076	4103	16632	28,73	85,95	100	42,77	16,96

Propane

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	453,1	0,7972	77,64	105	3,93	3472	18452	28,82	85,55	100	43,25	33,3
feb	453,1	0,7972	77,64	105	3,93	3472	18452	28,82	85,55	100	43,25	33,3
mar	453,1	0,7972	77,64	105	3,93	3472	18452	28,82	85,55	100	43,25	33,3
apr	454	0,7967	78,07	105,5	3,916	3472	18485	29,03	85,55	100	43,46	33,14
may	455,2	0,7958	78,72	106,3	3,894	3472	18540	29,33	85,55	100	43,76	32,9
jun	453,1	0,7972	77,65	105	3,929	3472	18452	28,82	85,55	100	43,25	33,3
jul	444,2	0,8028	73,52	100	4,069	3472	18088	26,81	85,55	100	41,24	34,94
aug	444,2	0,8028	73,52	100	4,069	3472	18088	26,81	85,55	100	41,24	34,94
sep	451,6	0,7981	76,99	104,2	3,95	3472	18393	28,52	85,55	100	42,95	33,55
oct	451,6	0,7981	76,99	104,2	3,95	3472	18393	28,52	85,55	100	42,95	33,55
nov	451,6	0,7981	76,99	104,2	3,95	3472	18393	28,52	85,55	100	42,95	33,55
dec	451,6	0,7981	76,99	104,2	3,95	3472	18393	28,52	85,55	100	42,95	33,55

Hydrogensulfide

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	498,4	0,8641	54,67	91,25	6,141	7507	13846	29,99	89,8	100	39,5	38,31
feb	481,6	0,8545	55,28	91,25	5,868	7507	13846	29,99	89,8	100	40,18	38,31
mar	481,6	0,8545	55,28	91,25	5,868	7507	13846	29,99	89,8	100	40,18	38,31
apr	482,5	0,854	55,58	91,65	5,847	7507	13871	30,2	89,8	100	40,39	38,14
may	484	0,8535	56	92,26	5,82	7507	13909	30,5	89,8	100	40,68	37,89
jun	481,8	0,8545	55,28	91,25	5,87	7507	13846	29,99	89,8	100	40,17	38,31
jul	473,4	0,8586	52,57	87,44	6,067	7507	13609	27,97	89,8	100	38,16	39,98
aug	473,4	0,8586	52,57	87,44	6,067	7507	13609	27,97	89,8	100	38,16	39,98
sep	480,4	0,8551	54,86	90,66	5,898	7507	13809	29,69	89,8	100	39,88	38,56
oct	480,4	0,8551	54,86	90,66	5,898	7507	13809	29,69	89,8	100	39,88	38,56
nov	480,4	0,8551	54,86	90,66	5,898	7507	13809	29,69	89,8	100	39,88	38,56
dec	480,4	0,8551	54,86	90,66	5,898	7507	13809	29,69	89,8	100	39,88	38,56

150 ºC source

Butene

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	687,1	0,8851	59,77	94,73	7,697	3236	27114	28,31	136	150	42,29	36,9
feb	687,1	0,8851	59,77	94,73	7,697	3236	27114	28,31	136	150	42,29	36,9
mar	687,1	0,8851	59,77	94,73	7,697	3236	27114	28,31	136	150	42,29	36,9
apr	688,2	0,8849	59,97	95,02	7,683	3236	27154	28,51	136	150	42,49	36,79
may	689,7	0,8846	60,28	95,46	7,661	3237	27216	28,82	136	150	42,81	36,62
jun	687,2	0,8851	59,77	94,73	7,698	3237	27114	28,31	136	150	42,29	36,9
jul	676,7	0,887	57,79	91,9	7,843	3231	26699	26,3	136	150	40,28	38,04
aug	676,6	0,8869	57,79	91,9	7,841	3231	26699	26,3	136	150	40,29	38,04
sep	685,6	0,8854	59,47	94,3	7,72	3235	27051	28,01	136	150	41,99	37,07
oct	685,6	0,8854	59,47	94,3	7,72	3235	27051	28,01	136	150	41,99	37,07
nov	685,6	0,8854	59,47	94,3	7,72	3235	27051	28,01	136	150	41,99	37,07
dec	685,6	0,8854	59,47	94,3	7,72	3235	27051	28,01	136	150	41,99	37,07

R142b

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	227,1	0,8111	73,07	100,9	4,293	3219	14724	28,35	127	150	51,33	34,65
feb	227,1	0,8111	73,07	100,9	4,293	3219	14724	28,35	127	150	51,33	34,65
mar	227,1	0,8111	73,07	100,9	4,293	3219	14724	28,35	127	150	51,33	34,65
apr	227,5	0,8109	73,33	101,2	4,285	3220	14746	28,55	127	150	51,52	34,54
may	228,1	0,8104	73,78	101,8	4,271	3225	14789	28,85	127	150	51,82	34,35
jun	227	0,8111	73,02	100,8	4,293	3217	14717	28,34	127	150	51,32	34,67
jul	223,8	0,8142	34,16	97,73	4,381	3210	14508	26,32	127	150	49,29	35,77
aug	224	0,8142	34,19	97,81	4,381	3215	14518	26,33	127	150	49,3	35,74
sep	226,7	0,8116	72,68	100,4	4,306	3220	14695	28,04	127	150	51,01	34,81
oct	226,7	0,8116	72,68	100,4	4,306	3220	14695	28,04	127	150	51,01	34,81
nov	226,7	0,8116	72,68	100,4	4,306	3220	14695	28,04	127	150	51,01	34,81
dec	226,7	0,8116	72,68	100,4	4,306	3220	14695	28,04	127	150	51,01	34,81

Ammonia

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	144,4	0,7696	59,92	22,88	3,338	9039	11354	29,06	122,1	150	56,93	152,8
feb	144,4	0,7696	59,92	22,88	3,338	9039	11354	29,06	122,1	150	56,93	152,8
mar	144,4	0,7696	59,92	22,88	3,338	9039	11354	29,06	122,1	150	56,93	152,8
apr	144,5	0,7692	60,11	22,94	3,331	9041	11364	29,26	122,1	150	57,13	152,4
may	144,9	0,7686	60,48	23,06	3,319	9045	11394	29,57	122,1	150	57,44	151,6
jun	144,4	0,7696	59,92	22,88	3,338	9039	11354	29,06	122,1	150	56,93	152,8
jul	142,2	0,7734	57,71	22,15	3,411	9015	11186	27,02	122,1	150	54,89	157,8
aug	142,2	0,7734	57,71	22,15	3,411	9015	11186	27,02	122,1	150	54,89	157,8
sep	144	0,7702	59,56	22,76	3,349	9035	11325	28,75	122,1	150	56,61	153,6
oct	144	0,7702	59,56	22,76	3,349	9035	11325	28,75	122,1	150	56,61	153,6
nov	144	0,7702	59,56	22,76	3,349	9035	11325	28,75	122,1	150	56,61	153,6
dec	144	0,7702	59,56	22,76	3,349	9035	11325	28,75	122,1	150	56,61	153,6

220 ºC source

R11

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	122,7	0,8334	34,84	73,06	4,998	3415	11136	27	187,8	220	59,16	47,85
feb	122,7	0,8334	34,84	73,06	4,998	3415	11136	27	187,8	220	59,16	47,85
mar	122,7	0,8334	34,84	73,06	4,998	3415	11136	27	187,8	220	59,16	47,85
apr	122,8	0,8332	34,92	73,21	4,992	3416	11148	27,2	187,8	220	59,36	47,75
may	123	0,8329	35,05	73,44	4,982	3417	11166	27,5	187,8	220	59,67	47,6
jun	122,7	0,8333	34,84	73,06	4,998	3415	11136	27	187,8	220	59,16	47,85
jul	135,9	0,869	32,66	71,55	5,896	3406	11018	25	187,8	220	50,54	48,86
aug	121,4	0,835	34,04	71,55	5,059	3406	11018	25	187,8	220	57,17	48,86
sep	122,5	0,8336	34,72	72,83	5,007	3413	11118	26,7	187,8	220	58,87	48
oct	122,5	0,8336	34,72	72,83	5,007	3413	11118	26,7	187,8	220	58,87	48
nov	122,5	0,8336	34,72	72,83	5,007	3413	11118	26,7	187,8	220	58,87	48
dec	122,5	0,8336	34,72	72,83	5,007	3413	11118	26,7	187,8	220	58,87	48

Cis-butene

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	86,58	0,7721	45,53	41,31	2,704	3373	13361	28,36	152,5	220	72,03	84,63
feb	86,58	0,7721	45,53	41,31	2,704	3373	13361	28,36	152,5	220	72,03	84,63
mar	86,58	0,7721	45,53	41,31	2,704	3373	13361	28,36	152,5	220	72,03	84,63
apr	87,05	0,7739	45,53	41,41	2,719	3374	13378	28,56	152,5	220	71,84	84,41
may	87,77	0,7766	45,53	41,58	2,741	3375	13404	28,87	152,5	220	71,56	84,08
jun	86,58	0,7721	45,53	41,31	2,704	3373	13361	28,36	152,5	220	72,03	84,63
jul	82,29	0,755	45,53	40,29	2,571	3373	13198	26,36	152,5	220	73,79	86,77
aug	82,29	0,755	45,53	40,29	2,571	3373	13198	26,36	152,5	220	73,79	86,77
sep	85,85	0,7694	45,53	41,14	2,681	3372	13333	28,06	152,5	220	72,33	84,97
oct	85,85	0,7694	45,53	41,14	2,681	3372	13333	28,06	152,5	220	72,33	84,97
nov	85,85	0,7694	45,53	41,14	2,681	3372	13333	28,06	152,5	220	72,33	84,97
dec	85,85	0,7694	45,53	41,14	2,681	3372	13333	28,06	152,5	220	72,33	84,97

Sulfurdioxide

month	A	ε	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	52,33	0,6205	45,67	58,93	1,634	6224	10709	28,88	147,4	220	101,4	59,32
feb	52,33	0,6205	45,67	58,93	1,634	6224	10709	28,88	147,4	220	101,4	59,32
mar	52,33	0,6205	45,67	58,93	1,634	6224	10709	28,88	147,4	220	101,4	59,32
apr	52,4	0,6201	45,81	59,09	1,632	6226	10722	29,09	147,4	220	101,6	59,16
may	52,5	0,6195	46,01	59,32	1,627	6228	10742	29,39	147,4	220	101,9	58,93
jun	52,34	0,6206	45,67	58,93	1,635	6224	10709	28,88	147,4	220	101,4	59,32
jul	51,71	0,6245	44,36	57,42	1,662	6208	10581	26,85	147,4	220	99,38	60,88
aug	51,71	0,6245	44,36	57,42	1,662	6208	10581	26,85	147,4	220	99,38	60,88
sep	52,24	0,6211	45,47	58,7	1,639	6222	10690	28,58	147,4	220	101,1	59,55
oct	52,24	0,6211	45,47	58,7	1,639	6222	10690	28,58	147,4	220	101,1	59,55
nov	52,24	0,6211	45,47	58,7	1,639	6222	10690	28,58	147,4	220	101,1	59,55
dec	52,24	0,6211	45,47	58,7	1,639	6222	10690	28,58	147,4	220	101,1	59,55

7.7 Condenser

The next tables show the different behavior of the chosen fluids in contact with condensers of diverse sizes, according to the ε-NTU system explaint in the 5º chapter. The most important data obtained from this analysis are the different temperature values, mass of working and cooling fluids and the parasit power demand.

Because of the proximity to the sea, cooling fluid is considered free to obtain, so the most important fact to choose will be to reduce the size (and the cost) of the condenser.

R22 Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	62,16	0,5	1568	219,5	0,6292	1102	149,4	32797	17	22	27	16,8	192,3
feb	62,16	0,5	1568	219,5	0,6292	1102	149,4	32797	17	22	27	16,8	192,3
mar	62,16	0,5	1568	219,5	0,6292	1102	149,4	32797	17	22	27	16,8	192,3
apr	62,5	0,5	1574	220,6	0,6291	1108	149,2	32916	17,2	22,2	27,2	16,72	193
may	45,73	0,5	1584	222,3	0,648	1116	149	33120	17,5	22,5	27,5	16,6	194,2
jun	62,16	0,5	1568	219,5	0,6292	1102	149,4	32797	17	22	27	16,8	192,3
jul	42,21	0,5	1508	208,7	0,6495	1044	151,2	31549	15	20	25	17,64	185
aug	42,21	0,5	1508	208,7	0,6495	1044	151,2	31549	15	20	25	17,64	185
sep	61,52	0,5	1559	217,4	0,6295	1093	150	32608	16,7	21,7	26,7	16,96	191,2
oct	61,52	0,5	1559	217,4	0,6295	1093	150	32608	16,7	21,7	26,7	16,96	191,2
nov	61,52	0,5	1559	217,4	0,6295	1093	150	32608	16,7	21,7	26,7	16,96	191,2
dec	61,52	0,5	1559	217,4	0,6295	1093	150	32608	16,7	21,7	26,7	16,96	191,2
jan	107,2	0,7	1103	216,1	1,102	1102	149,4	32289	17	24	27	16,8	135,2
feb	107,2	0,7	1103	216,1	1,102	1102	149,4	32289	17	24	27	16,8	135,2
mar	107,2	0,7	1103	216,1	1,102	1102	149,4	32289	17	24	27	16,8	135,2
apr	107,8	0,7	1107	217,2	1,102	1108	149,2	32405	17,2	24,2	27,2	16,72	135,7
may	78,64	0,7	1113	218,8	1,132	1116	149	32603	17,5	24,5	27,5	16,6	136,5
jun	107,2	0,7	1103	216,1	1,102	1102	149,4	32289	17	24	27	16,8	135,2
jul	72,63	0,7	1061	205,5	1,134	1044	151,2	31079	15	22	25	17,64	130,2
aug	72,63	0,7	1061	205,5	1,134	1044	151,2	31079	15	22	25	17,64	130,2
sep	106,1	0,7	1096	214	1,103	1093	150	32106	16,7	23,7	26,7	16,96	134,5
oct	106,1	0,7	1096	214	1,103	1093	150	32106	16,7	23,7	26,7	16,96	134,5
nov	106,1	0,7	1096	214	1,103	1093	150	32106	16,7	23,7	26,7	16,96	134,5
dec	106,1	0,7	1096	214	1,103	1093	150	32106	16,7	23,7	26,7	16,96	134,5
jan	210,2	0,9	960,2	215,1	2,172	1102	149,4	32134	17	25	27	16,8	117,7
feb	210,2	0,9	960,2	215,1	2,172	1102	149,4	32134	17	25	27	16,8	117,7
mar	210,2	0,9	960,2	215,1	2,172	1102	149,4	32134	17	25	27	16,8	117,7
apr	211,8	0,9	989,2	216,3	2,175	1108	149,2	32276	17,2	25	27,2	16,72	121,3
may	153,5	0,9	1036	218,2	2,216	1116	149	32518	17,5	25	27,5	16,6	127,1
jun	210,2	0,9	960,2	215,1	2,172	1102	149,4	32134	17	25	27	16,8	117,7
jul	139,8	0,9	818,7	203,9	2,202	1044	151,2	30824	15	24	25	17,64	100,4
aug	139,8	0,9	818,7	203,9	2,202	1044	151,2	30824	15	24	25	17,64	100,4
sep	207,3	0,9	919,2	212,8	2,167	1093	150	31914	16,7	25	26,7	16,96	112,7
oct	207,3	0,9	919,2	212,8	2,167	1093	150	31914	16,7	25	26,7	16,96	112,7
nov	207,3	0,9	919,2	212,8	2,167	1093	150	31914	16,7	25	26,7	16,96	112,7
dec	207,3	0,9	919,2	212,8	2,167	1093	150	31914	16,7	25	26,7	16,96	112,7

Propane Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	67,83	0,5	1617	110,9	0,625	1002	304,9	33823	17	22	27	33,3	198,3
feb	67,83	0,5	1617	110,9	0,625	1002	304,9	33823	17	22	27	33,3	198,3
mar	67,83	0,5	1617	110,9	0,625	1002	304,9	33823	17	22	27	33,3	198,3
apr	68,21	0,5	1623	111,5	0,6249	1007	304,5	33948	17,2	22,2	27,2	33,14	199
may	53,81	0,5	1633	112,3	0,641	1014	304	34151	17,5	22,5	27,5	32,9	200,2
jun	67,83	0,5	1617	110,9	0,625	1002	304,9	33823	17	22	27	33,3	198,3
jul	49,82	0,5	1555	105,5	0,6426	952,2	308,2	32517	15	20	25	34,94	190,6
aug	49,82	0,5	1555	105,5	0,6426	952,2	308,2	32517	15	20	25	34,94	190,6
sep	67,24	0,5	1607	110,1	0,6252	994,1	305,4	33615	16,7	21,7	26,7	33,55	197,1
oct	67,24	0,5	1607	110,1	0,6252	994,1	305,4	33615	16,7	21,7	26,7	33,55	197,1
nov	67,24	0,5	1607	110,1	0,6252	994,1	305,4	33615	16,7	21,7	26,7	33,55	197,1
dec	67,24	0,5	1607	110,1	0,6252	994,1	305,4	33615	16,7	21,7	26,7	33,55	197,1
jan	117	0,7	1137	109,2	1,095	1002	304,9	33283	17	24	27	33,3	139,4
feb	117	0,7	1137	109,2	1,095	1002	304,9	33283	17	24	27	33,3	139,4
mar	117	0,7	1137	109,2	1,095	1002	304,9	33283	17	24	27	33,3	139,4
apr	117,6	0,7	1141	109,7	1,095	1007	304,5	33405	17,2	24,2	27,2	33,14	139,9
may	92,59	0,7	1147	110,5	1,121	1014	304	33601	17,5	24,5	27,5	32,9	140,7
jun	117	0,7	1137	109,2	1,095	1002	304,9	33283	17	24	27	33,3	139,4
jul	85,76	0,7	1093	103,9	1,123	952,2	308,2	32018	15	22	25	34,94	134,1
aug	85,76	0,7	1093	103,9	1,123	952,2	308,2	32018	15	22	25	34,94	134,1
sep	116	0,7	1130	108,3	1,096	994,1	305,4	33082	16,7	23,7	26,7	33,55	138,5
oct	116	0,7	1130	108,3	1,096	994,1	305,4	33082	16,7	23,7	26,7	33,55	138,5
nov	116	0,7	1130	108,3	1,096	994,1	305,4	33082	16,7	23,7	26,7	33,55	138,5
dec	116	0,7	1130	108,3	1,096	994,1	305,4	33082	16,7	23,7	26,7	33,55	138,5
jan	229,8	0,9	989,6	108,6	2,163	1002	304,9	33118	17	25	27	33,3	121,4
feb	229,8	0,9	989,6	108,6	2,163	1002	304,9	33118	17	25	27	33,3	121,4
mar	229,8	0,9	989,6	108,6	2,163	1002	304,9	33118	17	25	27	33,3	121,4
apr	231,7	0,9	1020	109,3	2,166	1007	304,5	33268	17,2	25	27,2	33,14	125
may	181,5	0,9	1068	110,2	2,203	1014	304	33511	17,5	25	27,5	32,9	131
jun	229,8	0,9	989,6	108,6	2,163	1002	304,9	33118	17	25	27	33,3	121,4
jul	165,5	0,9	843,3	103	2,186	952,2	308,2	31747	15	24	25	34,94	103,4
aug	165,5	0,9	843,3	103	2,186	952,2	308,2	31747	15	24	25	34,94	103,4
sep	227	0,9	946,9	107,7	2,158	994,1	305,4	32878	16,7	25	26,7	33,55	116,1
oct	227	0,9	946,9	107,7	2,158	994,1	305,4	32878	16,7	25	26,7	33,55	116,1
nov	227	0,9	946,9	107,7	2,158	994,1	305,4	32878	16,7	25	26,7	33,55	116,1
dec	227	0,9	946,9	107,7	2,158	994,1	305,4	32878	16,7	25	26,7	33,55	116,1

Hydrogensulfide Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	49,11	0,5	1432	95,83	0,6387	2117	312,6	29957	17	22	27	38,31	175,6
feb	49,11	0,5	1432	95,83	0,6387	2117	312,6	29957	17	22	27	38,31	175,6
mar	49,11	0,5	1432	95,83	0,6387	2117	312,6	29957	17	22	27	38,31	175,6
apr	49,37	0,5	1438	96,28	0,6386	2127	312,4	30077	17,2	22,2	27,2	38,14	176,3
may	32,3	0,5	1446	96,94	0,6588	2142	312	30245	17,5	22,5	27,5	37,89	177,3
jun	49,11	0,5	1432	95,83	0,6387	2117	312,6	29957	17	22	27	38,31	175,6
jul	30,05	0,5	1380	91,67	0,6597	2016	314,9	28867	15	20	25	39,98	169,2
aug	30,05	0,5	1380	91,67	0,6597	2016	314,9	28867	15	20	25	39,98	169,2
sep	31,55	0,5	1424	95,18	0,6591	2101	312,9	29783	16,7	21,7	26,7	38,56	174,6
oct	31,55	0,5	1424	95,18	0,6591	2101	312,9	29783	16,7	21,7	26,7	38,56	174,6
nov	31,55	0,5	1424	95,18	0,6591	2101	312,9	29783	16,7	21,7	26,7	38,56	174,6
dec	31,55	0,5	1424	95,18	0,6591	2101	312,9	29783	16,7	21,7	26,7	38,56	174,6
jan	84,69	0,7	1009	94,48	1,117	2117	312,6	29533	17	24	27	38,31	123,7
feb	84,69	0,7	1009	94,48	1,117	2117	312,6	29533	17	24	27	38,31	123,7
mar	84,69	0,7	1009	94,48	1,117	2117	312,6	29533	17	24	27	38,31	123,7
apr	85,14	0,7	1013	94,91	1,117	2127	312,4	29650	17,2	24,2	27,2	38,14	124,2
may	55,54	0,7	1018	95,55	1,149	2142	312	29813	17,5	24,5	27,5	37,89	124,8
jun	84,69	0,7	1009	94,48	1,117	2117	312,6	29533	17	24	27	38,31	123,7
jul	51,71	0,7	972,4	90,42	1,151	2016	314,9	28473	15	22	25	39,98	119,2
aug	51,71	0,7	972,4	90,42	1,151	2016	314,9	28473	15	22	25	39,98	119,2
sep	54,26	0,7	1003	93,85	1,15	2101	312,9	29364	16,7	23,7	26,7	38,56	123
oct	54,26	0,7	1003	93,85	1,15	2101	312,9	29364	16,7	23,7	26,7	38,56	123
nov	54,26	0,7	1003	93,85	1,15	2101	312,9	29364	16,7	23,7	26,7	38,56	123
dec	54,26	0,7	1003	93,85	1,15	2101	312,9	29364	16,7	23,7	26,7	38,56	123
jan	165,4	0,9	878,6	94,06	2,191	2117	312,6	29403	17	25	27	38,31	107,7
feb	165,4	0,9	878,6	94,06	2,191	2117	312,6	29403	17	25	27	38,31	107,7
mar	165,4	0,9	878,6	94,06	2,191	2117	312,6	29403	17	25	27	38,31	107,7
apr	166,6	0,9	905,4	94,57	2,194	2127	312,4	29542	17,2	25	27,2	38,14	111
may	107,9	0,9	948	95,33	2,237	2142	312	29742	17,5	25	27,5	37,89	116,2
jun	165,4	0,9	878,6	94,06	2,191	2117	312,6	29403	17	25	27	38,31	107,7
jul	99,26	0,9	750,6	89,74	2,226	2016	314,9	28259	15	24	25	39,98	92,04
aug	99,26	0,9	750,6	89,74	2,226	2016	314,9	28259	15	24	25	39,98	92,04
sep	104,7	0,9	841,1	93,33	2,231	2101	312,9	29203	16,7	25	26,7	38,56	103,1
oct	104,7	0,9	841,1	93,33	2,231	2101	312,9	29203	16,7	25	26,7	38,56	103,1
nov	104,7	0,9	841,1	93,33	2,231	2101	312,9	29203	16,7	25	26,7	38,56	103,1
dec	104,7	0,9	841,1	93,33	2,231	2101	312,9	29203	16,7	25	26,7	38,56	103,1

Butene Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	27,94	0,5	925,7	52,63	0,6458	315,5	367,9	19362	17	22	27	68,58	113,5
feb	27,94	0,5	925,7	52,63	0,6458	315,5	367,9	19362	17	22	27	68,58	113,5
mar	27,94	0,5	925,7	52,63	0,6458	315,5	367,9	19362	17	22	27	68,58	113,5
apr	20,79	0,5	928	52,79	0,6587	317,3	367,7	19409	17,2	22,2	27,2	68,38	113,8
may	20,91	0,5	931,2	53,02	0,6586	320,1	367,3	19476	17,5	22,5	27,5	68,08	114,2
jun	27,94	0,5	925,8	52,64	0,6458	315,5	367,9	19365	17	22	27	68,57	113,5
jul	27	0,5	903,9	51,04	0,6463	296,8	370,4	18906	15	20	25	70,66	110,8
aug	27	0,5	903,9	51,04	0,6463	296,8	370,4	18906	15	20	25	70,66	110,8
sep	27,8	0,5	922,6	52,39	0,6458	312,7	368,3	19296	16,7	21,7	26,7	68,88	113,1
oct	27,8	0,5	922,6	52,39	0,6458	312,7	368,3	19296	16,7	21,7	26,7	68,88	113,1
nov	27,8	0,5	922,6	52,39	0,6458	312,7	368,3	19296	16,7	21,7	26,7	68,88	113,1
dec	27,8	0,5	922,6	52,39	0,6458	312,7	368,3	19296	16,7	21,7	26,7	68,88	113,1
jan	48,38	0,7	655,1	52,14	1,128	315,5	367,9	19184	17	24	27	68,58	80,34
feb	48,38	0,7	655,1	52,14	1,128	315,5	367,9	19184	17	24	27	68,58	80,34
mar	48,38	0,7	655,1	52,14	1,128	315,5	367,9	19184	17	24	27	68,58	80,34
apr	35,94	0,7	656,7	52,3	1,149	317,3	367,7	19230	17,2	24,2	27,2	68,38	80,53
may	36,14	0,7	659	52,53	1,149	320,1	367,3	19296	17,5	24,5	27,5	68,08	80,81
jun	48,38	0,7	655,2	52,15	1,128	315,5	367,9	19187	17	24	27	68,57	80,35
jul	46,75	0,7	639,8	50,58	1,129	296,8	370,4	18736	15	22	25	70,66	78,46
aug	46,75	0,7	639,8	50,58	1,129	296,8	370,4	18736	15	22	25	70,66	78,46
sep	48,13	0,7	653	51,91	1,129	312,7	368,3	19120	16,7	23,7	26,7	68,88	80,07
oct	48,13	0,7	653	51,91	1,129	312,7	368,3	19120	16,7	23,7	26,7	68,88	80,07
nov	48,13	0,7	653	51,91	1,129	312,7	368,3	19120	16,7	23,7	26,7	68,88	80,07
dec	48,13	0,7	653	51,91	1,129	312,7	368,3	19120	16,7	23,7	26,7	68,88	80,07
jan	94,28	0,9	571,6	51,99	2,206	315,5	367,9	19129	17	25	27	68,58	70,09
feb	94,28	0,9	571,6	51,99	2,206	315,5	367,9	19129	17	25	27	68,58	70,09
mar	94,28	0,9	571,6	51,99	2,206	315,5	367,9	19129	17	25	27	68,58	70,09
apr	69,71	0,9	588	52,18	2,234	317,3	367,7	19185	17,2	25	27,2	68,38	72,1
may	70,24	0,9	614,1	52,45	2,237	320,1	367,3	19266	17,5	25	27,5	68,08	75,3
jun	94,3	0,9	571,7	52	2,206	315,5	367,9	19132	17	25	27	68,57	70,1
jul	90,4	0,9	495,2	50,33	2,195	296,8	370,4	18643	15	24	25	70,66	60,72
aug	90,4	0,9	495,2	50,33	2,195	296,8	370,4	18643	15	24	25	70,66	60,72
sep	93,59	0,9	548,7	51,73	2,202	312,7	368,3	19051	16,7	25	26,7	68,88	67,29
oct	93,59	0,9	548,7	51,73	2,202	312,7	368,3	19051	16,7	25	26,7	68,88	67,29
nov	93,59	0,9	548,7	51,73	2,202	312,7	368,3	19051	16,7	25	26,7	68,88	67,29
dec	93,59	0,9	548,7	51,73	2,202	312,7	368,3	19051	16,7	25	26,7	68,88	67,29

R142b Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	29,51	0,5	953	97,9	0,6444	358,8	203,6	19933	17	22	27	36,9	116,9
feb	29,51	0,5	953	97,9	0,6444	358,8	203,6	19933	17	22	27	36,9	116,9
mar	29,51	0,5	953	97,9	0,6444	358,8	203,6	19933	17	22	27	36,9	116,9
apr	21,7	0,5	955	98,2	0,6582	360,9	203,4	19974	17,2	22,2	27,2	36,79	117,1
may	21,83	0,5	958,6	98,67	0,6581	364,2	203,2	20049	17,5	22,5	27,5	36,62	117,5
jun	29,51	0,5	953	97,9	0,6444	358,8	203,6	19933	17	22	27	36,9	116,9
jul	20,8	0,5	930,6	94,9	0,6588	337,7	205,1	19463	15	20	25	38,04	114,1
aug	20,8	0,5	930,6	94,9	0,6588	337,7	205,1	19463	15	20	25	38,04	114,1
sep	21,49	0,5	949,5	97,44	0,6583	355,5	203,8	19858	16,7	21,7	26,7	37,07	116,4
oct	21,49	0,5	949,5	97,44	0,6583	355,5	203,8	19858	16,7	21,7	26,7	37,07	116,4
nov	21,49	0,5	949,5	97,44	0,6583	355,5	203,8	19858	16,7	21,7	26,7	37,07	116,4
dec	21,49	0,5	949,5	97,44	0,6583	355,5	203,8	19858	16,7	21,7	26,7	37,07	116,4
jan	51,1	0,7	674,3	96,98	1,126	358,8	203,6	19744	17	24	27	36,9	82,68
feb	51,1	0,7	674,3	96,98	1,126	358,8	203,6	19744	17	24	27	36,9	82,68
mar	51,1	0,7	674,3	96,98	1,126	358,8	203,6	19744	17	24	27	36,9	82,68
apr	37,5	0,7	675,7	97,27	1,148	360,9	203,4	19785	17,2	24,2	27,2	36,79	82,85
may	37,72	0,7	678,2	97,73	1,148	364,2	203,2	19859	17,5	24,5	27,5	36,62	83,16
jun	51,1	0,7	674,3	96,98	1,126	358,8	203,6	19744	17	24	27	36,9	82,68
jul	35,95	0,7	658,5	94,02	1,149	337,7	205,1	19283	15	22	25	38,04	80,75
aug	35,95	0,7	658,5	94,02	1,149	337,7	205,1	19283	15	22	25	38,04	80,75
sep	37,14	0,7	671,8	96,52	1,149	355,5	203,8	19671	16,7	23,7	26,7	37,07	82,38
oct	37,14	0,7	671,8	96,52	1,149	355,5	203,8	19671	16,7	23,7	26,7	37,07	82,38
nov	37,14	0,7	671,8	96,52	1,149	355,5	203,8	19671	16,7	23,7	26,7	37,07	82,38
dec	37,14	0,7	671,8	96,52	1,149	355,5	203,8	19671	16,7	23,7	26,7	37,07	82,38
jan	99,65	0,9	588,3	96,69	2,203	358,8	203,6	19686	17	25	27	36,9	72,13
feb	99,65	0,9	588,3	96,69	2,203	358,8	203,6	19686	17	25	27	36,9	72,13
mar	99,65	0,9	588,3	96,69	2,203	358,8	203,6	19686	17	25	27	36,9	72,13
apr	72,75	0,9	604,9	97,03	2,233	360,9	203,4	19737	17,2	25	27,2	36,79	74,18
may	73,33	0,9	632	97,57	2,236	364,2	203,2	19827	17,5	25	27,5	36,62	77,5
jun	99,65	0,9	588,3	96,69	2,203	358,8	203,6	19686	17	25	27	36,9	72,13
jul	69,2	0,9	509,6	93,54	2,224	337,7	205,1	19185	15	24	25	38,04	62,49
aug	69,2	0,9	509,6	93,54	2,224	337,7	205,1	19185	15	24	25	38,04	62,49
sep	71,82	0,9	564,5	96,17	2,229	355,5	203,8	19599	16,7	25	26,7	37,07	69,22
oct	71,82	0,9	564,5	96,17	2,229	355,5	203,8	19599	16,7	25	26,7	37,07	69,22
nov	71,82	0,9	564,5	96,17	2,229	355,5	203,8	19599	16,7	25	26,7	37,07	69,22
dec	71,82	0,9	564,5	96,17	2,229	355,5	203,8	19599	16,7	25	26,7	37,07	69,22

Ammonia Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	26,19	0,5	961,3	23,65	0,6507	1067	850,2	20106	17	22	27	152,8	117,9
feb	26,19	0,5	961,3	23,65	0,6507	1067	850,2	20106	17	22	27	152,8	117,9
mar	26,19	0,5	961,3	23,65	0,6507	1067	850,2	20106	17	22	27	152,8	117,9
apr	17,81	0,5	963,2	23,71	0,665	1073	849,6	20146	17,2	22,2	27,2	152,4	118,1
may	17,94	0,5	967,4	23,84	0,6649	1083	848,7	20234	17,5	22,5	27,5	151,6	118,6
jun	26,19	0,5	961,3	23,65	0,6507	1067	850,2	20106	17	22	27	152,8	117,9
jul	16,93	0,5	936,5	22,88	0,6656	1003	856,1	19588	15	20	25	157,8	114,8
aug	16,93	0,5	936,5	22,88	0,6656	1003	856,1	19588	15	20	25	157,8	114,8
sep	17,61	0,5	957,2	23,52	0,6651	1057	851,1	20020	16,7	21,7	26,7	153,6	117,4
oct	17,61	0,5	957,2	23,52	0,6651	1057	851,1	20020	16,7	21,7	26,7	153,6	117,4
nov	17,61	0,5	957,2	23,52	0,6651	1057	851,1	20020	16,7	21,7	26,7	153,6	117,4
dec	17,61	0,5	957,2	23,52	0,6651	1057	851,1	20020	16,7	21,7	26,7	153,6	117,4
jan	45,31	0,7	680,1	23,42	1,136	1067	850,2	19915	17	24	27	152,8	83,4
feb	45,31	0,7	680,1	23,42	1,136	1067	850,2	19915	17	24	27	152,8	83,4
mar	45,31	0,7	680,1	23,42	1,136	1067	850,2	19915	17	24	27	152,8	83,4
apr	30,74	0,7	681,4	23,49	1,159	1073	849,6	19954	17,2	24,2	27,2	152,4	83,56
may	30,98	0,7	684,4	23,61	1,159	1083	848,7	20040	17,5	24,5	27,5	151,6	83,92
jun	45,31	0,7	680,1	23,42	1,136	1067	850,2	19915	17	24	27	152,8	83,4
jul	29,24	0,7	662,7	22,67	1,16	1003	856,1	19406	15	22	25	157,8	81,27
aug	29,24	0,7	662,7	22,67	1,16	1003	856,1	19406	15	22	25	157,8	81,27
sep	30,4	0,7	677,2	23,3	1,159	1057	851,1	19830	16,7	23,7	26,7	153,6	83,04
oct	30,4	0,7	677,2	23,3	1,159	1057	851,1	19830	16,7	23,7	26,7	153,6	83,04
nov	30,4	0,7	677,2	23,3	1,159	1057	851,1	19830	16,7	23,7	26,7	153,6	83,04
dec	30,4	0,7	677,2	23,3	1,159	1057	851,1	19830	16,7	23,7	26,7	153,6	83,04
jan	88,08	0,9	593,3	23,35	2,216	1067	850,2	19855	17	25	27	152,8	72,76
feb	88,08	0,9	593,3	23,35	2,216	1067	850,2	19855	17	25	27	152,8	72,76
mar	88,08	0,9	593,3	23,35	2,216	1067	850,2	19855	17	25	27	152,8	72,76
apr	59,44	0,9	610	23,43	2,247	1073	849,6	19905	17,2	25	27,2	152,4	74,81
may	60	0,9	637,7	23,57	2,249	1083	848,7	20008	17,5	25	27,5	151,6	78,2
jun	88,08	0,9	593,3	23,35	2,216	1067	850,2	19855	17	25	27	152,8	72,76
jul	56,14	0,9	512,8	22,55	2,24	1003	856,1	19306	15	24	25	157,8	62,88
aug	56,14	0,9	512,8	22,55	2,24	1003	856,1	19306	15	24	25	157,8	62,88
sep	58,6	0,9	569	23,21	2,243	1057	851,1	19756	16,7	25	26,7	153,6	69,78
oct	58,6	0,9	569	23,21	2,243	1057	851,1	19756	16,7	25	26,7	153,6	69,78
nov	58,6	0,9	569	23,21	2,243	1057	851,1	19756	16,7	25	26,7	153,6	69,78
dec	58,6	0,9	569	23,21	2,243	1057	851,1	19756	16,7	25	26,7	153,6	69,78

R11 Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	15,1	0,5	638,1	74,69	0,6566	113,2	178,7	13347	17	22	27	47,85	78,25
feb	15,1	0,5	638,1	74,69	0,6566	113,2	178,7	13347	17	22	27	47,85	78,25
mar	15,1	0,5	638,1	74,69	0,6566	113,2	178,7	13347	17	22	27	47,85	78,25
apr	15,13	0,5	639,5	74,85	0,6566	114	178,7	13376	17,2	22,2	27,2	47,75	78,42
may	10,55	0,5	640,8	75,09	0,6682	115,1	178,5	13404	17,5	22,5	27,5	47,6	78,58
jun	15,1	0,5	638,1	74,69	0,6566	113,2	178,7	13347	17	22	27	47,85	78,25
jul	14,77	0,5	627,2	73,12	0,6568	105,6	179,4	13118	15	20	25	48,86	76,91
aug	14,77	0,5	627,2	73,12	0,6568	105,6	179,4	13118	15	20	25	48,86	76,91
sep	10,44	0,5	636,5	74,45	0,6683	112	178,8	13312	16,7	21,7	26,7	48	78,05
oct	10,44	0,5	636,5	74,45	0,6683	112	178,8	13312	16,7	21,7	26,7	48	78,05
nov	10,44	0,5	636,5	74,45	0,6683	112	178,8	13312	16,7	21,7	26,7	48	78,05
dec	10,44	0,5	636,5	74,45	0,6683	112	178,8	13312	16,7	21,7	26,7	48	78,05
jan	26,18	0,7	452,9	74,22	1,146	113,2	178,7	13262	17	24	27	47,85	55,54
feb	26,18	0,7	452,9	74,22	1,146	113,2	178,7	13262	17	24	27	47,85	55,54
mar	26,18	0,7	452,9	74,22	1,146	113,2	178,7	13262	17	24	27	47,85	55,54
apr	26,24	0,7	453,9	74,37	1,146	114	178,7	13291	17,2	24,2	27,2	47,75	55,66
may	18,27	0,7	454,8	74,61	1,164	115,1	178,5	13318	17,5	24,5	27,5	47,6	55,77
jun	26,18	0,7	452,9	74,22	1,146	113,2	178,7	13262	17	24	27	47,85	55,54
jul	25,61	0,7	445,2	72,66	1,146	105,6	179,4	13036	15	22	25	48,86	54,59
aug	25,61	0,7	445,2	72,66	1,146	105,6	179,4	13036	15	22	25	48,86	54,59
sep	18,08	0,7	451,7	73,98	1,164	112	178,8	13228	16,7	23,7	26,7	48	55,39
oct	18,08	0,7	451,7	73,98	1,164	112	178,8	13228	16,7	23,7	26,7	48	55,39
nov	18,08	0,7	451,7	73,98	1,164	112	178,8	13228	16,7	23,7	26,7	48	55,39
dec	18,08	0,7	451,7	73,98	1,164	112	178,8	13228	16,7	23,7	26,7	48	55,39
jan	50,8	0,9	395,5	74,07	2,228	113,2	178,7	13236	17	25	27	47,85	48,5
feb	50,8	0,9	395,5	74,07	2,228	113,2	178,7	13236	17	25	27	47,85	48,5
mar	50,8	0,9	395,5	74,07	2,228	113,2	178,7	13236	17	25	27	47,85	48,5
apr	50,98	0,9	406,7	74,25	2,23	114	178,7	13269	17,2	25	27,2	47,75	49,87
may	35,35	0,9	424	74,53	2,255	115,1	178,5	13304	17,5	25	27,5	47,6	52
jun	50,8	0,9	395,5	74,07	2,228	113,2	178,7	13236	17	25	27	47,85	48,5
jul	49,41	0,9	345,1	72,41	2,219	105,6	179,4	12991	15	24	25	48,86	42,31
aug	49,41	0,9	345,1	72,41	2,219	105,6	179,4	12991	15	24	25	48,86	42,31
sep	34,85	0,9	380	73,8	2,25	112	178,8	13195	16,7	25	26,7	48	46,6
oct	34,85	0,9	380	73,8	2,25	112	178,8	13195	16,7	25	26,7	48	46,6
nov	34,85	0,9	380	73,8	2,25	112	178,8	13195	16,7	25	26,7	48	46,6
dec	34,85	0,9	380	73,8	2,25	112	178,8	13195	16,7	25	26,7	48	46,6

Cis-butene Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	15,75	0,5	809,1	42,48	0,6634	227,5	398,4	16923	17	22	27	84,63	99,22
feb	15,75	0,5	809,1	42,48	0,6634	227,5	398,4	16923	17	22	27	84,63	99,22
mar	15,75	0,5	809,1	42,48	0,6634	227,5	398,4	16923	17	22	27	84,63	99,22
apr	22,16	0,5	810,9	42,59	0,6506	229	398,2	16960	17,2	22,2	27,2	84,41	99,43
may	22,26	0,5	813,5	42,76	0,6505	231,2	397,9	17015	17,5	22,5	27,5	84,08	99,76
jun	15,75	0,5	809,1	42,48	0,6634	227,5	398,4	16923	17	22	27	84,63	99,22
jul	15,24	0,5	792,3	41,41	0,6638	213,5	400,2	16571	15	20	25	86,77	97,15
aug	15,24	0,5	792,3	41,41	0,6638	213,5	400,2	16571	15	20	25	86,77	97,15
sep	21,99	0,5	806,6	42,3	0,6507	225,4	398,8	16871	16,7	21,7	26,7	84,97	98,91
oct	21,99	0,5	806,6	42,3	0,6507	225,4	398,8	16871	16,7	21,7	26,7	84,97	98,91
nov	21,99	0,5	806,6	42,3	0,6507	225,4	398,8	16871	16,7	21,7	26,7	84,97	98,91
dec	21,99	0,5	806,6	42,3	0,6507	225,4	398,8	16871	16,7	21,7	26,7	84,97	98,91
jan	27,24	0,7	573,3	42,14	1,157	227,5	398,4	16787	17	24	27	84,63	70,3
feb	27,24	0,7	573,3	42,14	1,157	227,5	398,4	16787	17	24	27	84,63	70,3
mar	27,24	0,7	573,3	42,14	1,157	227,5	398,4	16787	17	24	27	84,63	70,3
apr	38,39	0,7	574,5	42,25	1,136	229	398,2	16823	17,2	24,2	27,2	84,41	70,45
may	38,56	0,7	576,4	42,42	1,136	231,2	397,9	16878	17,5	24,5	27,5	84,08	70,68
jun	27,24	0,7	573,3	42,14	1,157	227,5	398,4	16787	17	24	27	84,63	70,3
jul	26,36	0,7	561,5	41,08	1,157	213,5	400,2	16440	15	22	25	86,77	68,85
aug	26,36	0,7	561,5	41,08	1,157	213,5	400,2	16440	15	22	25	86,77	68,85
sep	38,1	0,7	571,5	41,97	1,136	225,4	398,8	16736	16,7	23,7	26,7	84,97	70,09
oct	38,1	0,7	571,5	41,97	1,136	225,4	398,8	16736	16,7	23,7	26,7	84,97	70,09
nov	38,1	0,7	571,5	41,97	1,136	225,4	398,8	16736	16,7	23,7	26,7	84,97	70,09
dec	38,1	0,7	571,5	41,97	1,136	225,4	398,8	16736	16,7	23,7	26,7	84,97	70,09
jan	52,66	0,9	500,4	42,03	2,242	227,5	398,4	16745	17	25	27	84,63	61,36
feb	52,66	0,9	500,4	42,03	2,242	227,5	398,4	16745	17	25	27	84,63	61,36
mar	52,66	0,9	500,4	42,03	2,242	227,5	398,4	16745	17	25	27	84,63	61,36
apr	74,78	0,9	514,5	42,16	2,218	229	398,2	16788	17,2	25	27,2	84,41	63,09
may	75,29	0,9	537,2	42,36	2,221	231,2	397,9	16855	17,5	25	27,5	84,08	65,88
jun	52,66	0,9	500,4	42,03	2,242	227,5	398,4	16745	17	25	27	84,63	61,36
jul	50,69	0,9	434,8	40,9	2,235	213,5	400,2	16369	15	24	25	86,77	53,32
aug	50,69	0,9	434,8	40,9	2,235	213,5	400,2	16369	15	24	25	86,77	53,32
sep	73,95	0,9	480,5	41,83	2,213	225,4	398,8	16683	16,7	25	26,7	84,97	58,92
oct	73,95	0,9	480,5	41,83	2,213	225,4	398,8	16683	16,7	25	26,7	84,97	58,92
nov	73,95	0,9	480,5	41,83	2,213	225,4	398,8	16683	16,7	25	26,7	84,97	58,92
dec	73,95	0,9	480,5	41,83	2,213	225,4	398,8	16683	16,7	25	26,7	84,97	58,92

Sulfurdioxide Condenser

month	A	ε	mc	mv	NTU	P1	qc	qdot	tci	tco	te	wm	wp
jan	11,41	0,5	785,7	60,55	0,6712	419	271,4	16434	17	22	27	59,32	96,35
feb	11,41	0,5	785,7	60,55	0,6712	419	271,4	16434	17	22	27	59,32	96,35
mar	11,41	0,5	785,7	60,55	0,6712	419	271,4	16434	17	22	27	59,32	96,35
apr	11,46	0,5	787,3	60,72	0,6712	421,8	271,2	16467	17,2	22,2	27,2	59,16	96,55
may	19,79	0,5	789,9	60,96	0,6543	426	271	16521	17,5	22,5	27,5	58,93	96,86
jun	11,41	0,5	785,7	60,55	0,6712	419	271,4	16434	17	22	27	59,32	96,35
jul	19,11	0,5	769,1	58,97	0,6547	392,2	272,8	16087	15	20	25	60,88	94,31
aug	19,11	0,5	769,1	58,97	0,6547	392,2	272,8	16087	15	20	25	60,88	94,31
sep	11,35	0,5	783,2	60,31	0,6713	414,9	271,6	16381	16,7	21,7	26,7	59,55	96,04
oct	11,35	0,5	783,2	60,31	0,6713	414,9	271,6	16381	16,7	21,7	26,7	59,55	96,04
nov	11,35	0,5	783,2	60,31	0,6713	414,9	271,6	16381	16,7	21,7	26,7	59,55	96,04
dec	11,35	0,5	783,2	60,31	0,6713	414,9	271,6	16381	16,7	21,7	26,7	59,55	96,04
jan	19,73	0,7	556,9	60,08	1,169	419	271,4	16306	17	24	27	59,32	68,29
feb	19,73	0,7	556,9	60,08	1,169	419	271,4	16306	17	24	27	59,32	68,29
mar	19,73	0,7	556,9	60,08	1,169	419	271,4	16306	17	24	27	59,32	68,29
apr	19,8	0,7	558	60,25	1,169	421,8	271,2	16339	17,2	24,2	27,2	59,16	68,42
may	34,28	0,7	559,8	60,48	1,142	426	271	16391	17,5	24,5	27,5	58,93	68,64
jun	19,73	0,7	556,9	60,08	1,169	419	271,4	16306	17	24	27	59,32	68,29
jul	33,1	0,7	545,2	58,52	1,143	392,2	272,8	15964	15	22	25	60,88	66,85
aug	33,1	0,7	545,2	58,52	1,143	392,2	272,8	15964	15	22	25	60,88	66,85
sep	19,62	0,7	555,1	59,84	1,169	414,9	271,6	16254	16,7	23,7	26,7	59,55	68,07
oct	19,62	0,7	555,1	59,84	1,169	414,9	271,6	16254	16,7	23,7	26,7	59,55	68,07
nov	19,62	0,7	555,1	59,84	1,169	414,9	271,6	16254	16,7	23,7	26,7	59,55	68,07
dec	19,62	0,7	555,1	59,84	1,169	414,9	271,6	16254	16,7	23,7	26,7	59,55	68,07
jan	38	0,9	486,1	59,93	2,258	419	271,4	16266	17	25	27	59,32	59,6
feb	38	0,9	486,1	59,93	2,258	419	271,4	16266	17	25	27	59,32	59,6
mar	38	0,9	486,1	59,93	2,258	419	271,4	16266	17	25	27	59,32	59,6
apr	38,18	0,9	499,7	60,12	2,259	421,8	271,2	16306	17,2	25	27,2	59,16	61,28
may	66,79	0,9	521,8	60,41	2,228	426	271	16370	17,5	25	27,5	58,93	63,98
jun	38	0,9	486,1	59,93	2,258	419	271,4	16266	17	25	27	59,32	59,6
jul	63,85	0,9	422,2	58,27	2,214	392,2	272,8	15896	15	24	25	60,88	51,78
aug	63,85	0,9	422,2	58,27	2,214	392,2	272,8	15896	15	24	25	60,88	51,78
sep	37,76	0,9	466,7	59,66	2,256	414,9	271,6	16204	16,7	25	26,7	59,55	57,23
oct	37,76	0,9	466,7	59,66	2,256	414,9	271,6	16204	16,7	25	26,7	59,55	57,23
nov	37,76	0,9	466,7	59,66	2,256	414,9	271,6	16204	16,7	25	26,7	59,55	57,23
dec	37,76	0,9	466,7	59,66	2,256	414,9	271,6	16204	16,7	25	26,7	59,55	57,23

7.8 Cost Analysis

With equations and estimations explaint in chapter 5, we analyze the costs of different parts. After that, we obtain the values of NPV and IRR in order to establish the best option and its viability:

	depth (m)	T_{src} (ºC)	A_b (m^2)	P_{max} (kPa)	C_B($)	F	C_{HX}($)	Drilling Cost($)	n_w
R22	1000	100	425	4111	83738,87	3,85	322394,65	306556,60	5
propane	1000	100	460	3472	88192,66	3,85	339541,74	306556,60	5
hydrogensulfide	1000	100	500	7507	93255,62	3,97	370224,81	306556,60	5
butene	3000	150	690	3237	117065,40	3,85	450701,79	448729,40	2
R142b	3000	150	230	3225	58205,85	3,85	224092,52	448729,40	2
ammonia	3000	150	145	9045	46311,99	3,99	184784,84	448729,40	2
R11	6000	220	140	3417	45585,22	3,85	175503,09	688562,60	1
cis-butene	6000	220	90	3375	38069,57	3,09	117634,97	688562,60	1
sulfurdioxide	6000	220	55	6228	32461,44	3,15	102253,54	688562,60	1
CONDENSER									

	T_{mx} (ºC)	A_c (m^2)	P_{max} (kPa)	C_B($)	F	C_{HX}($)	C_T($)	C_{Pe}($)	C_{Pwf}($)
R22	27	65	1150	34097,11	2,14	72967,82	918397,29	12769,14	91839,73
propane	27	70	1020	34905,02	1,91	66668,59	918397,29	13161,53	91839,73
hydrogensulfide	27	50	2150	31634,83	2,48	78454,38	918397,29	11652,79	91839,73
butene	27	30	325	28329,67	1,51	42777,80	918397,29	7387,69	91839,73
R142b	27	30	365	28329,67	1,51	42777,80	918397,29	7612,31	91839,73
ammonia	27	30	1085	28329,67	1,69	47877,14	918397,29	7687,20	91839,73
R11	27	20	120	26837,36	1,51	40524,41	918397,29	4982,31	91839,73
cis-butene	27	25	235	27547,47	1,51	41596,68	918397,29	6406,78	91839,73
sulfurdioxide	27	20	430	26837,36	1,51	40524,41	918397,29	6210,45	91839,73

R22	2951151,63
propane	2962391,88
hydrogensulfide	2408563,10
butene	2182178,45
R142b	1919809,43
ammonia	1864438,05
R11	1847788,02
cis-butene	3003352,00
sulfurdioxide	2148045,00

Average Cost kWh in Indonesia: 1352 Rp= 0,101361 $
Cost per year: 0,101361 $/kWh * 6198 kWh/day * 365 days/year = 229305,95 $/year

$$\mathrm{NPV}(i,N) = \sum_{1}^{N} \frac{Rt}{(1+i)^t} - I_0$$

10 years	i=5%
15 years	i=9%
20 years	i=11%
25 years	i=12%

8 DALMATOVSKOYE MINE

На то и ум, чтобы достичь того, чего хочешь.

Ф. Достоевский

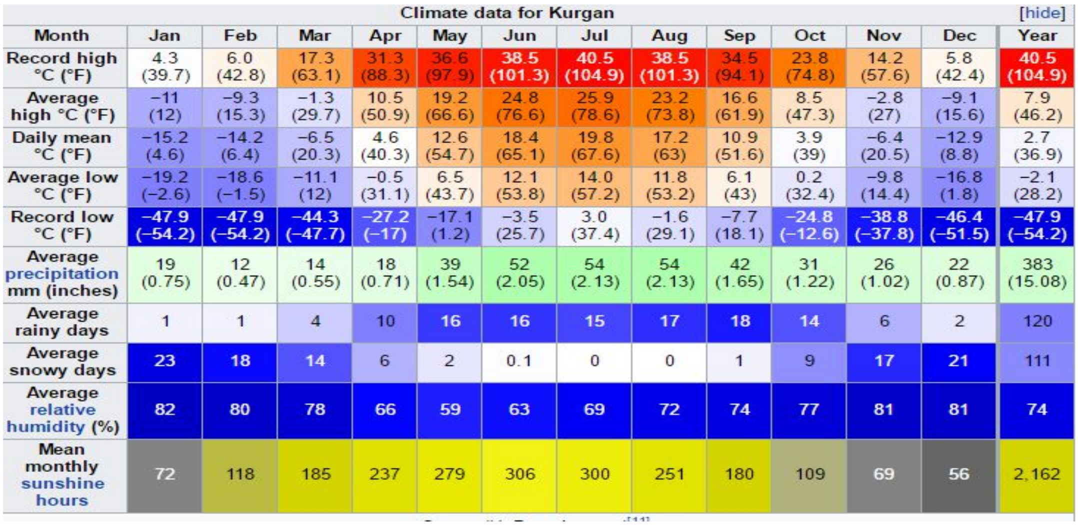
The **Dalmatovkoye mine** is a large open pit mine located in the southern part of Russia in Kurgan Oblast. Dalmatovkoye represents one of the largest uranium reserves in Russia having estimated reserves of 25.5 million tons of ore grading 0.04% uranium.

Kurgan Oblast is located in Southern Russia and is part of the Urals Federal District. It shares borders with Chelyabinsk Oblast to the west, Sverdlovsk Oblast to the north-west, Tyumen Oblast to the north-east, and Kazakhstan to the south.

Figure 8.1 Kurganskij Oblast location in Russia

The oblast of Kurgan has a severe continental climate with long cold winters and warm summers with regular droughts. The average January temperature is −18 °C, and the average temperature in the warmest month (July) is +19 °C. Annual precipitation is about 400 mm.

Dates about Kurgan temperature will be shown below:



Climate data for Kurgan [hide]

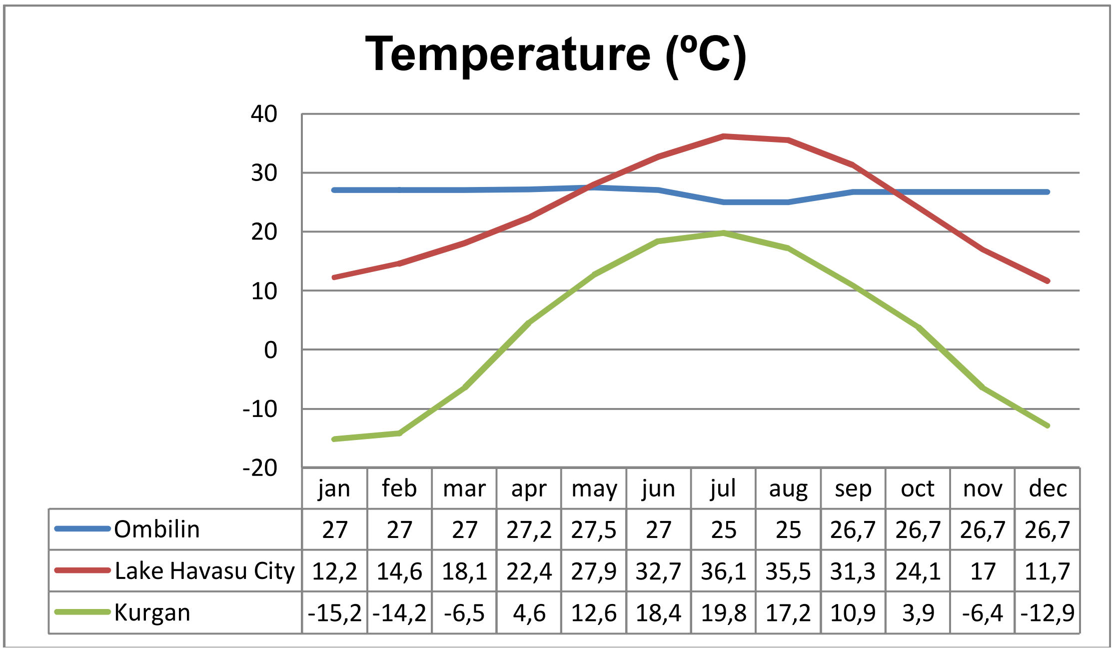
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	4.3 (39.7)	6.0 (42.8)	17.3 (63.1)	31.3 (88.3)	36.6 (97.9)	38.5 (101.3)	40.5 (104.9)	38.5 (101.3)	34.5 (94.1)	23.8 (74.8)	14.2 (57.6)	5.8 (42.4)	40.5 (104.9)
Average high °C (°F)	−11 (12)	−9.3 (15.3)	−1.3 (29.7)	10.5 (50.9)	19.2 (66.6)	24.8 (76.6)	25.9 (78.6)	23.2 (73.8)	16.6 (61.9)	8.5 (47.3)	−2.8 (27)	−9.1 (15.6)	7.9 (46.2)
Daily mean °C (°F)	−15.2 (4.6)	−14.2 (6.4)	−6.5 (20.3)	4.6 (40.3)	12.6 (54.7)	18.4 (65.1)	19.8 (67.6)	17.2 (63)	10.9 (51.6)	3.9 (39)	−6.4 (20.5)	−12.9 (8.8)	2.7 (36.9)
Average low °C (°F)	−19.2 (−2.6)	−18.6 (−1.5)	−11.1 (12)	−0.5 (31.1)	6.5 (43.7)	12.1 (53.8)	14.0 (57.2)	11.8 (53.2)	6.1 (43)	0.2 (32.4)	−9.8 (14.4)	−16.8 (1.8)	−2.1 (28.2)
Record low °C (°F)	−47.9 (−54.2)	−47.9 (−54.2)	−44.3 (−47.7)	−27.2 (−17)	−17.1 (1.2)	−3.5 (25.7)	3.0 (37.4)	−1.6 (29.1)	−7.7 (18.1)	−24.8 (−12.6)	−38.8 (−37.8)	−46.4 (−51.5)	−47.9 (−54.2)
Average precipitation mm (inches)	19 (0.75)	12 (0.47)	14 (0.55)	18 (0.71)	39 (1.54)	52 (2.05)	54 (2.13)	54 (2.13)	42 (1.65)	31 (1.22)	26 (1.02)	22 (0.87)	383 (15.08)
Average rainy days	1	1	4	10	16	16	15	17	18	14	6	2	120
Average snowy days	23	18	14	6	2	0.1	0	0	1	9	17	21	111
Average relative humidity (%)	82	80	78	66	59	63	69	72	74	77	81	81	74
Mean monthly sunshine hours	72	118	185	237	279	306	300	251	180	109	69	56	2,162

Table 8.1 Climate data for Kurgan

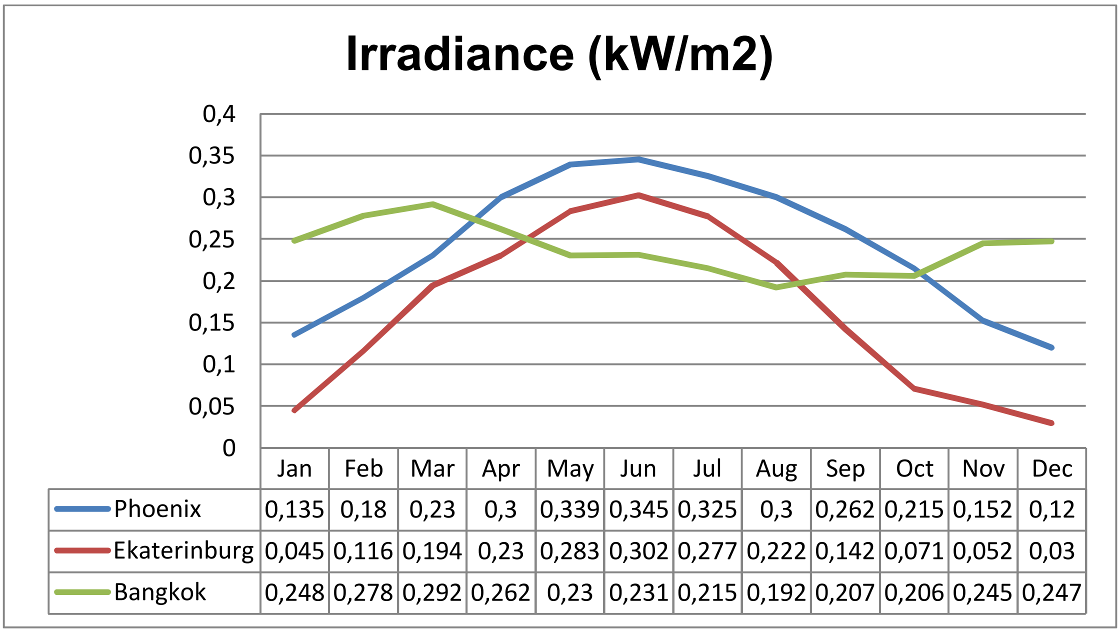
Radiation daily values per month are shown below:

Table 8.2 Average Daily Solar Global Radiation

	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
kWh/m^2	0,82	1,71	3,32	4,43	5,34	5,99	5,61	4,34	2,89	1,44	0,80	0,47



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Ombilin	27	27	27	27,2	27,5	27	25	25	26,7	26,7	26,7	26,7
Lake Havasu City	12,2	14,6	18,1	22,4	27,9	32,7	36,1	35,5	31,3	24,1	17	11,7
Kurgan	-15,2	-14,2	-6,5	4,6	12,6	18,4	19,8	17,2	10,9	3,9	-6,4	-12,9



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phoenix	0,135	0,18	0,23	0,3	0,339	0,345	0,325	0,3	0,262	0,215	0,152	0,12
Ekaterinburg	0,045	0,116	0,194	0,23	0,283	0,302	0,277	0,222	0,142	0,071	0,052	0,03
Bangkok	0,248	0,278	0,292	0,262	0,23	0,231	0,215	0,192	0,207	0,206	0,245	0,247

In Russia, almost half of energy use goes toward heating. Direct use of geothermal can offer significant resource to provide this energy, potentially up to 30% (IGA, 2005), and this has been the predominant use of geothermal energy in Russia. Direct utilization of thermal water with temperature 30–100 °C for heating and hot water supply of buildings takes place mainly at the Northern Caucasia and at Far East (peninsula Kamchatka, Kuriles). Locally the thermal water is also used in the separate settlements of Western Siberia, near Lake Baikal, in Magadan and Chukot regions and at Sakhalin. Even within Lake Baikal, geothermal heat has been noticed to be breaking through thick ice in two specific locations, despite the depth of the lake.The Northern Caucasus has well studied geothermal resources with temperatures ranging from 70 to 180°C °C at depths of 300 to 5000 m. Local geothermal waters are used for heat and hot water supply for a long time already.

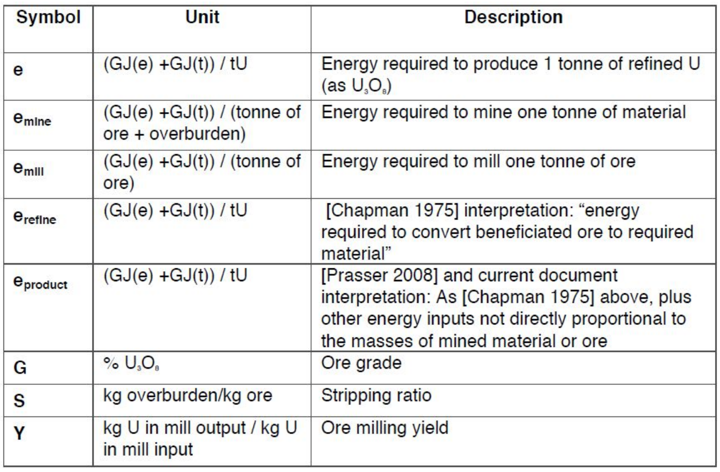
Figure 8.2 Russian Geothermal Resources Map

8.1 Energy Consumption in the Mining and Milling of Uranium

The first attempt to create a generalized model of energy use in uranium mining was by Peter Chapman. Chapman's primary study was done "to investigate the effect of the grade of uranium ore on the viability of thermal reactor systems. . .by an analysis of the energy to produce copper which showed that the energy required was inversely proportional to the grade of ore" [Chapman 1975]. Chapman was the first to notice the trend that decreasing ore grade has on energy consumption and exemplified this with theoretical energy numbers from copper mining, milling, and refining [Chapman 1974]. Chapman's formulation of the energy required to produce a ton of refined product incorporated contributions from the mining, milling and product refining steps.

Since Earth's known resources are being slowly exhausted, Chapman wanted to answer at what point mining uranium would take more energy than the uranium ore would produce in a nuclear reactor. Chapman used real and hypothetical data to model energy consumption at the mine and mill. By including a 1/G term for the grade of the ore, Chapman depicts the relationship between grade and energy use as being inversely proportional.

In order to quantitatively describe the reviewed models, it is necessary to identify all terms that will be used



Symbol	Unit	Description
e	(GJ(e) +GJ(t)) / tU	Energy required to produce 1 tonne of refined U (as U_3O_8)
e_{mine}	(GJ(e) +GJ(t)) / (tonne of ore + overburden)	Energy required to mine one tonne of material
e_{mill}	(GJ(e) +GJ(t)) / (tonne of ore)	Energy required to mill one tonne of ore
e_{refine}	(GJ(e) +GJ(t)) / tU	[Chapman 1975] interpretation: "energy required to convert beneficiated ore to required material"
$e_{product}$	(GJ(e) +GJ(t)) / tU	[Prasser 2008] and current document interpretation: As [Chapman 1975] above, plus other energy inputs not directly proportional to the masses of mined material or ore
G	% U_3O_8	Ore grade
S	kg overburden/kg ore	Stripping ratio
Y	kg U in mill output / kg U in mill input	Ore milling yield

Table 8.3 Chapman's Model Symbol

Chapman's 1975 model was the following:

$$e = \frac{100}{0.848G}\left(e_{mill} + (1+S)e_{mine}\right) + e_{refine}$$

Where e_{mill} is the mass flow proportional to the amount of ore, the quantity $(1+S)e_{mine}/G$ is the energy required to extract the necessary ore plus overburden in order to extract one ton of mill-able uranium from the mine. The factor 0,848 converts a ton U_3O_8 to a ton of U. Chapman also included a term e_{refine}, representing the energy needed to produce and purify yellowcake from milling product containing 1 ton of uranium, but he did not estimate its value nor did he include it in his final formulation of the energy intensity of uranium production.

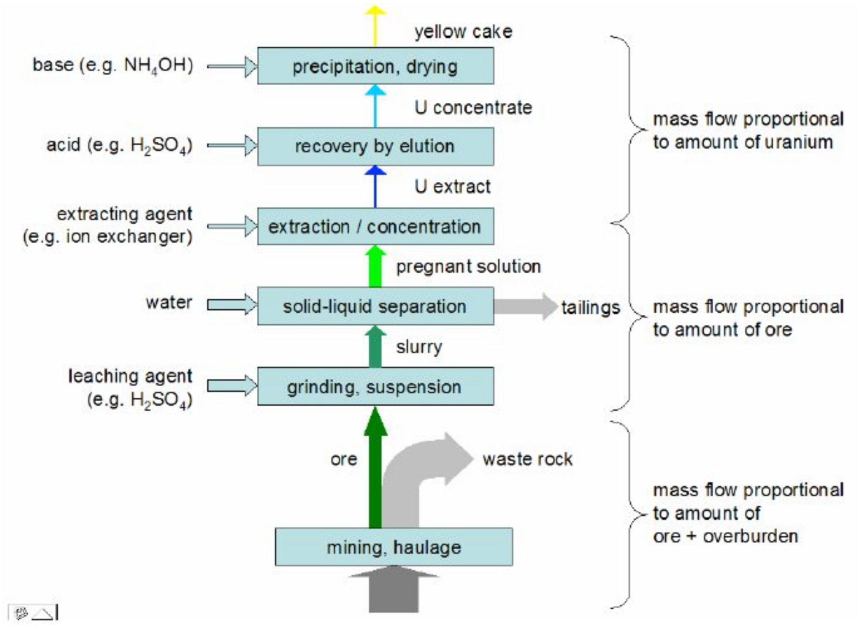


Figure 8.3: Mass flows in uranium mining and milling, Source: [Prasser 2008]

Due to the limiting factor of mine data availability, a problem still seen today, Chapman could only assemble two data points in order to define his energy coefficients. The data that he used from [Everett 1963] included four mines operating in Wyoming in the early 1960s with an average ore grade of .31% and stripping ratio of 24. Chapman weighted the mines proportional to their estimated reserves to acquire 1210 MJ(t) per ton of ore for mining and 99 MJ(e) + 828 MJ(t) per ton of ore for milling.

Often energy data is separated into thermal and electric carriers. At open pit mines, it is common for diesel fuel (thermal units) to run the equipment on site, whereas at the milling and refining facilities most of the energy comes from electricity (electric units). Chapman aggregated the thermal and electrical energy consumed when deriving his model coefficients. Reports to follow, as well as the body of this report, follow this method. At the mine, energy carriers may change over time (as technology for electric driven shovels etc advances), and thermal-to electric conversion efficiencies are difficult to identify, so common practice is to use aggregated energy when expressing consumption.

The second data point that Chapman used was for mining and milling of Chattanooga shale at .007% ore grade using underground mines [Bieniewski 1971]. The stripping ratio is assumed zero because for this hypothetical situation the ore body was considered the entire shale formation (no overburden).

Although energy use for both data sets comes primarily from direct energy use from fuel and electricity, embodied energies, or energy from the consumption of chemicals, machinery, and machine parts, were also considered in Chapman's analysis [Chapman, 1975]. In practice embodied energy only constitutes about 10-20% of energy, or 1-4% of total energy costs [Chapman 1974]. Analysis similar to what Chapman did for the US mines was again done for the Chattanooga shale mine to acquire energy inputs for mining and milling the ore compiled in the 8.4 table.

	GJ(e)/t U	GJ(t)/t U
Mining, S=0	32.7	36
Milling	77.5	21.95

Chapman claims that although production technique and technology will vary by metal, technology is similar enough to be considered equal. Chapman states, "the energy of mining depends upon a large number of factors: mining method, rock hardness, equipment used, scale of operation, distance from mine to mill, and so on. However many studies have shown there are typical values for energy, one for open pit and one for underground." Using theoretical minimum values from [Kellogg] and [Batelle] for the three energies, Chapman surmised:

For open pit metal mining: E= 400 MJ/ton produced

For underground metal mining: E= 1000 MJ/ton produced

Also in the past decade, companies have begun to release sustainability reports for each of their mines. These reports often give energy use, sometimes by carrier, but more usually aggregated as one number. Table 8.5 shows data from a mine-specific company sustainability report. In this case, both energy use and mass throughputs were given for this gold producing mine.

Table 8.5 mine-specific company sustainability report data

	2004	2005
Ore mined (tons)	2.766.033	3.043.595
total material moved (tons)	17.049.525	14.400.476
Ore crushed (tons)	2.753.876	3.006.390
Average gold grade (g/t)	0,96	1,03
Gold produced (ounces)	76.186	62.471
Employees	113	100
Mine life	March-07	March-07
Energy Use		
Electricity (MWh)	18.467	17.247
Diesel Fuel (kl)	7.052	5.869

The table below shows the coefficients obtained for open pit (OP) and underground (UG) mining from regressing the uranium mine data from Appendix A, for the 28 OP and 7 UG data points, onto equations 3.1 and 3.2 using the statistical analysis toolkit in Microsoft Excel. The R-squared value for the fit was 0.904. The statistical quality associated with this fit is acceptable, with the exception of the coefficient for mining e_{mine} where the t-statistic is low. This is where the regression falls short due to lack of data from mines operating at high stripping ratios.

Table 8.6 Energy intensity coefficients obtained from regression analysis

Coefficient	Applies to	Value	Standard Error [GJ(t+e)/t]	T Statistic
$e_{product}$	OP, UG	178[GJ(t+e)/t U]	12,2	14,6
e_{mill}	OP	0,0236[GJ(t+e)/(t ore)]	0,0053	4,44
e_{mine}	OP	0,0125[GJ(t+e)/t(ore + ob)]	0,0119	1,04
e_{mine}	UG	0,291[GJ(t+e)/(tore)]	0,0340	8,55

Finally, for a daily production of 1000 tons of ore, and considering the similarities between different metal mining demand of energy, the next values of energy demand (both electric and fuel) are going to be selected for our case of study:

Energy Use

Electricity (kWh/day)	5.667
Diesel Fuel (L/day)	1.929
Power (kW)	3.196,2

8.2 Fluid Selection

The choice of the optimal working fluid depends basically on the heat source and the heat sink temperature. For any heat temperature level there are a number of candidates which show a good match between heat source and heat sink temperatures and cycles boundary conditions. The choice the right working fluid is not an easy process. The fluid selection process is a trade-off between thermodynamic specifications, safety, environmental and economy aspects.

Simulation assumptions

Following are the assumption for this scenario

- The cycle is considered to work at steady state
- Pressure drop in heat exchangers is neglected
- Isentropic efficiency for pump and expander is assumed to be 0.8
- Min Ambient temperature T_{Min} = -16 ºC
- Max Ambient temperature T_{Max} = 20 ºC
- Heat sinks temperature T_{Sink} = T_{Amb} ºC
- The Evaporating temperature is depending on the thermodynamical properties of every fluid. It will be considered the value of T_{Crit} -10 ºC
- Heat source temperature dependant on the source depth. T_{1km} = 100 ºC, T_{1km} = 150 ºC

The evaporation temperatures are too high in this scenario and much higher than the critical temperature for many working fluids. For this reason, many working fluid with low critical temperature can´t be used in this scenario.

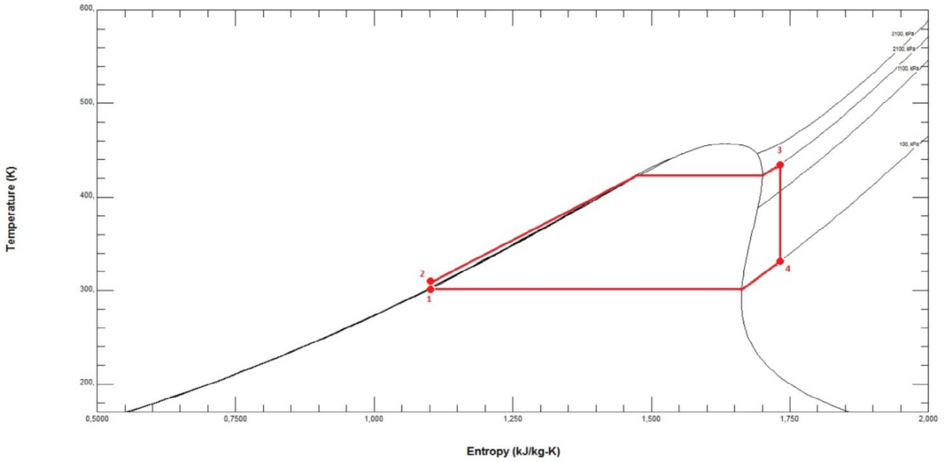
Due to the extremely low environment temperatures, many fluids were not studied because of their high Normal Boiling Point.

FLUID	**T_{NBP}**	**T_{crit}**	**P_{crit}**	**efficiency$_{min}$**	**T_{efmin}**	**efficiency$_{max}$**	**T_{efmax}**
R134a	-26,15	100,85	4059	0,1127	20	0,1594	-20
R1234yf	-29,65	94,55	3380	0,1031	20	0,1530	-20
R12	-29,95	111,85	4140	0,1256	20	0,1718	-20
Ammonia	-33,45	132,1	11333	0,1563	20	0,2021	-20
R161	-37,75	102,05	5090	0,1165	20	0,1640	-20
R22	-40,95	95,95	4990	0,1090	20	0,1575	-20
Propane	-42,15	96,55	4247	0,1070	20	0,1550	-20
Propylene	-47,75	90,95	4560	0,1011	20	0,1498	-20
Carbonylsulfide	-50,31	105,47	6370	0,1222	20	0,1706	-20
Hydrogensulfide	-60,45	99,8	9000	0,1166	20	0,1657	-20

With these results obtained from the described operations in an Organic Rankine Cycle (ORC), 4 working fluids were selected for a better analysis, according to environment conditions:

8.3 Organic Rankine Cycle (ORC)

The Organic Rankine Cycle has the same working principles and main components (evaporator, condenser, expander and pump) as the Steam Rankine Cycle. At the same time, there are some major differences between the two cycles. The differences are mainly related to the used working fluid in the cycle, the working fluid's thermo-physical properties, the heat source temperature and the cycle architecture. Organic Rankine Cycle can extract energy and generate power from much lower heat source temperature than traditional Rankine cycle.



From the analisys of different fluids values such as temperatures (ºC), pressures (kPa), mass heat and work exchanges (kW/kg) and process efficiency are obtained for the next step moduling heat exchangers and condensers.

T_{source}=100 ºC

R22

month	efficiency	P1	P2	qb	qc	T1	T2	T3	te	V4	wnet
jan	0,1497	419,1	3954	217,6	175,3	-5,2	-3,615	85,95	-15,2	0,04677	32,57
feb	0,148	433,5	3960	216,2	174,7	-4,2	-2,6	85,95	-14,2	0,04527	32,01
mar	0,1356	557,4	3960	207,2	170,6	3,5	5,191	85,95	-6,5	0,03575	28,08
apr	0,1175	780,5	3960	193,9	164	14,6	16,42	85,95	4,6	0,02594	22,79
may	0,1048	978,3	4092	178,3	153,4	22,6	24,58	85,95	12,6	0,02017	18,69
jun	0,09552	1143	4092	171	149,2	28,4	30,44	85,95	18,4	0,01728	16,34
jul	0,09327	1186	4092	169,3	148,1	29,8	31,86	85,95	19,8	0,01666	15,79
aug	0,09745	1108	4092	172,5	150,1	27,2	29,23	85,95	17,2	0,01784	16,81
sep	0,1076	933,4	4092	180,4	154,6	20,9	22,86	85,95	10,9	0,02113	19,4
oct	0,1188	764,7	4091	188,9	159,4	13,9	15,78	85,95	3,9	0,02566	22,44
nov	0,1354	559,1	4001	205,4	169,1	3,6	5,312	85,95	-6,4	0,03536	27,82
dec	0,1459	452,8	3967	214,4	173,8	-2,9	-1,282	85,95	-12,9	0,04341	31,29

Hydrogensulfide

month	efficiency	P1	P2	qb	qc	T1	T2	T3	te	V4	wnet
jan	0,1578	883,4	7343	442,5	350,9	-5,2	-2,804	89,8	-15,2	0,04967	69,84
feb	0,1562	910,7	7343	440,4	350,2	-4,2	-1,787	89,8	-14,2	0,04832	68,79
mar	0,1435	1142	7343	424,3	344	3,5	6,047	89,8	-6,5	0,03929	60,89
apr	0,1254	1549	7497	392,1	326,5	14,6	17,4	89,8	4,6	0,02907	49,17
may	0,1123	1900	7497	374,7	318,1	22,6	25,53	89,8	12,6	0,02401	42,09
jun	0,1028	2189	7506	361,3	311	28,4	31,41	89,8	18,4	0,02098	37,15
jul	0,1005	2263	7506	358,2	309,3	29,8	32,83	89,8	19,8	0,02033	36,01
aug	0,1048	2127	7506	364	312,4	27,2	30,2	89,8	17,2	0,02156	38,14
sep	0,1151	1821	7506	377,9	319,4	20,9	23,81	89,8	10,9	0,02495	43,49
oct	0,1265	1520	7506	393,1	326,7	13,9	16,69	89,8	3,9	0,02953	49,74
nov	0,1433	1146	7505	415,1	336,4	3,6	6,214	89,8	-6,4	0,03836	59,49
dec	0,1539	947,1	7504	428,8	341,9	-2,9	-0,4039	89,8	-12,9	0,04567	65,99

T_{source}=150 ºC

R12

month	efficiency	P1	P2	qb	qc	T1	T2	T3	te	V4	wnet
jan	0,1644	258,9	3231	184	145	-5,2	-5,2	101,9	-15,2	0,06163	30,25
feb	0,1628	267,9	3235	182,9	144,5	-4,2	-4,2	101,9	-14,2	0,05966	29,79
mar	0,1509	345,4	3270	174,8	140,6	3,5	3,5	101,9	-6,5	0,04675	26,38
apr	0,1339	485,2	3317	162,9	134,4	14,6	14,6	101,9	4,6	0,03352	21,8
may	0,1216	609,6	3350	154,1	129,5	22,6	22,6	101,9	12,6	0,02668	18,75
jun	0,1128	713,5	3373	147,6	125,7	28,4	28,4	101,9	18,4	0,02272	16,65
jul	0,1107	740,4	3378	146,1	124,7	29,8	29,8	101,9	19,8	0,02187	16,17
aug	0,1146	691	3368	149	126,5	27,2	27,2	101,9	17,2	0,02348	17,08
sep	0,1242	581,4	3343	156	130,6	20,9	20,9	101,9	10,9	0,02799	19,38
oct	0,1349	475,4	3315	163,6	134,8	13,9	13,9	101,9	3,9	0,03421	22,08
nov	0,1508	346,5	3270	174,7	140,6	3,6	3,6	101,9	-6,4	0,04661	26,34
dec	0,1608	280	3241	181,6	143,9	-2,9	-2,9	101,9	-12,9	0,0572	29,2

Ammonia

month	efficiency	P1	P2	qb	qc	T1	T2	T3	te	V4	wnet
jan	0,1947	352,1	8632	1237	929	-5,2	-3,674	122,1	-15,2	0,2537	241
feb	0,1932	366,1	8646	1232	927,1	-4,2	-2,66	122,1	-14,2	0,2447	238
mar	0,1814	488,7	8747	1188	910,9	3,5	5,15	122,1	-6,5	0,1869	215,4
apr	0,1645	719,2	8889	1123	884,4	14,6	16,43	122,1	4,6	0,1299	184,7
may	0,1524	931,4	8987	1075	862,9	22,6	24,58	122,1	12,6	0,1015	163,8
jun	0,1436	1113	9055	1040	846	28,4	30,49	122,1	18,4	0,08548	149,4
jul	0,1415	1160	9055	1034	843,2	29,8	31,91	122,1	19,8	0,08222	146,3
aug	0,1454	1073	9041	1048	849,6	27,2	29,26	122,1	17,2	0,08853	152,4
sep	0,155	882,7	8966	1085	867,6	20,9	22,84	122,1	10,9	0,1068	168,2
oct	0,1656	702,6	8879	1127	886,3	13,9	15,72	122,1	3,9	0,1328	186,6
nov	0,1813	490,5	8749	1187	910,7	3,6	5,252	122,1	-6,4	0,1862	215,1
dec	0,1912	384,9	8663	1224	924,5	-2,9	-1,343	122,1	-12,9	0,2335	234,1

8.4 Heat Exchanger

The next tables show the different behavior of the chosen fluids in contact with the geothermal water source through heat exchangers, calculated according to the ε-NTU system explaint in the 5º chapter. The most important data obtained from this analysis are the different temperature values, mass of working and cooling fluids and the parasit power demand.

The mass ofworking fluid was calculated taking in consideration the maximum power demand of the mine and the mass net work value calculated by the Rankine cycle (W_m)

100 ºC source:

R22

month	A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	123,1	0,8644	67,92	98,13	2,729	3954	11395	-3,615	85,95	100	60	32,57
feb	125,4	0,8631	68,47	99,85	2,725	3960	11486	-2,6	85,95	100	60	32,01
mar	143,9	0,8518	72,44	113,8	2,697	3960	12153	5,191	85,95	100	60	28,08
apr	180,4	0,8319	79,12	140,2	2,665	3960	13274	16,42	85,95	100	60	22,79
may	224	0,8137	87,03	171	2,655	4092	14600	24,58	85,95	100	60	18,69
jun	262,1	0,798	91,86	195,6	2,662	4092	15411	30,44	85,95	100	60	16,34
jul	273,1	0,7938	93,11	202,4	2,666	4092	15621	31,86	85,95	100	60	15,79
aug	253,4	0,8015	90,84	190,1	2,659	4092	15240	29,23	85,95	100	60	16,81
sep	214,7	0,8179	85,72	164,8	2,656	4092	14381	22,86	85,95	100	60	19,4
oct	182,5	0,8332	80,73	142,4	2,667	4091	13544	15,78	85,95	100	60	22,44
nov	145,2	0,8516	72,98	114,9	2,697	4001	12243	5,312	85,95	100	60	27,82
dec	128,4	0,8613	69,19	102,1	2,72	3967	11607	-1,282	85,95	100	60	31,29

Hydrogensulfide

month	A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	119,7	0,9008	58,25	45,76	3,2	7343	9772	-2,804	89,8	100	60	69,84
feb	121,8	0,8998	58,62	46,46	3,198	7343	9835	-1,787	89,8	100	60	68,79
mar	139,8	0,8914	61,74	52,49	3,189	7343	10357	6,047	89,8	100	60	60,89
apr	178,8	0,8765	68,1	65	3,194	7497	11425	17,4	89,8	100	60	49,17
may	216,6	0,863	72,58	75,94	3,225	7497	12177	25,53	89,8	100	60	42,09
jun	254,8	0,8513	76,41	86,03	3,272	7506	12819	31,41	89,8	100	60	37,15
jul	265,7	0,8481	77,37	88,76	3,289	7506	12980	32,83	89,8	100	60	36,01
aug	246	0,8539	75,6	83,8	3,26	7506	12683	30,2	89,8	100	60	38,14
sep	207,8	0,8661	71,67	73,49	3,215	7506	12024	23,81	89,8	100	60	43,49
oct	176,2	0,8776	67,82	64,26	3,193	7506	11379	16,69	89,8	100	60	49,74
nov	142,9	0,8912	62,96	53,73	3,188	7505	10562	6,214	89,8	100	60	59,49
dec	127	0,8984	60,27	48,43	3,196	7504	10111	-0,4039	89,8	100	60	65,99

150 ºC source:

R12

month	A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	53,89	0,6901	146,3	105,7	1,394	3231	11676	-5,2	101,9	150	110	30,25
feb	54,59	0,6881	147,5	107,3	1,388	3235	11768	-4,2	101,9	150	110	29,79
mar	60,42	0,6717	156,8	121,2	1,339	3270	12518	3,5	101,9	150	110	26,38
apr	70,74	0,6448	172,6	146,6	1,264	3317	13778	14,6	101,9	150	110	21,8
may	80,01	0,6224	186	170,5	1,205	3350	14848	22,6	101,9	150	110	18,75
jun	88,11	0,6044	197,3	192	1,16	3373	15748	28,4	101,9	150	110	16,65
jul	90,2	0,5998	200,1	197,7	1,148	3378	15971	29,8	101,9	150	110	16,17
aug	86,31	0,6083	194,8	187,1	1,169	3368	15549	27,2	101,9	150	110	17,08
sep	77,89	0,6274	183	164,9	1,218	3343	14608	20,9	101,9	150	110	19,38
oct	70	0,6466	171,5	144,8	1,269	3315	13690	13,9	101,9	150	110	22,08
nov	60,49	0,6714	157	121,3	1,339	3270	12526	3,6	101,9	150	110	26,34
dec	55,51	0,6854	149	109,5	1,38	3241	11889	-2,9	101,9	150	110	29,2

Ammonia

month	A	epsilon	mh	mv	NTU	P2	qdot	tci	tco	thi	tho	wm
jan	48,79	0,8184	105,3	13,26	2,06	8632	8402	-3,674	122,1	150	110	241
feb	49,35	0,8172	105,9	13,43	2,054	8646	8451	-2,66	122,1	150	110	238
mar	54,03	0,8074	111	14,84	2,012	8747	8856	5,15	122,1	150	110	215,4
apr	62,15	0,7911	119,2	17,3	1,947	8889	9512	16,43	122,1	150	110	184,7
may	69,36	0,7775	126	19,51	1,897	8987	10055	24,58	122,1	150	110	163,8
jun	75,46	0,7665	131,4	21,39	1,859	9055	10487	30,49	122,1	150	110	149,4
jul	76,92	0,7637	132,5	21,85	1,85	9055	10578	31,91	122,1	150	110	146,3
aug	74,1	0,7689	130,2	20,97	1,867	9041	10390	29,26	122,1	150	110	152,4
sep	67,7	0,7806	124,4	19	1,908	8966	9932	22,84	122,1	150	110	168,2
oct	61,57	0,7922	118,6	17,13	1,951	8879	9466	15,72	122,1	150	110	186,6
nov	54,1	0,8073	111	14,86	2,012	8749	8862	5,252	122,1	150	110	215,1
dec	50,09	0,8157	106,7	13,65	2,047	8663	8517	-1,343	122,1	150	110	234,1

8.5 Condenser

The next tables show the different behavior of the chosen fluids in contact with condensers of diverse sizes, according to the ε-NTU system explaint in the 5º chapter. The most important data obtained from this analysis are the different temperature values, mass of working and cooling fluids and the parasit power demand.

In this case, the cooling fluid will be the environmental air.

Condenser R22

A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	th	wm	wp
26,04	0,5	3431	98,18	0,6433	419,1	175,3	17210	-15,2	-10,2	-5,2	32,57	1,435
26,54	0,5	3479	99,89	0,643	433,5	174,7	17452	-14,2	-9,2	-4,2	32,01	1,435
30,67	0,5	3872	113,9	0,6409	557,4	170,6	19427	-6,5	-1,5	3,5	28,08	1,435
38,66	0,5	4584	140,3	0,6372	780,5	164	23011	4,6	9,6	14,6	22,79	1,435
47,91	0,5	5227	171,1	0,6318	978,3	153,4	26245	12,6	17,6	22,6	18,69	1,435
40,53	0,5	5814	195,7	0,6477	1143	149,2	29198	18,4	23,4	28,4	16,34	1,435
42,37	0,5	5972	202,5	0,6468	1186	148,1	29992	19,8	24,8	29,8	15,79	1,435
53,92	0,5	5686	190,2	0,6295	1108	150,1	28552	17,2	22,2	27,2	16,81	1,435
32,47	0,5	5076	164,8	0,6517	933,4	154,6	25482	10,9	15,9	20,9	19,4	1,435
39,09	0,5	4525	142,5	0,6357	764,7	159,4	22714	3,9	8,9	13,9	22,44	1,435
20,52	0,5	3874	114,9	0,6592	559,1	169,1	19436	-6,4	-1,4	3,6	27,82	1,435
27,2	0,5	3541	102,2	0,6426	452,8	173,8	17761	-12,9	-7,9	-2,9	31,29	1,435

Condenser Hydrogensulfide

A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	th	wm	wp
21,95	0,5	3203	45,79	0,6485	883,4	350,9	16066	-15,2	-10,2	-5,2	69,84	1,435
13,13	0,5	3245	46,48	0,6676	910,7	350,2	16279	-14,2	-9,2	-4,2	68,79	1,435
15,34	0,5	3600	52,51	0,6662	1142	344	18065	-6,5	-1,5	3,5	60,89	1,435
32,26	0,5	4230	65,03	0,643	1549	326,5	21233	4,6	9,6	14,6	49,17	1,435
24,54	0,5	4813	75,97	0,6606	1900	318,1	24166	12,6	17,6	22,6	42,09	1,435
28,85	0,5	5330	86,07	0,6585	2189	311	26769	18,4	23,4	28,4	37,15	1,435
30,05	0,5	5469	88,8	0,6579	2263	309,3	27465	19,8	24,8	29,8	36,01	1,435
42,99	0,5	5215	83,84	0,6386	2127	312,4	26191	17,2	22,2	27,2	38,14	1,435
23,5	0,5	4678	73,53	0,6611	1821	319,4	23484	10,9	15,9	20,9	43,49	1,435
19,75	0,5	4184	64,29	0,6631	1520	326,7	21003	3,9	8,9	13,9	49,74	1,435
26,09	0,5	3604	53,75	0,6458	1146	336,4	18082	-6,4	-1,4	3,6	59,49	1,435
13,75	0,5	3303	48,46	0,6668	947,1	341,9	16567	-12,9	-7,9	-2,9	65,99	1,435

Condenser R12

A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	th	wm	wp
15,7	0,5	3056	105,7	0,6603	258,9	145	15328	-15,2	-10,2	-5,2	30,25	1,435
16	0,5	3092	107,3	0,66	267,9	144,5	15511	-14,2	-9,2	-4,2	29,79	1,435
25,51	0,5	3397	121,2	0,6438	345,4	140,6	17043	-6,5	-1,5	3,5	26,38	1,435
23,55	0,5	3928	146,7	0,6545	485,2	134,4	19714	4,6	9,6	14,6	21,8	1,435
36,76	0,5	4399	170,5	0,6378	609,6	129,5	22085	12,6	17,6	22,6	18,75	1,435
41,78	0,5	4807	192,1	0,6353	713,5	125,7	24141	18,4	23,4	28,4	16,65	1,435
33,87	0,5	4910	197,8	0,6482	740,4	124,7	24660	19,8	24,8	29,8	16,17	1,435
40,65	0,5	4716	187,2	0,6359	691	126,5	23683	17,2	22,2	27,2	17,08	1,435
35,48	0,5	4292	165	0,6384	581,4	130,6	21549	10,9	15,9	20,9	19,38	1,435
30,84	0,5	3889	144,8	0,6409	475,4	134,8	19522	3,9	8,9	13,9	22,08	1,435
25,55	0,5	3402	121,4	0,6438	346,5	140,6	17069	-6,4	-1,4	3,6	26,34	1,435
22,9	0,5	3141	109,5	0,6454	280	143,9	15758	-12,9	-7,9	-2,9	29,2	1,435

Condenser Ammonia

A	epsilon	mc	mv	NTU	P1	qc	qdot	tci	tco	th	wm	wp
8,239	0,5	2457	13,27	0,6721	352,1	929	12326	-15,2	-10,2	-15,2	241	1,435
14,35	0,5	2483	13,44	0,6559	366,1	927,1	12456	-14,2	-9,2	-14,2	238	1,435
9,651	0,5	2695	14,85	0,6706	488,7	910,9	13522	-6,5	-1,5	-6,5	215,4	1,435
18,86	0,5	3050	17,31	0,6532	719,2	884,4	15311	4,6	9,6	4,6	184,7	1,435
21,49	0,5	3355	19,52	0,6517	931,4	862,9	16845	12,6	17,6	12,6	163,8	1,435
23,75	0,5	3605	21,4	0,6504	1113	846	18107	18,4	23,4	18,4	149,4	1,435
16,7	0,5	3669	21,86	0,6642	1160	843,2	18430	19,8	24,8	19,8	146,3	1,435
15,76	0,5	3550	20,98	0,665	1073	849,6	17826	17,2	22,2	17,2	152,4	1,435
13,7	0,5	3285	19,01	0,6668	882,7	867,6	16494	10,9	15,9	10,9	168,2	1,435

18,66	0,5	3026	17,14	0,6533	702,6	886,3	15188	3,9	8,9	3,9	186,6	1,435
9,67	0,5	2698	14,87	0,6706	490,5	910,7	13538	-6,4	-1,4	-6,4	215,1	1,435
14,61	0,5	2517	13,66	0,6558	384,9	924,5	12628	-12,9	-7,9	-12,9	234,1	1,435

8.6 Cost Analysis

With equations and estimations explaint in chapter 5, we analyze the costs of different parts. After that, we obtain the values of NPV and IRR in order to establish the best option and its viability:

	depth (m)	T_{src} (ºC)	A_b (m^2)	P_{max} (kPa)	C_B($)	F	C_{HX}($)	Drilling Cost($)	n_w
R22	1000	100	275	4092	64252,96	3,85	247373,90	306556,60	5
hydrogensulfide	1000	100	270	7506	63587,25	3,88	246718,53	306556,60	5
R12	3000	150	95	3378	38844,77	3,85	149552,37	448729,40	2
ammonia	3000	150	80	9055	36500,47	3,13	114246,47	448729,40	2

CONDENSER									
	T_{mx} (ºC)	A_c (m^2)	P_{max} (kPa)	C_B($)	F	C_{HX}($)	C_T($)	C_{Pc}($)	C_{Pwf}($)
R22	30	65	1186	34097,11	2,14	72967,82	463736,36	0	46373,63
hydrogensulfide	30	70	2263	34905,02	2,48	86564,45	463736,36	0	46373,63
R12	30	50	740,4	31634,83	1,91	60422,53	463736,36	0	46373,63
ammonia	30	30	1160	28329,67	1,69	47877,14	463736,36	0	46373,63

R22	2865696,47
hydrogensulfide	2877132,93
R12	2917338,66
ammonia	2320417,21

Average Cost kWh in Siberia: 4,795 ₽= 0,0832 $
Cost per year: 0,0832 $/kWh * 5667 kWh/day * 365 days/year = 172095,46 $/year

$$\mathrm{NPV}(i,N) = \sum_{1}^{N} \frac{Rt}{(1+i)^t} - I_0$$

15 years	i=1%
20 years	i=4%
25 years	i=5%

9 COMPARATIVE ANALYSIS

All the simulations shown before were obtained by the program EES (Engineering Equation Solver). It is compulsory to contrast these values in order to set and explain the best alternatives realted to the main topic of the study, alternative energies in the mining industry.

9.1 Energy demand

The first point to compare is the difference between the energy demand depending on the material extract and the amount of production. Below we can observe how different they are, especially taking in consideration that the electricity demand in the extraction of granite is much lower compared to the extraction of coal and uranium. On the other hand, the demand of diesel in the extraction of uranium is much higher comparing all the values. These differences will influence hugely in the final price of the material, although it is not the focus of this project.

	Granite Mine	Ombilin Mine	Dalmatovskoje Mine
Production	Granite (mineral)	Coal	Uranium (metal)
Ore production (tons/day)	5000	1000	1000
Electricity demand (kWh/day)	639	6198	5667
Electricity demand (kWh/ton)	0,1278	6,198	5,667
Diesel demand (l/day)	4,751	58,68	1929
Diesel demand (l/ton)	0,00002556	0,05868	1,929
Max. Power Demand (kW)	360,4	3495,71	3196,22
Max. Power Demand (kW/ton)	0,07208	3,49571	3,19622

9.2 Environment conditions

It is normally considered the key question when speaking about renewable energies. The places where our mines are located belong to very diverse countries whose climates vary hugely, although with something in common: potential to produce geothermal energy. In fact, both Sumatra and Arizona are regions located over the Pacific Fire Ring, that provides the greatest geothermal energy potential in the world (it is noteworthy that both countries are, with Philippines, the world biggest producers of geothermal energy). Although the third location (Siberia) is out of this Ring, it also has potential to produce geothermal energy.

When speaking about the weather, below will be shown how different they are. In Arizona there are very extreme temperatures in summer,with high temperatures, while in winter it will be very low. Indonesia has a constant climate during the whole year with only two seasons: dry and rainning. There is almost no variations of temperatures. In contrast, Kurgan has very extreme temperatures especially in winter, when the temperature arrive to values greatly under 0ºC.

	Granite Mine	Ombilin Mine	Dalmatovskoje Mine
Location	Arizona (USA)	Sumatra (Indonesia)	Kurgan (Russia)
Lowest temperature (ºC)	11,7	25	-15,2
Highest temperature (ºC)	36,1	27	19,8
Temprature difference (ºC)	24,4	2	35,0
Highest Irradiance (kWh/m^{2}d)	7,9	4,94	5,99
Lowest Irradiance (kWh/m^{2}d)	2,9	4,34	0,47

9.3 Organic Rankine Cycle

The next table shows the results obtained by the simulations in EES related to the ORC and the heat exchangers in charge to add and remove the heat of the chosen working fluid. It is intention to describe briefly all the relevant conditions of the chosen instalation. Finally, we compare the different IRR (InternalRatios of Return).

	Granite Mine	Ombilin Mine	Dalmatovskoje Mine
Location	Arizona (USA)	Sumatra (Indonesia)	Kurgan (Russia)
Chosen Working Fluid	R22	R11	Ammonia
Heating Temperature (ºC)	100	220	150
Source depth (km)	1	6	3
Drilling cost ($)	306556,60	688562,60	448729,40
Cooling source	lake water	sea water	air
Lowest Irradiance (kWh/m^{2}d)	2,9	4,34	0,47
Working Fluid Mass (kg/s)	28,86	73,44	21,86
Heat Exchanger Area (m^2)	48	140	80
Condenser Area (m^2)	6,4	20	30
Heat Exchanger cost ($)	96413,02	175503,09	114246,47
Condenser cost ($)	39439,30	40524,41	47877,14
Max. Power Demand (kW)	360,4	3495,71	3196,22
Turbine cost ($)	145853,32	918397,29	463736,36
Total cost ($)	606236,75	1847788,02	2320417,21
Electricity cost ($/kWh)	0,1129	0,101361	0,101361
Electricity demand (kWh/day)	639	6198	5667
Annual Electricity cost ($/year)	26332,23	229305,95	172095,46
IRR for 10 year (%)	-	5%	-
IRR for 15 year (%)	-	9%	1%
IRR for 20 year (%)	-	11%	4%
IRR for 25 year (%)	-	12%	5%
IRR for 27 year (%)	1%	12%	5%

10. CONCLUSION

To conclude, this projects finishes with a discussion of every chapter as summarize, pretending to explain the main impressions and trying to help to explain better all the concepts developed.

This project starts explaining the global situation of the renewable and low carbon energies and their expectations in the near future. The main goal for every government and industry (being mining not an exception) is to increase the amount of energy suply from this kind of sources to achieve the two most important purposes: reduce CO_2 emissions to stop the greenhouse effect and the global warming in one hand, and in the other hand to become more independent of the fuel producer countries and the fuel market, always volatile and predictably rising with the pass of the years.

The second chapter describes the possible synergy fields that the mining industry posseses. The most important fact is the product itself, because the influence of its production and its final price has a big influence in the final price of the product and even decides if the production is able or not. After managing them carefully, many mine wastes can have other uses in industries such as the water in the agriculture. Finally, the social impact that a mine has in the population around must be named.

About the potential Low Carbon Technologies, we have focused on the geothermal power plants through a simple Organic Rankine Cycle (ORC), but photovoltaic systems and hybrid systems of thermosolar and geothermal energy were also taken in consideration. As depending on the climate (even in Siberia it would be compulsory a mechanical study of its viability to support the snow weight), the solar energy may be unpredictable and requires energy storage systems, connection to the electricity web or even both. Their profitability depends on the allowance of this conexion and the possibility of selling the energy over, that requires of especial permission. They have the advantage of flexibility in instalation. The hybrid system could be interesting to supply of heat during the hot seasons, when the efficiency of geothermal systems become reduced.

Finally, it results tested that the profitability of this kind of energy depends on factors such as the environment, the size of the mining plant and the amount and kind of material extracted, and the price of the electricity in the place of the mine. In fact, we have confirmed that the complete miningand milling of uranium requires a lot of energy in both electricity and fuel, probably used to the treatment of the raw ore, a need that coal does not have, so it is reflected in both demands of diesel (1,93 l/tonand 0,06 l/ton, respectively), despite a similar electricity demand, used for other purposes (6,20 kWh/ton and 5,67 kWh/ton). Mineral mining energy demand is, in the other hand, much lower in proportion (0,13 kWh/ton and 0,000026 l/ton). It results interesting to point that the IRR value may be higher the bigger the mine production is (or higher the energy demand). This is especially true in the case of the granite mine, whose energy demand is not high enough to make the project profitable (IRR_{27}=1%, in contrast to 12% of the coal mine or 5% of the uranium mine). The cost of drilling is decisive for it, as it is the highest investment and it would need more than one hole. The price varies a lot with the weather, because the size of the heat exchangers depend on the variation of temperatures, and in this case a constant weather like in Indonesian is better than the high variations of Siberia or Arizona. It is, with these variations, where hybrid systems could take place.

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ISO: International Organization for Standardization	4
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