// CRONIMET / TH*Energy* study

Solar projects, energy efficiency and load shifting for an optimized energy management in the mining industry

September 2015

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1 Introduction

In many parts of the world, low commodity prices have recently increased the pressure on mining companies. On the cost side, the biggest blocks are labor and energy. The price for labor is often very difficult to control. Traditionally, mining companies have tended not to consider energy as one of their core competencies. Their main objective is to quickly install a power source, not to establish an efficient and reliable supply structure. This is especially the case at remote locations, where power is generated with rental diesel gensets that are often not very cost efficient.

The increasing price pressure on the commodity side is changing the situation. More and more mining companies have identified energy costs as a strategic differentiator. Energy costs – mostly for electricity – comprise typically between 15% and 25% of the overall costs. At remote mines, the transport costs for energy are usually very high; tax and theft are other cost blocks that are added into the equation and lead to very high electricity prices. In the solar–diesel hybrid plant concept, solar plants are added to existing diesel gensets and reduce the diesel consumption during daytime. In comparison to expensive diesel electricity, solar energy is very cost competitive. Usually, the cost reduction potential is in the range of 25%–30%, and sometimes well above.

Other levers for reducing energy costs are energy-efficiency measures and load shifting. These actions require lower capital expenditure (CAPEX) and are normally also economical for grid-connected mines. The study explores the isolated advantages of solar–diesel hybrids, energy efficiency and load shifting at mines, and in a second step, it analyzes additional benefits derived from a simultaneous approach.

CRONIMET Mining AG was the first mining company to adopt the hybrid solar application in the MW-class, integrating Photovoltaic (“PV”) into one of their chrome mines in South Africa (CRONIMET Chrome Mine). The installation remains the biggest PV–diesel hybrid plant in the mining sector. The experiences with this plant have resulted in the founding of CRONIMET Mining Power Solutions GmbH (“CRMPS”), which is dedicated to energy solutions for the mining industry. The entity’s main business areas are solar technology, energy efficiency and load shifting. Using its long experience of solar technology, CRMPS also builds utility-scale grid-tied PV systems. CRMPS finished in April 2015 Namibia’s first and with 5.16 MWp biggest photovoltaic power plant in the Omaruru District in the Erongo region of northern Namibia.

The study is based on CRMPS’ experience in the renewable-energy sector, especially with mines and power plants and on several external consulting references that CRMPS has for energy management and load shifting. Expert interviews suggest that the findings are not CRMPS specific, and that they can also be transferred to other cases.

2 Methodology and design of the study

Expert interviews are the methodological framework of the study.[1] Twenty-six experts from different backgrounds were interviewed: 20 from the mining industry and six from the energy sector.

The interviews were conducted by phone or in personal meetings. The interviewed experts are from three different continents with a strong focus on Africa. The experts from the mining industry are COOs, energy managers and mine managers. On the energy side, half of the interviewees are managing directors. The others are responsible for engineering and business development.

To complement the findings CRMPS supplied technical knowledge from their experience in planning and designing PV hybrid systems worldwide. Additionally CRMPS provided operational data from the 1 MWp PV hybrid system in South Africa operated at the Thabazimbi chrome ore mine. It is located in the South African Limpopo province, about 20 km southwest of Thabazimbi. The operations started in April 2011 and has now an average extraction rate of about 25,000 tons of chromite rock per month by means of opencast mining. The final product from the spiral plant is approximately 10,000 to 12,000 tons of chromite concentrate per month.

In the first two years of operation, the electrical energy was produced by two 800 kVA diesel gensets consuming about 1.9 million liters of diesel per year. To reduce the operating costs, the 1 MWp PV plant was completed by the end of November 2012. The electricity generated by the PV plant during the day effectively decreases diesel consumption by about 450,000 liters per year, thus reducing CO_2 emissions by approximately 1,200 tons annually. The CRONIMET Thabazimbi mine was the first off-grid PV–diesel hybrid system in the megawatt range. In April 2014 a grid connection, limited to 500 kVA, was added to into the existing power system. The connection of the PV–diesel hybrid system to the national electricity grid changes the control strategy and energy management of the system. The three different power sources need a prioritization based on their technical characteristics and the cost of electricity.

[1] Bogner, A., Littig, B. and Menz, W. (eds.) (2009). Interviewing Experts: Methodology and Practice. Basingstoke England: Palgrave Macmillan.

3 Energy management based on energy efficiency and load shifting

3.1 Main consumers in typical mining operations

Energy is one of the main cost blocks in mining. The energy costs can make up around 25% of the total costs in an underground mining operation. The exact figures depend very much on the specific case. In the following some general figures for a typical underground mine are given based on expert interviews.[2]

In such a typical underground mining operation, the main electricity consumers can be categorized as follows:

- Compressed air systems
- Ventilation
- Material handling
- Pumping
- Crushing
- Milling

3.1.1 Compressed air

The compressed air system is used predominantly to drill but also to power pumping and pneumatic systems for ore-pass box fronts. In big mines, it may be used to deliver instrument air. Compressed air can comprise 25% to 50% of electricity costs at underground mines.[3]

3.1.2 Ventilation

The purpose of ventilation in mining operations is to replace air in working areas with fresh air at a lower air temperature. Ventilation can account for one-third of an underground mine's total electricity costs.[4] Typical values are around 15%. In deep vertical shafts ventilation and refrigeration may comprise up to 60% of the total load.

3.1.3 Material handling

Material handling mainly consists of conveying and stockpiling. Typical electricity consumption is around 15% of the total electricity consumption of a mine.

3.1.4 Pumping

Water is normally sent underground by gravity and later pumped out. If required, pumps also dewater the pit. Up to 11% of the electricity cost of a mine is due to the pumping of water.[5] Usually, electricity consumption of pumps is in the range of 5–10% of overall electricity consumption.

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[2] For opencast mining, the energy consumption is typically much lower, especially as compressed air and ventilation are less important.

[3] Cunha, I. F. da (2007). Implementing a Sustainable compressed air leak program – lessons learned and best practices.

[4] De la Vergne, J. (2003). Hard Rock Miner's Handbook. Tempe/North Bay: McIntosh Engineering.

[5] Rautenbach, W., Krueger, D.L.W. and Mathews, E.H. (2005). Reducing the electricity cost of a Three-Pipe Water Pumping System – a case study using software.

3.1.5 Crushing

In crushing, machines are used to reduce raw material, such as mined ore, into smaller rocks or gravel. Mining crusher machines apply pressure and mechanical force to the raw materials, breaking them down at an efficient pace and rate of processing. Crushing normally comprises 10–15% of the total electricity consumption.

3.1.6 Milling

Finally, milling, or fine grinding, is the process of reducing materials to a powder size. It is distinct from crushing, which means size reduction to rock or grain size. Typically, another 10–15% of the total electricity consumption can be attributed to milling.

3.2 Energy efficiency

The term "energy efficiency" describes the ratio of the benefit gained to the energy used.[6] In other words it is a measure of the intensity of use of electricity per unit of production. In the context of mining a good example is how much electricity a processing plant consumes to crush a specific amount of ore to a specific size. If the particle size and feed rate remain constant the amount of energy used is referred to as a baseline. With production and sizing remaining constant the more energy the plant consumes for the same output the less energy efficient it is becoming and vice versa

In the following, some examples of possible energy-efficiency improvements are indicated:

<u>Compressed air</u>

A study from the Ontario Mining Association[7] shows that up to 70% of compressed air is wasted through leaks; the problem of leaks in compressed air lines is very costly. The study shows that a single 1/2-inch-diameter leak, assuming energy costs of $0.10/kWh, can sum up to $47,850 for a three-shift operation. In a typical mining operation, leaks in compressed air lines can number in the hundreds, resulting in wasted energy costs of more than $100,000 a year.[8]

Another popular method of controlling air to the workings is through either level control valves or surface control valves. Through the control of a valve air consumption can be shut down to a level (or entire shaft) based on the times when the shaft is not being manned. Through making use of an actuated valve, flow to the workings can be controlled and delivered when required. This eliminates air lost through leaks (when the shaft is not in production i.e. dead shifts, holidays or prior and after blasting) as well as air lost due to it being used to supplement ventilation in the form of open ended pipes.

[6] Irrek, W. and Thomas, S. (2008). Defining Energy Efficiency.
[7] See also Cunha, Ivor F. da (2007). Implementing a sustainable compressed air leak program – lessons learned and best practices.
[8] Here in Canadian dollars. At the end of 2007, a Canadian dollar was approximately equal to the U.S. dollar. 1 Canadian dollar was equal to 1.0123952301 U.S. dollars.

The legal requirement (in many countries) to have a constant flow of compressed air to the safety zones in the workings can be overcome by a bypass valve which feeds the workings with a constant flow of low pressure air.

Although costly actuated valves can save up to 10% of the energy required to power compressors. This saving is very dependent on how compressors are sized, controlled and maintained at various operations.

<u>Material handling</u>

Material handling is largely performed through the use of either Trackless Mobile Machines (TMM) or conveyors.

With regards to conveyors there are many ways in which energy can be saved. It is preferred that conveyors that are not conveying load, are switched of manually or by means of interlocking. Keeping belts well maintained and cleaned will also assist although the saving cannot easily be quantified. Ensuring that power transmission from the motor to the belt occurs as efficiently as possible may in itself prove to delivering savings of up to 5%. Belt slippage is the most common inefficiency on a conveyor installation. Conveyor speed is critical and should be matched to that of required production throughput whenever possible through the use of variable speed drives.

The use of TMMs to convey material is a more complex and capital intensive way in which to transport ore/material. Good fleet management systems will enable theft, losses and inefficiencies to be highlighted and addressed on a daily basis. The theft of diesel fuel is a problem experienced by most mines across the world. Optimizing vehicle routes and regular scheduled maintenance will also improve energy efficiency in terms of fuel consumption.

<u>Pumping</u>

Leakage is a major problem of the water system. Repair and upgrade of pipes and the pumping system can create additional electricity savings.

<u>Motor management and control (in most of the outlined processes)</u>

It is important to run motors at the operation point that provides optimal efficiency. A standard motor running at 90% speed can require only 70% of the electricity compared to a motor that runs at full speed. Variable-speed drives are a possibility for managing the existing motors in such a way that they are run more efficiently. When motors need to be replaced it is always an important consideration to replace them with motors that are of a higher efficiency rating (IE2 or IE3) than the motor currently being used. Even though the initial capital expenditure may seem high, the saving will prove to exceed the upfront cost.

Were possible mines should always keep track of motor repairs. Rewinding motors, and the quality of such work being done, can always greatly impact the efficiency of the motor due to varying amounts of copper that the components are rewound with.

<u>Lighting</u>

Optimization of the lighting system can often bring considerable energy savings. This could include rather expensive new systems such as LEDs or rather inexpensive voltage-optimization devices.

Typical total electricity savings due to such energy-efficiency measures are between 5% and 20%.

3.3 Load shifting

In mining, some loads are not time critical and are, to some extent, flexible. An example is dewatering pumps. Specialized equipment such as pressure sensors, electrically actuated valves and logic controllers allow for shifting the usage of dewatering pumps to off-peak periods.

Another good example of load shifting is to only hoist use the winding engine when underground storage capacity has been reached or when the cost of using energy is at its lowest. This methodology must be considered taking into account the constraints of each mine.

The objective of the load-shifting approach is to decrease the load during peak times, when electricity prices are elevated or the on-site power plant, normally diesel gensets, do not have the capacity to generate the necessary power.

Another example can be found in South Africa. Grid-connected mining operations try to avoid non-critical loads during daytime peak hours, and they shift flexible loads to the nighttime when electricity is usually cheaper. The opposite effect appears if the mine operates a PV plant – in that case, the cheap daytime energy has to be utilized optimally.

In off-grid mines, highly automated control systems also permit the shifting of smaller flexible loads and run diesel gensets within their most efficient power range. In this example, there is a certain overlap between load shifting and energy efficiency. The optimized management of the loads leads to a more efficient operation of the generators, which increases the energy efficiency and thus reduces the electricity costs.

Typical total electricity savings due such energy-efficiency measures are between 5% and 10%.

The following data is based on patterns of CRONIMET's Chrome SA (Pty) Ltd. chromium mine in Thabazimbi.[9] It illustrates the potential of load shifting for a mine in South Africa with and without solar. The duration curve is shown in dark blue. This illustrates the electric power demand for all 8760 hours of the year sorted by the maximum demand. The dark grey curve shows the demand with subtracted solar power. Comparing both shows the effect of the solar power on the consumption of other power sources. The solar power production (light grey curve) is primarily used to cover the peak power demand from the mine. This is achieved by

[9] The data and graphs for the following example were provided by CRONIMET Mining Power Solutions GmbH.

working with stockpiles and operating the crusher only during daytime. The value of this peak power energy is even higher than the base load energy.

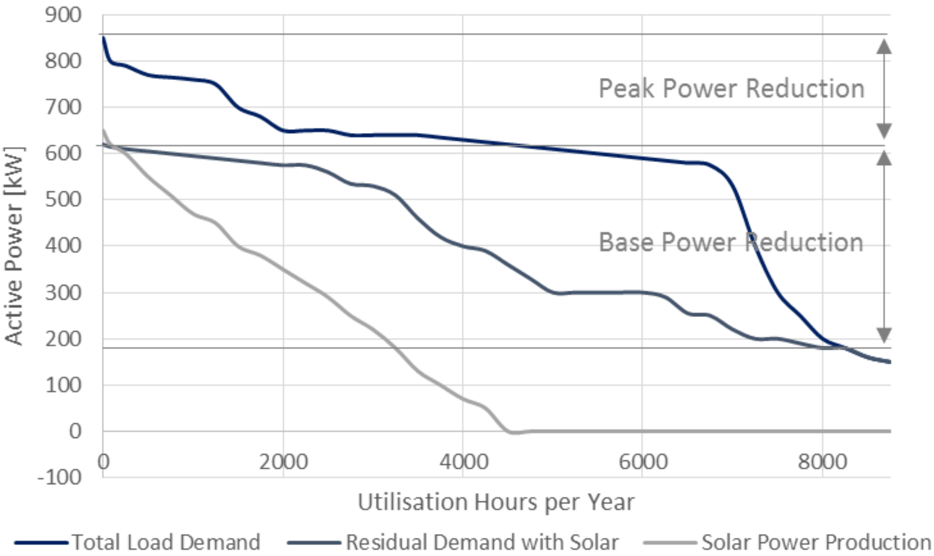

Figure 1: Duration curve of the power demand of a medium scale mine, with (dark blue) and without (dark grey) the share of a solar pv power plant (light grey).

The load shifting strategy is different without a solar plant. The following paragraph discusses typical scenarios in South Africa without solar based on exemplary daily load profiles.

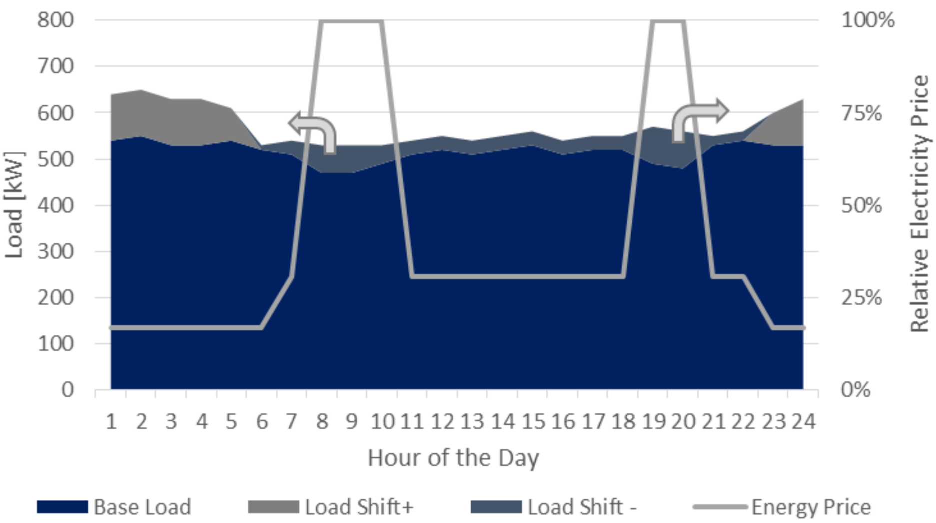

Figure 2: Exemplary load shifting with regards to the utility power tariff.

Electricity prices in South Africa are typically high during the morning and evening of a working day and particularly low during the night. The strategy is to shift flexible loads toward night time.

In the example, the dark grey load (Load Shift-) is shifted toward the period from 22:00 to 6:00 (Load Shift+).

The economics change completely when solar power is taken into consideration. The following scenario describes strategy as discussed with the duration curve above.

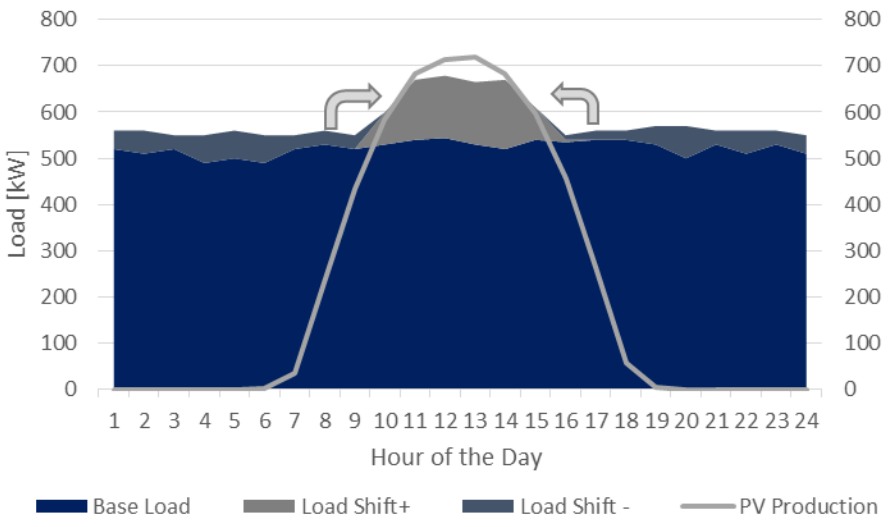

Figure 3: Exemplary load shifting with regards to solar pv production.

The direct cost of solar power is very low. The grey curve shows that PV production is typically a bell curve with its peak in the early afternoon. Flexible loads are now shifted from night, early morning and evening (Load Shift-) toward the middle of the day (Load Shift+).

The example illustrates that load shifting can be a powerful tool. Nevertheless, an efficient load shifting requires a thorough knowledge of mining processes in order to identify and shift flexible processes.

3.4 Solar energy

Many mines are located very remotely or in areas where the grid is not very stable. Often, mining companies have their own power plants, normally diesel generators. In particular, in remote locations, the transport costs of diesel are high, and theft during transportation is an additional problem. Even with the recent decrease of the oil price, electricity produced from diesel generators is very expensive. The cost per kWh is frequently above 300 Euro/MWh. Given that the prices of PV plants have decreased considerably during recent years, solar energy is an attractive alternative.

Hybrid power plants combine at least two different energy types. In mining, the combination of diesel gensets and solar power is rather common. Usually, the existing power plant with diesel gensets remains and a solar PV power plant is added. The idea is to replace expensive electricity from the diesel gensets during daytime with cheaper solar power. With some systems there is also a grid connection with limited capacity available.

Special controllers facilitate the integration of the solar power plant and allow for a smooth operation, even at times when the PV power plant does not deliver constant energy. The diesel gensets are run in a way that they can provide enough spinning reserve if, for example, clouds lower the power generation from the PV plant. Frequently, even without additional storage 60% solar power and more are the energy-cost optimum.[10] This ratio strongly depends on the operation, electricity cost, and type of power station, solar potential and financial aspects like the interest rate. It has to be determined for every project independently.

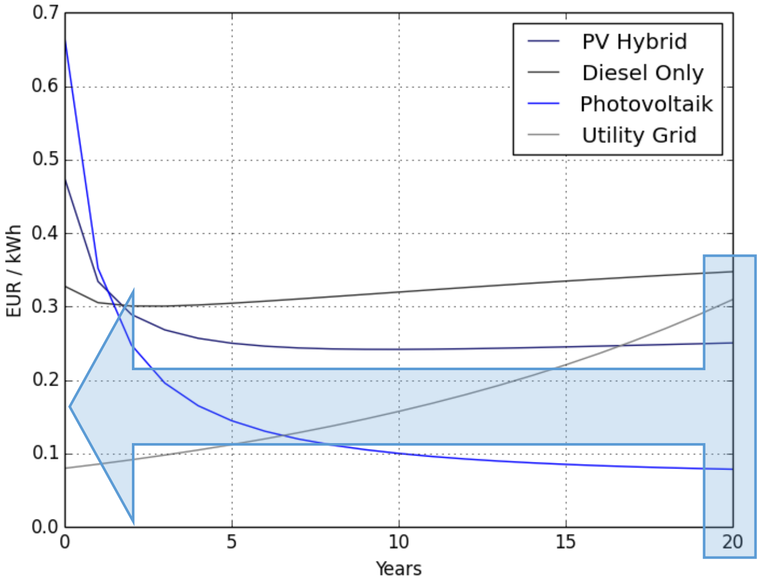

Figure 4: Exemplary levelized costs of electricity for different power sources.

The figure above shows exemplary levelized costs of electricity for different energy sources in South Africa. These energy production costs model the investment and operational costs including fuel prices for every power source over its lifetime. The price after the expected project lifetime (e.g. 20 years, blue box) gives the price of each kWh in that period. The modeled price depends on various parameters (energy demand, interest rate, fuel price, electricity and fuel price inflation, solar irradiation, etc.) of each energy source and has to be examined for every project and no general price can be derived. Doubtless is, however, that the price for fossil fuels and especially in southern Africa the price for electricity from the public utility grid will rise. Solar energy can be used to hedge that price risk as the main cost driver of the technology are the capital expenditures for construction in year one, but the overall costs decrease with a longer project lifetime as there are no fuel and very low maintenance cost. The opposite applies for

[10] The 60% solar power refers to the combined apparent peak power of diesel gensets (kVA) and the solar plant. Also, the coefficient is called the penetration rate.

diesel gensets. The invest costs are significantly lower but the fuel cost and the estimated fuel price inflation lead to much higher costs per kWh considering whole lifetime.

Typical cost savings from the PV power plant are in the range of 25–30%. In very remote locations with elevated electricity prices, the savings can amount to more than 70%.

3.5 Energy management through a combined optimization of energy efficiency, load shifting and solar technology

There are several advantages to an approach combining all of these three measures:

- energy efficiency,
- load shifting, and
- integration of a solar power plant.

Load shifting and basic energy-efficiency measures, such as the elimination of leaks in the compressed air system, are normally not very cost intensive and usually provide the best return on investment. In addition, a thorough energy-efficiency optimization in combination with an analysis of the load-shifting potential is the perfect basis for the dimensioning of the solar power plant.

Solar power is characterized by very low direct costs. After the plant has been constructed, the operational costs are almost zero, as the plant has no moving parts and does not need any fuel. For the integrated optimization approach, this means that the solar energy with almost no marginal costs, should be fully used, and energy-intensive processes that are flexible should be performed during the day when the solar output is at its maximum. If certain loads can be controlled in an automated way, less spinning reserve is needed for situations when clouds decrease the output of the solar plant. Instead of covering these cases with a large spinning reserve from the diesel gensets, a more cost-efficient method is to reduce flexible loads such as water pumping.

The optimal configuration and operation of the solar power plant depends on many mining process-specific details and is much more complex than engineering and operating a grid-connected PV plant. Knowledge and experience of mining, and of utilizing solar energy, are a prerequisite. A combined approach can reduce the necessary CAPEX considerably.

4 Summary and outlook

The study gives an aggregate overview of the main electricity-consumption processes in typical mining operations. In the next step, examples are given for energy-cost savings in the fields of energy efficiency, load shifting and the construction of a solar power plant. The experience from CRMPS and the output from the expert interviews underline that in all three subareas lies a considerable savings potential for energy costs. The highest savings potential comes from the solar power plant, which is usually in the range of 25–30%.

The study highlights that the best results can be achieved if all three subareas are optimized. Normally, load shifting and basic energy-efficiency measures do not require high investment costs and are characterized by an excellent return on investment. At the same time, energy efficiency and load shifting are the basis for an optimal planning of the solar power plant. If the mine is optimized regarding energy efficiency, less energy is needed. On the one hand, this results in lower diesel consumption, and on the other hand, the size of the PV plant can be optimized, which can decrease the CAPEX requirements considerably.

Automated load shifting of flexible mining processes is the most cost-efficient way to balance power fluctuations of the PV plant due to temporary shading of the solar modules. The study shows that an optimal approach requires knowledge and experience of mining processes and of solar power plants.

In mining, CRMPS has built so far the only PV–diesel hybrid power plant in the MW-scale. In the last two-and-a-half years, the plant has allowed for intensive testing and further improvements of the combined approach that CRMPS applies.

The market for solar–diesel hybrid power plants in the mining industry is likely to grow quickly in the near future. The expectation is that, on the one hand, quite a few large solar power plants will be built at mining sites, while on the other hand, the integrated approach will allow for many excellent business cases that sometimes will not require very big solar power plants as their energy consumption was reduced beforehand through energy-efficiency measures. To reduce the overall energy cost, it is therefore important to not only have excellent knowledge of designing solar systems but also to bring operational experience with regards to the mining application and to understand site-specific mining requirements. Bringing together the needs and benefits from optimized demand and supply sides will result in an optimized power system.

> About Dr. Thomas Hillig Energy Consulting (TH*Energy*)

TH*Energy* assists companies in dealing with energy related challenges. Renewable energy companies are offered strategy, marketing and sales consulting services. For industrial companies TH*Energy* develops energy concepts and shows how they can become more sustainable. TH*Energy* combines experience from conventional and renewable energy with industry knowledge in consulting. In addition to business consulting, TH*Energy* is active in marketing intelligence and as an information provider in select fields such as renewables and mining through the platform www.th-energy.net/mining.

> About CRONIMET Mining Power Solutions GmbH (CRMPS)

CRMPS specializes in development, financing, construction and long term operation of captive power solutions for the global mining and industrial sectors. CRMPS provides its clients with innovative and bankable power generation facilities and cost saving solutions. CRMPS's hybrid power integration expertise allows remote businesses such as mines that often rely on increasingly expensive diesel or HFO gen-sets for prime power to significantly cut operating costs by integrating renewable energy (solar, hydro, wind, biomass) into their energy mix. Its portfolio ranges from energy efficiency advisory services to PV/Diesel Hybrid Power, IPP Development, trade financing to turnkey EPC contracting. CRMPS is headquartered in Munich, Germany, and with subsidiaries in South Africa, Namibia and Botswana. Together with its mother company, the CRONIMET AG, CRMPS is acting globally with 54 offices worldwide (www.crm-ps.com).

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