Mine Energy Guidelines

Executive Summary

Based on the findings of the Deepmine research programme and more specifically the findings of Deepmine Task 13.1.1 it is possible, with careful selection of; refrigeration and ventilation strategies, and efficient systems, that mining at depths down to 5 000m may not require any more energy than that currently used at 3000m. Energy usage in mining is particularly sensitive to system inefficiencies and therefore if mining to ultra deep levels is to be feasible then system inefficiencies must be eliminated. Factors which have a high potential to effect significant reductions in energy costs at both current and ultra deep levels are:

- The replacement of pneumatic drilling systems with more efficient systems such as hydropower or electro-hydraulic systems .
- Improvements in the efficiencies of both pumping and energy recovery systems
- Introduction of air re-circulation
- Application of cyclic cooling strategies
- Effective use of real time pricing tariffs

However, in order to take advantage of cyclical cooling and variable tariffs several requirements must be satisfied.

- An accurate energy model of the mine is required. This could possibly be a further development of the model used in Tasks 6.5.1. and 13.1.1
- An in mine data bus to provide the information to run the energy model in real time
- An effective control system to allow rapid load shifting. The model would restrict the loads that can be shifted, based on a functional specification mindful of the safety and health of the work force.

Further points for summary (not in any specific order)
Sizing and positioning of u/g plant
Ice systems
Backfill
Concentrated mining
Heat rejection into return water

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1.0 Introduction

Energy costs constitute typically 10-15 per cent of the total operating costs of deep level mines. While it is accepted that energy costs will increase with depth, the increase will not be directly proportional to the increase in depth, largely because new layouts and mining methods that minimise mine energy consumption are likely to be applied to future deep mines.. These guidelines present the primary factors which should be considered to achieve the Mission Statement / Technology Project Objective of the Energy section of the Deepmine Research Programme which was defined as:

Through technological innovation, to avoid incremental power increases so that total power costs for ultra-deep mines are lower than current deep mine costs.

Energy consumption and efficiencies are therefore important factors in the determination of the most suitable systems, technologies, methodologies and approaches to be applied to deep level mining not withstanding other equally (or more) important criteria such as safety, availability and reliability, capital and other costs, and suitability for operation underground.

The main objectives of these guidelines are;

- to present the energy implications of the various methods, approaches, and technologies considered within the Deepmine programme
- to provide a clear picture of the energy consumption patterns on a general shaft system, with depth as a variable
- to provide indications of the possibilities for improving energy efficiency.
- to identify opportunities for reducing energy costs on future shafts through appropriate technology selection and integration.

To facilitate comparisons of dissimilar processes all energy requirements have been determined in terms of kWh/ton. [1 kWh/t equals 3,6 MJ/t]

2.0 Design Criteria

The provision of workplace environmental conditions conducive to safe and productive mining requires a number of issues to be addressed. Although many aspects of the ultra-deep environment will be similar to that in existing deep-level mines, new challenges posed by the greater depths include higher rock temperatures and a higher heat load imposed on the mine by auto-compression of ventilation air drawn from surface.

The energy requirements are related to the target conditions for the underground environment. These have been set, following the recommendations of Task 6.1.1, at:

The recommendations (Task 6.1.1) regarding design criteria are as follows:-

- For design purposes, an ACP (Air Cooling Power) level of 300 W/m^2 should be regarded as the minimum requirement.
- Wet-bulb temperatures should be maintained below 29±1°C where moderate physical work will be performed.
- A wet-bulb temperature of 27,5°C should be the maximum design reject temperature in areas of strenuous physical work such as production zones.

- Minimising the air mass flow rate to reduce the impact of auto compression on total heat load should be an integral part of ultra-deep ventilation strategies. This indicates a need for more refrigeration and less ventilation than used in present mine designs.
- Controlled re-circulation and reconditioning of ventilation air should form part of any ultra-deep mine system design.

3.0 Current Energy Usage

An essential part of Deepmine investigation was to analyse the current profiles of energy consumption of deep level mines and to develop a baseline against which the energy benefits of new and improved technologies could be assessed. While there have been several theoretical studies based on reasonably assumed values, there is little published information where the actual energy consumption of a specific mine has been investigated. In fact, there are very few mines in the industry with sufficient metering points to provide the level of detail necessary for such investigations. However, using MinEcon (a mine costing model) with actual data it was determined that:

Energy costs are typically 12-15 per cent of the total working costs of conventionally powered mines and 11 per cent of the total working costs of a mine using hydropower.

The distribution of energy costs between the various mine processes is shown in figure 3.1

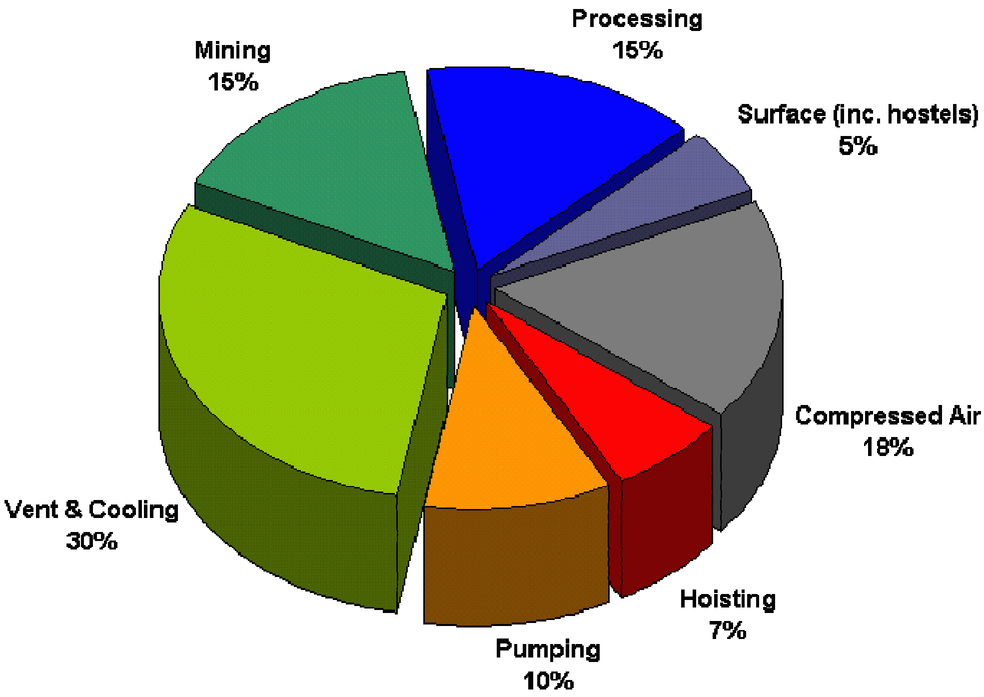

Figure 3.1 Distribution of mine energy requirements.[based on MinEcon studies]

4.0 Effect of Mining Depth on Energy Requirements

Section 3 presents the total energy requirements for the mine, including mineral processing and surface infrastructure. With a specific emphasis on depth related issues, the rest of the report focuses on the depth-related components which account for 80% of the total. Greater depths introduce a tendency for higher workplace temperatures, primarily due to the auto compression of air and higher virgin rock temperatures (VRT), with longer delivery routes for cooling media and ventilation air exacerbating the engineering issues.

Consequently, as the depth and heat loads increase the energy required to maintain a safe working environment will also increase and therefore :

The major contributors to increased energy consumption at increased mining depths are:

- **Pumping**
- **Ventilation**
- **Refrigeration**
- **Hoisting**

4.1 Mine Energy Model

In order to make predictions regarding the energy requirements for mining at greater depths a mine energy model is required which adequately accounts for the following depth-sensitive energy components:

- hoisting,
- in-stope production equipment,
- pumping,
- energy recovery,
- ventilation,
- refrigeration and
- cooling distribution [including horizontal pumping].

(Horizontal transport and rock processing are specifically excluded as being insensitive to mining depth and can be debated as stand-alone issues, although they may have implications on the cooling needs).

However, while several researchers noted that:

There are no all-embracing software or modelling procedures available to effectively study all of the energy consumption categories within deep level mining.

the entire ventilation, refrigeration and cooling systems of an ultra-deep level mine were rigorously modelled in Task 13.1.1 using a combination of Environ, a model developed from that of Task 6.4.1 that included the annualised effect of surface conditions to determine the optimum refrigeration machinery requirements, and extensive spreadsheets, developed from those created in Task 6.5.3, to construct and analyse the distribution network. Full account was taken of the complex interaction between cooling distribution and ventilation networks as well as losses in the refrigeration system, to arrive at the power requirements for all the system components.

This energy model was used to analyse a detail base case which included consideration of the findings of Deepmine Task 3.2.1 on mining layouts and Task 6.5.1 on optimised cooling and ventilation systems. The base case, was a development of an existing mine to a depth of 3 500 m with a new tertiary shaft down to 5 000 m, producing 180 ktpm [reef] [225 ktpm broken] from 4 000 m to 5 000 m. The time-frame for the model represents the mid-life period when the mine is at full production and the new infrastructure is fully established with stoping on all levels. The basic designs included in the base case to reflect current practice include:

- chilled water and ice mixing centralised at the 3 500 m platform level
- Pneumatic drilling
- 30 per cent re-circulation at 3500 m level
- Turbine energy recovery system
- face cleaning by electrical scraper winches assisted by water jetting
- gully cleaning by electrical scraper winches

The total energy requirements for the base scenario as a function of depth as determined in Task 13.1.1 are presented in table 4.1.1.

Table 4.1.1 Base case energy requirements determined in Task 13.1.1

Mining Depth (m)	Total Energy (kWh/t)
2 000 m to 3 000 m	188
3 000 m to 4 000 m	248
4 000 m to 5 000 m	322

The Deepmine model considers the capital and finance cost of ventilation, refrigeration and cooling on mine energy and found that for the base case model:

The cost of the capital infrastructure for the ventilation, refrigeration and cooling is about R 1 000 m. The total power consumption is 70 MW with a life-of-mine power operating cost of R 700 m.

Having established the energy requirements of a base case the energy model can be used to evaluate the performance of different strategies for energy reduction.

For the base case the energy cost of blast hole drilling was:

Mining to 3 000 m compressed air drilling energy = 55 kWh/t
Mining to 4 000 m compressed air drilling energy = 61 kWh/t
Mining to 5 000 m compressed air drilling energy = 67 kWh/t

Whereas the energy for face cleaning was:

Mining at all depths face cleaning and winch energy = 5 kWh/t

5.0 Scenarios for reducing energy requirements

The reduction of the overall energy consumption during mining operations reduces to the following major approaches.

- The selection of the most appropriate systems
- The improvement of efficiencies of the systems
- The reduction of the heat flow into the mine.

5.1 Selection of appropriate systems

The selection of the most appropriate systems to minimise the energy requirements for deep level mining cannot be done without reference to an integrated mine energy model as most systems interact with each other and cannot, therefore, be considered in isolation

5.1.1 Hydropower and electro-hydraulic

The impact of hydropower on the ventilation, refrigeration and cooling systems are complex [absence of compressed air cooling, different water cooling efficiencies and distribution of air coolers] and have been thoroughly analysed in Task 13.3.2. There are power savings for the surface fans that no longer have to extract the compressed air, but the net effect on the cooling system is very small. The savings in the power consumption are dominated by the absence of air compressors [55 to 67 kWh/t]. Hydropower may require extra pumpingto establish the necessary head. For the 5000m scenario, the difference in these combined aspects is about 11 kWh/t or 4% of total when compared to the base case, i.e. of secondary significance,. The entire system for the base case mine layout was accurately modelled, and the total energy values are as follows: The model does not take account of different mining layouts and cooling distribution strategies that could be possible with hydropower,.

Mining to 3 000 m	total energy	142 kWh/t [-23%]
Mining to 4 000 m	total energy	198 kWh/t [-20%]
Mining to 5 000 m	total energy	265 kWh/t [-18%]

The use of hydropower reduces the energy requirement by 46, 52, and 59 (kWh/t) at 3 000, 4 000 and 5 000 m depth respectively.

The implications of using electro-hydraulic drilling are very similar to the hydropower scenario except that the energy for drilling comes from localised power packs rather than additional pumping energy. This introduces an additional heat load at the stope entrance. Service water returns to 1,0 t/t and additional in-stope cooling is required to replace that provided by the compressed air and extra water used by hydropower. For the 5000m scenario, the difference in these combined aspects is about 5 kWh/t or 2% of total when compared to the base case, i.e. of secondary significance The entire system for the base case layout was accurately modelled, and again, the net result on the cooling system is subtle and small. The total energy values are as follows: :

Mining to 3 000 m	total energy	139 kWh/t [-25%]
Mining to 4 000 m	total energy	195 kWh/t [-21%]
Mining to 5 000 m	total energy	262 kWh/t [-19%]

From an energy point of view, there is little difference between the hydropower and electro-hydraulic systems. They both benefit from the enormous power savings from the air compressors and with little extra energy required to supply the additional power and cooling required. The total energy requirements for the three systems are shown in table 5.1.1:

Table 5.1.1 Energy usage of three powering methods as a function of depth

kWh/t	3 000 m	4 000 m	5 000 m
Compressed air	185	248	322
Hydropower	142	198	265
Electro-hydraulic	139	195	262

The replacement of pneumatic power for mining operations is essential .

The macro cooling strategy for ultra deep mines is insensitive to the use of hydro-power or electro-hydraulic as a power source.

5.1.3 Water from surface vs. ice

The effect of operating without an ice plant is that far more water is pumped to surface, the heat rejection system for the underground plant increases, the capacity of the underground plant increases, the water temperature on surface must decrease to maintain 5°C at 3 500 m and the capacity of the surface plant decreases but the water chillers increase in capacity to replace the ice makers.

From an energy perspective, the primary benefit of using ice is that much less water is required to be circulated and returned to surface. This reduces the pumping energy very significantly. There are however two disadvantages that should be noted, first, the required refrigerant compressor energy per unit of cooling is higher for ice makers [low COP] than water chillers and second, with water-from-surface systems the higher water flow enjoys more inexpensive cooling in surface pre-cooling towers.

The composition of the energy consumption pattern changes accordingly, but the total energy required, if ice is not used, will increase from 2% to 3% of total for the 3 000m deep scenario, to nearly 10% of total for the 5 000 m scenario.

Energy consumption for the 5 000 m scenario increases by 22 kWh/t for chilled-water-from-surface [no ice].

5.1.4 Cyclical cooling

The possible benefits of cyclical ventilation and cooling tactics were explored for the first time. As this is not practised on any relevant mine, the industry proposed a regime witha 6-hour 'off-shift' period during which re-circulation and all cooling down the tertiary shaft is stopped [Task 6.5.1]. The energy requirements for ventilation and refrigeration reduce by 12%, which is equivalent to 7% of total energy.
These findings indicate that the benefits are significant and that further research in this area is warranted.

Energy consumption for the 5 000 m scenario decreases by 23 kWh/t with cyclical cooling tactics.

5.1.5 Ventilation, refrigeration and cooling Systems summary

The application of available cooling generation systems to ultra deep mines was investigated in Task 6.4.1 and resulted in the following major conclusions and recommendations:

- Hybrid cooling generation systems (a combination of surface and underground plants) were by far the most cost effective cooling option. In all cases it was shown that the use of underground plants should be maximised.
- The use of return water for heat rejection was found to increase the capacity of the underground plant.
- Ice systems were in general found to be the least expensive cooling medium for surface cooling generation (when comparing similar classes). It was however found that the benefits of ice only became apparent at depths in excess of 3000m.
- Hydro-lift devices show considerable potential and if operated effectively they will result in substantial savings
- The effectiveness of the cooling distribution system was found to affect the cost of the system significantly. Lower return water temperatures (caused by less effective coolers) were found to increase the cost of the system substantially.

Further work in Task 6.5.1 to optimise ventilation and cooling systems resulted in the following major conclusions and recommendations:

- Underground plant duties must be maximised to the limit dictated by the heat rejection capacity of upcast air and water returning to surface.
- Ice-from-surface must be used to make up the underground cooling requirements. Ice must be produced at the highest ice mass fraction possible (not less than 70 %).
- Major reductions in system costs can be realised with primary controlled re-circulation fractions of 30%up to 50% of total mixed airflow.
- Surface bulk air-cooling duties must be maximised to produce the minimum tolerable downcast mixed air temperature [common practice suggests about 10°C and not less than 8°C].
- Typically, two underground bulk air coolers located on a transfer level to a tertiary shaft must be used [one for downcast air and one for re-circulated air]. The outlet air temperature of these coolers should be set at an optimum value of 20°C.
- Air temperatures on the intake levels must be kept in a high narrow band, close to 29 +-1°C wb. Discharge air temperatures from secondary air coolers [closed circuit cooling coils] in intake system should not be lower than 24°C wb.
- Air-cooling must be applied at the entrance to stope with the discharge air temperatures from these air coolers [closed circuit cooling coils] as cold as possible (, but 20°C is a practical target).
- In-stope air coolers must be developed and implemented. In-stope chilled water, in addition to that used as normal mining service water must be applied in a controlled manner in high efficiency air cooler heat exchangers.
- Cyclical air conditioning tactics must be pursued,e.g. 6-hour off-shift period during which all re-circulation and all secondary and tertiary cooling would be stopped.

5.2 System Efficiencies

Major improvements have been achieved in the design of effective and efficient cooling systems for mines. Achievements include the introduction of pre-cooling towers, energy recovery turbines for cooling water, three chamber pipe feeding systems, the use of ice instead of water to reduce the amount of water to be pumped to surface and the introduction of hydropower to combine powering of equipment with cooling. While all of these measures have resulted in improved system efficiencies the maintenance of high system efficiency levels in a deep mining environment is difficult.

5.2.1 Cooling Distribution Efficiency

Task 6.5.3 investigated the efficiency of cooling distribution systems for ultra deep mines

If typical cooling distribution losses cannot be rectified, the economic exploitation of ultra-deep mines may not be possible.

5.2.2 Energy Recovery Efficiency

As the turbines now contribute 25% of the energy required for the refrigeration system [down to the platform level] a sensitivity study was carried out on the 5 000 m model. This showed that for every 5% improvement in efficiency the power consumption decreased by 1,3 MW. This represents 3,5% of the refrigeration system power consumption. For no energy recovery, total energy required would increase by 20% for the 5 000m scenario.

Energy consumption for the 5 000 m scenario reduces by 3,6 kWh/t per 5% increase in turbine efficiency (For chilled-water-from-surface cooling system [no ice])

Turbine generator systems have an overall energy recovery effectiveness of 70% at best. But typically the effectiveness of existing systems is less than 35% [often due to control strategy]. The three chamber pipe system and water transformers have the potential to achieve energy recovery at higher efficiency levels. Neither of these systems has been subject to a rigorous determination of overall system efficiency.

5.2.3 Pump Efficiency

The pumps account for 55% of the energy consumption of the refrigeration system. The sensitivity study for the pumps showed that for every 5% deterioration in pump efficiency power consumption increased by 2.8 MW. This represents 7% of the refrigeration system power consumption.

Energy consumption for the 5 000 m scenario increases 7.8 kWh/t per 5% decrease in pump efficiency (For chilled-water-from-surface cooling system [no ice])

Understanding and monitoring these efficiencies will be vital in the selection and operation of refrigeration systems at these depths. Likewise the coefficients of performance of the refrigeration components will impact on the selection of appropriate systems.

5.2.4 General poor practice

An exercise within Deepmine Task 6.5.1 highlighted the enormous power penalties associated with generally poor practice, which included no re-circulation, bad leakage and poor cooling strategies [ref. 6.5.1]. In the context of Task 13.1.1 energy model, the energy requirements for ventilation and refrigeration increased by 75%, which is equivalent to 50% of total energy for the 5 000 m scenario.

Energy consumption for the 5 000 m scenario increases by more than 150 kWh/t [50%] with generally poor practice

5.2.5 System Efficiency Summary

- Each and every component of a chilled water systems must be addressed and cooling losses minimised.
- Use must be made of all viable and affordable novel and creative methods to reduce losses.
- Full system design approach is required in order to achieve best results. Overall design will need to include the interaction of the cooling generation system, cooling distribution system, ventilation system, pumping and dam system and the mine heat load profile.
- Small energy recovery devices [e.g. turbine generators] should be used as regulators to replace energy dissipating valves.
- In-stope air coolers must be compact and have a high thermal efficiency [operating at different design constraints to those presently available].
- Mining service water must be cold and in addition extra cold water will be needed for local in-stope air coolers. This water must be as cold as possible.

- All system pumps must be highly efficient and regularly maintained.

5.3 Reduced Heat Loads

There are two major sources of heat in deep level mining. First, heat flow from the exposed hot rock surfaces. This heat flow is proportional to the difference between the VRT and the air temperature (dry bulb) and therefore increases with depth. The heat flow is also proportional to the area of exposed rock. Second, the temperature rise of the ventilation air as a result of auto-compression . The heat load from this source is directly proportional to the amount of air used and the depth of mining.

Identified approaches to reduce the heat influx into mines include:

- Backfill
- Insulated airways and cooling distribution systems
- Controlled re-circulation of air
- Concentrated mining
- Increase rates of face advance

5.3.1 Backfill

For most of the proposed mine layouts backfill has been identified as a basic requirement for stope support. Beside this benefit for regional support, backfill effectively reduces heat flow from the worked out stope areas and concentrates ventilation in the face zone. Therefore, exposed surface areas in the stopes are reduced and lower air quantities are required, reducing the heat generation from auto-compression. However, backfill is a source of heat in itself due to the conversion of its potential energy. The guidelines recommend the cooling of backfill to arrive thermally neutral in the stopes and backfill could also be used as a cooling medium itself.

5.3.2 Insulated airways and cooling distribution systems

Deepmine task 6.3.1 provided proof that selective tunnel insulation combined with optimised positioning of heat exchangers would provide significant financial benefits arising from reduced chilled water circulation requirements.

At best [with insulation of the footwall] tunnel heat loads can be reduced up to 50% of their initial value depending on the applied material properties and insulation coverage of the tunnel. A more practical value would be 25%.

While the results of task 6.3.1 indicate clearly that the benefits are tangible and that the application of suitable materials is beneficial further work is required in the development of a suitable one-pass material and to finalise the composition of a perlite and polyethylene fibre mix.

5.3.3 Controlled Re-circulation of air

Deepmine Task 6.5.1 [and Task 6.1.1] showed that the use of large scale controlled recirculation of ventilation would be a major contributor to reducing operating costs and energy requirements. Recirculation has two primary benefits; to reduce heat load from downcast ventilation autocompression and overall fan power.

The base case model included nominal 30% recirculation of primary ventilation. Energy simulations were carried out, using the base case scenario [compressed air], but removing the recirculation and reverting to once-through ventilation with all other VCRP aspects optimal. The total energy required increases by 16% of total [for 5 000 m deep scenario]. This effect is greater with depth but still significant benefits for the 3 000 m scenario.

Had the base case model employed 50% recirculation and, if this degree of recirculation was removed, the total energy required would increase by about 26% of total for the 5 000 m deep scenario.

Total Energy consumption for the 5 000 m scenario increases by 16% with no re-circulation [compared to 30% recirculation]
Total Energy consumption decreases by 10% if recirculation increased to 50% [from 30%]

5.3.4 High Advance Rates

High advance rates reduce the number of stopes and airways and thereby the extent of exposed surface areas. Furthermore, less ventilation air is required and therefore less heat influx as a result of auto-compression. High advance rates will require elements of hydropower such as water hydraulic rock drills or mechanised mining methods

Concentrated mining, with high face advances, can significantly reduce in-stope cooling resources. Full advantage should be taken of hydropower's potential for achieving higher face advance rates.

5.4 General

5.4.1 Energy required for hoisting

Empirical data from internal metering of a selection of Anglogold and Gold Fields mines gave reasonable correlation between hoisting energy and depth of hoisting with a value of 25 kWh/t at 3 000 m. A theoretical study that accounted for the overlap of shafts produced the following values:

Mining to 3 000 m hoisting energy = 25 kWh/t
Mining to 4 000 m hoisting energy = 37 kWh/t
Mining to 5 000 m hoisting energy = 50 kWh/t

5.5 Summary

From the preceding data it can be inferred that, with good practice, the use of hydropower or electro-hydraulic drilling, and increased re-circulation to 50 per cent, that the energy requirements at 5000 m need be no more than the current requirements at 3500 m depth

Using mine energy models enables the identification of the net effect of various scenarios. The findings of task 13.1.1 regarding the effect of various strategies are summarised graphically in Figure 5.5.1.

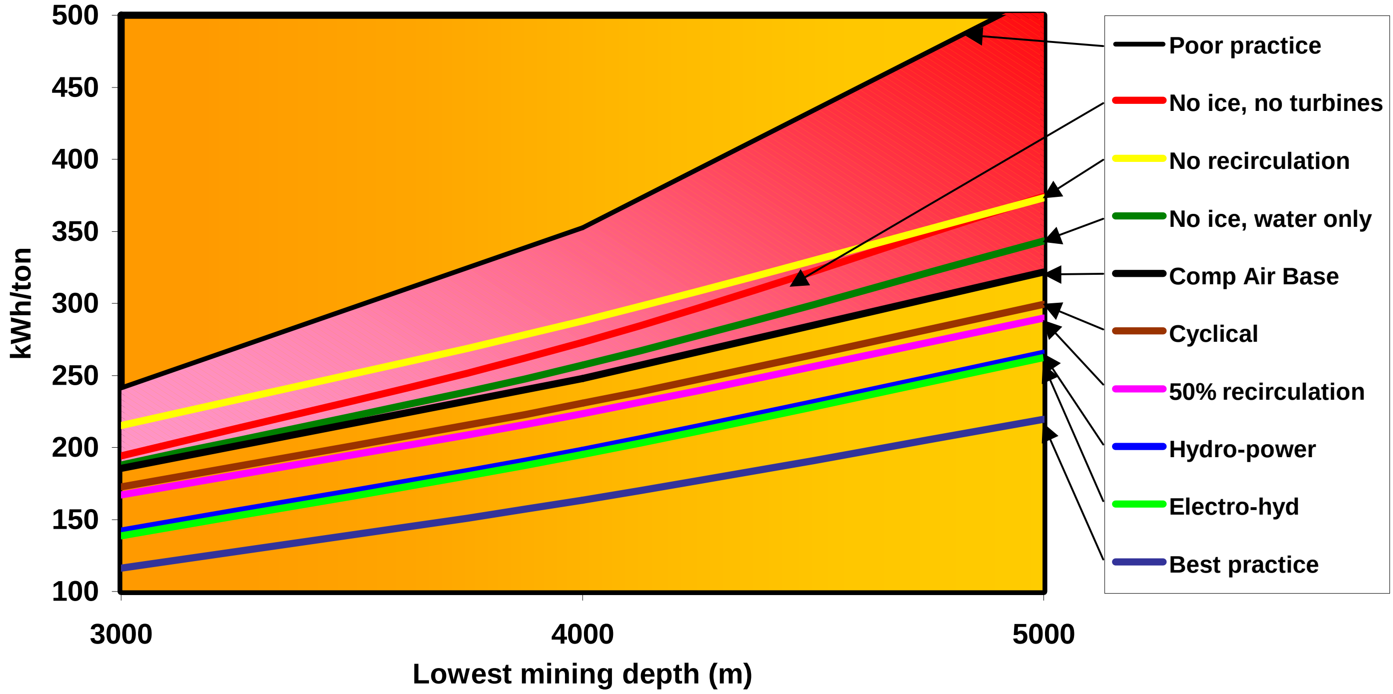

Figure 5.5.1 Effect of various scenarios on energy requirements

6.0 Real Time Pricing

In line with DSM (Demand Side Management) developments in Europe and the USA, Eskom has introduced "Real Time Pricing" (RTP) as an option for consumers who comply with the qualification criteria. It is a pricing methodology which exposes the customers' consumption decisions to the marginal cost of electricity. This is particularly suited to mine operations, and was initially implemented locally at Western Deep Levels. It is now being made available for other customers who satisfy the following criteria:

- They operate loads and production processes that are flexible.
- Loads and processes can be adapted and adjusted at short notice.
- They have an annual average maximum demand in excess of 25 MVA.

In the first year a Customer Baseline Load (CBL) is defined, basically being the complete demand profile of the previous year. Some negotiation or "customisation" is possible on the exact CBL through statistical smoothing of the demand profile. The previously used tariff (Standard or Megaflex) is applied to this, and the resulting cost is called the "Access Charge", which may be levied as a monthly basic charge or as an effective CBL energy cost per kWh.

The second major component of the RTP pricing structure is the "Additional Load" (AL) which is the difference between the customer's actual current load and the CBL at any time of the day. Eskom provides hourly marginal energy prices for the next day, sent by 15:15 on the previous day. The marginal rates can be subject to extreme variability, recently ranging from 0,5c per kWh on a public holiday, to 70c at peak times - compared with a normal average of around 10c per kWh.
The Additional Load in any hour may be positive, in which case the customer pays for additional energy at the current marginal price, or negative, implying that the load is less than the CBL in which case the customer gets a refund on the Access rate at the prevailing marginal rate.

The consumer is therefore in the position to actively manage energy demand to reduce the average cost of electricity by:

- reducing loads during expensive periods
- increasing loads during the cheaper periods.

Control systems that monitor and/or control maximum demand have been developed over many years. These vary from very simple rudimentary load shedding operations, to sophisticated computer control networks. Where maximum demand is charged by kVA, power factor correction is essential.

RTP requires consumers to review their approach to matters such as:

- Considering management of maximum demand during the design stage of new equipment and plant.
- The efficiency of electrically driven equipment.
- Use of more sophisticated control systems.

Since Real Time Pricing provides the opportunity for mines to exert a major influence on the cost of electricity for their operations, the following are recommended.

- A senior person who understands the tariffs and who is familiar with mine electrical distribution systems, be assigned adequate authority and time to monitor, control, advise on, and implement the effective use of electrical energy on a day to day basis.
- Each mine should install metering and data acquisition equipment on all major substation incoming circuits, feeders and loads so that instantaneous and historical information on demand levels and energy consumed is available.
- All components on the mine must be integrated and co-ordinated using computer based technology and software, and a common structure for the storage and reporting of electrical consumption and cost data must be developed.
- Execution of all operations associated with mining processes that use electric power should be made as flexible as possible so that loads may be shifted from hour to hour in accordance with the RTP rates.
- Design of new equipment and plant must take into account the flexibility of operation required specifically to exploit the RTP cost of energy. This may for example mean that pumping systems, pipelines, dams or conveyors are sized so that cheaper power may be consumed over the appropriate periods to achieve the same results.

In the future of mining operations, the mines will to a greater and greater extent be able to play an active role in determining what the total cost of electrical energy consumed will be. A full time Energy Manager is essential and continuing investment in suitable monitoring and control systems and equipment will be necessary.

7.0 Emergency Power

Task 6.7.1 investigated the emergency power requirements for the safety of the underground work force and determined that emergency power may be supplied in one of three ways or combination of these:

- Diesel engine alternators which are less sophisticated yet are suitable to absorb variations in loads (up to 20%). Only available to supply low range power per unit [up to 7 MW] at varying speeds thus requiring multiple units for larger applications.
- Gas turbine powered alternators are more sophisticated and less rugged and not suited to hoisting due to their poor variable load characteristics. These units perform in a higher power range – up to 30MW.

- Water turbines are very simple units [up to 3MW] and may be operated by allowing water to gravity-flow into the mine. However, they must be coupled to synchronous generators [as opposed to squirrel cage rotor generators presently used to feed into an energised grid] and they require a flow of water into the mine.

In order to ensure acceptable environmental conditions at ultra deep levels during extended power outages, equipment such as booster fans, refrigeration plants and circulating pumps will have to be activated with the available emergency power. This will also require the remote switching, sensing and control of machinery that, as the result of the outage, is out of reach. This requires the refinement of monitoring and switching instrumentation.

8.0 Conclusions

Based on the findings of the Deepmine research programme and more specifically the findings of Deepmine Task 13.1.1 it is possible, with careful selection of; refrigeration and ventilation strategies, and efficient systems, that mining at depths down to 5 000m may not require any more energy than that currently used at 3000m. Energy usage in mining is particularly sensitive to system inefficiencies and therefore if mining to ultra deep levels is to be feasible then system inefficiencies must be eliminated. Scenarios which have a high potential to effect significant reductions in energy costs at both current and ultra deep levels are:

- The replacement of pneumatic drilling systems with more efficient systems such as hydropower or electro-hydraulic systems would form the basis of any energy reduction scenario.
- Improvements in the efficiencies of both pumping and energy recovery systems
- Introduction of air re-circulation
- Application of cyclic cooling strategies
- Effective use of real time pricing tariffs

However, in order to take advantage of cyclical cooling and variable tariffs several requirements must be satisfied.

- An accurate energy model of the mine is required. This could possibly be a further development of the model used in Tasks 6.5.1. and 13.1.1
- An in mine data bus to provide the information to run the energy model in real time
- An effective control system to allow rapid load shifting. The model would restrict the loads that can be shifted, based on a functional specification determined on the basis on the safety and health of the work force.

9.0 References

Anglogold:1999 Analysis of energy usage in future Anglogold mines. Anglogold Contract No AG000216, April 1999.