The study presents the analysis of the power generation requirements of the mineral exploration sector and identifies fields of application for renewable energy solutions.

PFISTERER/THEnergy Study

Mobile Solar- and Wind Diesel Hybrid Solutions for Mineral Exploration

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PFISTERER

THENERGY
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Content

1 Introduction

The power supply world is going through a process of fundamental change. Solar and wind energy have strong cost advantages in many remote locations in comparison to conventional energy sources. One of the best business cases for renewable energy is diesel displacement for consumers that are powered by onsite diesel generators. Electricity from diesel is rather expensive for several reasons:

- Transportation costs,
- Taxes,
- Losses and theft, and
- Inefficient diesel generators.

In these remote locations, we often see that solar or wind energy can reduce costs by up to 80%. Falling oil and subsequently falling diesel prices appear to decrease this reduction potential. This view does not consider the long-term investment horizon of renewable energy plants. The expected lifetimes of both solar and wind energy plants are beyond 25 years. The business case for diesel displacement is largely driven by long-term expectations about future diesel prices. However, psychologically, the current crash of oil prices influences the short-term deployment of solar- and wind-diesel hybrid applications.

In many of the remote applications, electricity is not needed for 25 years or more. That means that the expected lifetime of the solar or wind installations is greater than the requirement for electricity generation. Today, we are sometimes in a situation in which the off-taker does not know how long the electricity might be needed. We also see cases in which the off-taker signs a long-term renewable energy commitment that cannot be fulfilled. In mining, it could be that the commodity prices on the world market reduce to a level that does not allow economical mining. In remote locations, there are often no alternative off-takers. In off-grid locations, the excess electricity cannot be fed into the grid.

Both wind and solar solutions are normally designed and constructed to be erected once in a single location. This concept sometimes does not provide enough flexibility for differing circumstances. In the situations described above, it might be necessary to dismantle and rebuild solar or wind power plants at other sites. From this point of view, it makes sense to optimize solar and wind plants to make them semi-portable and to minimize costs for moving them to a new site.

Based on the expert interviews, the study derives some requirements for solar and wind solutions in mining applications with a focus on the mineral exploration stage. The study shows which paradigms must change for solar and wind energy to address applications within a relatively short timeframe.

2 Methodology of the Study

Part of the study is based on a literature search. As the topic is rather new and the literature is rather scarce, expert interviews have been conducted to illuminate various aspects.

In total, 16 industry experts have been interviewed. Seven are from the mining industry, and nine are from the renewable energy sector.

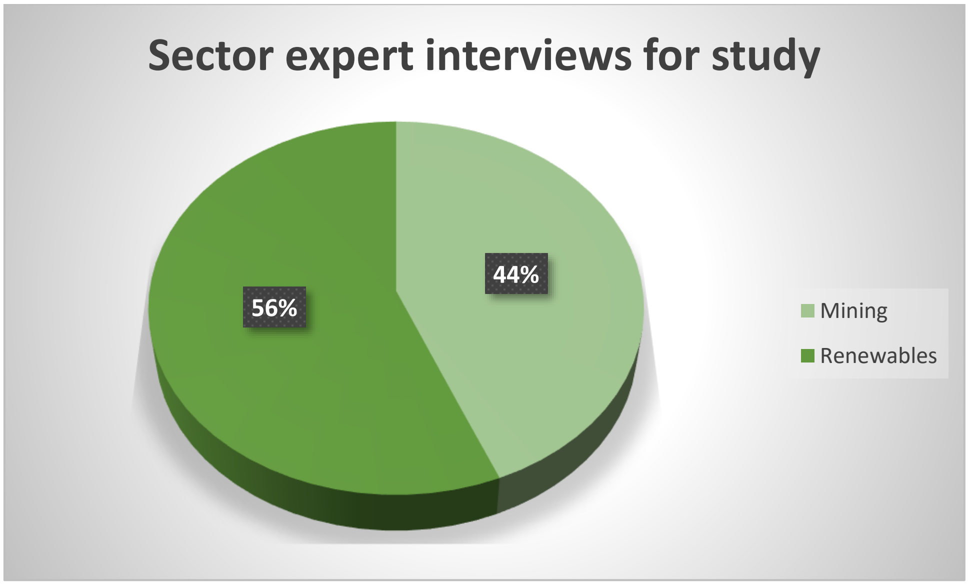

Figure 1: Industry background of the interviewed experts.

Most the experts are from Europe and overseas operations on various continents. In addition, most of the results are generic and not specific to a country or region. This procedure allows drawing conclusions that are valid on a global level.

3 Mobile Power Generation Solutions in Mining Applications

3.1 Mineral Exploration as a Stage of the Mining Process

Prospecting is the first stage in the geological analysis of a potential mine site. It is a small-scale form of mineral exploration to find commercially viable ore deposits. If the results of the prospecting point toward a commercially viable mining business case, the second stage in the geological analysis is initiated: the mineral exploration phase.

Figure 2: Phases of the mining process.

Mineral exploration is the process of identifying ore bodies in the earth's crust. It is a much more intensive, organized, and professional form of mineral prospecting.

Four types of exploration can be distinguished:

- Brownfield exploration,
- Greenfield exploration,
- Grassroots exploration, and
- Advanced exploration.

Greenfield exploration refers to finding mineral deposits in previously unexplored areas or in areas where they are not already known to exist. In brownfield exploration, geologists look for deposits near an already existing deposit.[1] The risk in brownfield exploration is much lower, as geologists can use existing data. In brownfield exploration, normally, no new mining camps need to be set up. The exploration can be done from the already operating mine. Regarding power generation, in brownfield exploration, power is frequently used from the already existing mine site.

In greenfield exploration, a new camp with various kinds of equipment is usually built. These camps need power. Power is typically needed for drilling and the camp itself. In remote locations, the camps are generally powered with diesel or oil. Transport of fuel to these locations can be critical.

The whole exploration process typically lasts between two and six years. Drilling is not done constantly. There are different drilling systems. Some of the systems are electricity-based with onsite power generation. In many cases, the onsite power generator is integrated into the drilling machinery (e.g., both are on a mobile truck). Sometimes, the camp is then powered by electricity from the drillers. We generally find this setting for smaller mining developments.

The infrastructure becomes much more sophisticated for larger mining developments. Mobile laboratories allow the exploration to be managed from containerized mobile office laboratories. Obviously, these laboratories require more power than short-term temporary structures. Typically, the power is again provided by diesel gensets. Some mobile laboratory approaches already comprise diesel gensets. In comparison to drillers, these mobile offices and laboratories are much more stationary. They often remain on one site and are not removed during the whole exploration period. If they are removed, this does not happen frequently.

The term *grassroots exploration* describes exploration projects at an early stage, in which the exploration activities start based on a conceptual idea regarding the location of mineral deposits. In the exploration process, substantial resources are needed to determine whether the minerals are indeed there. Common activities include airborne satellite surveys, ground-based geological and geophysical prospecting and surveying, and determining drill target areas.[2] Grassroot exploration projects are the riskiest projects in the mining business.[3] Some statistics indicate that 500 to 1,000 grassroots exploration projects are

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[1] Haldar, S.K. (2012), *Mineral Exploration: Principles and Applications*, p. 8.

[2] Marjoribanks, R. (2010), Geological Methods in Mineral Exploration and Mining.

[3] Gandhi, S. M., Sarkar, B. C. (2016), *Essentials of Mineral Exploration and Evaluation*, p. 162.

required to identify 100 targets for advanced exploration, which in turn lead to 10 development projects, one of which becomes a profitable mine.[4]

The term *advanced exploration* refers to projects with clearly defined mineral resources. Prospects for development into standalone mines or satellite mines are reasonable. In the mine lifecycle, these projects are generally positioned between the near pre-feasibility stage and the near bankable feasibility stage.[5] As many of the best mineral deposits have already been explored, the exploration process becomes increasingly challenging. There is a tendency for the duration of the exploration process to increase and for profitable deposits to be found in deeper layers. That means higher challenges for drilling processes regarding the number of necessary drills and the depth of drilling. Only technology progress is adversely influencing this trend to some extent.

3.2 Electrification of Exploration Camps

Electricity demand in mining exploration is generally increasing. This development is intensified cost-wise because more and more exploration activities are located at particularly remote sites, which has implications on the total price of diesel as transportation costs increase. It becomes obvious that electricity generation becomes a greater challenge for mineral exploration. Regarding the suitability of renewable energy, semi-stationary offices and laboratories and mobile drillers present a different degree of challenges. For drillers, integrated concepts might be a solution. The requirements regarding mobility are much higher. If storage prices reduce further, it might be an option in the future to power electrical drillers through batteries that are loaded centrally in the camps. To integrate renewables into highly mobile drillers, the drilling systems must be changed by electrification of the engines and the use of energy storage.

We can observe a direct fit between solar and wind energy plants for power generation as well as semi-mobile laboratories and offices. This is valid similarly for semi-mobile electrically powered drillers. Normally, diesel gensets for mid- to large-sized mining developments during the exploration stage are in the range of 10–150 kVA. The electricity is typically provided by standalone diesel gensets or by integrated solutions. The integrated solutions could be mobile laboratories, office containers, or drillers.

3.3 Requirements for Power Generation Solutions

For these applications, solar and wind energy can be an attractive solution. A business case for the use of mobile solar and wind energy devices depends to a large extent on site-specific wind profiles and solar irradiation data. The business case exists in reducing expensive electricity from diesel gensets using cheaper solar and wind energy. The combination of solar and wind energy allows a more stable output of the combined system. In addition, the existing diesel gensets and eventually energy storage solutions can balance the fluctuations from the intermittent solar and wind plants.

The use of renewable energy largely decreases the need for transporting diesel fuel. This not only lowers the transport costs but also decreases the wear on the local roads and the dependency on specific diesel deliveries.

[4] Eggert, R.G. (2012), *Mineral Exploration and Development: Risk and Reward*, p. 4.
[5] Government of South Australia (2015), *South Australian Mining Investment Guide*, p. 26.

4 Development of Photovoltaic Solutions and Suitability for Mining Applications

4.1 Development of Photovoltaics and Storage

In recent years, solar power has developed from a niche technology into a mainstream solution. One of the main reasons for this is that prices have considerably decreased. The price of photovoltaic (PV) systems has declined more 75% in the last 10 years.

The cost for solar power plants and solar electricity varies from location to location with different solar irradiations and interest rates for financing the investment. In 2014, extremely competitive calls for tenders demonstrated how inexpensive solar electricity has become in just a few years. For example, PV energy prices below 60 USD/MWh have been observed for a project in Dubai. Recently, the price for large solar power purchase agreements (PPA) has reduced to below the 30 USD/MWh threshold with prices at 24.2 USD/MWh in Abu Dhabi[6] and 2.91 USD/MWh in Chile.[7] These can be considered best-in-class examples for the solar generation cost within a favorable context. These examples show how the cost-competitiveness of solar electricity has quickly progressed and how PV is producing at similar price ranges at new conventional generation plants. While large-scale PV generation costs are already comparable with conventional electricity production today, at the distributed level, solar power production is now competitive with retail prices in many countries.

In 2015, 50.6 GW of new solar PV capacity had been installed globally. The total installed solar capacity could grow to over 600 GW by 2020, which is more than a 160% growth rate from 229 GW of commissioned PV systems at the end of 2015.[8] The situation for wind energy is similar.

For the future growth of renewables as intermittent energy sources, storage will play an important role. Storage solutions are still in a much earlier market phase than PV power plants. Expectations are that the price of storage will soon considerably decrease. Currently, it is not clear whether a single technology will prevail and, if so, which technology. It can be expected that the best technology differs from application to application.

In recent years, there has been a trend for larger installations, as the prices per MW and MWh are typically lower for large installations than for small installations. In recent years, it has become obvious that this market is and will be dominated by a small number of large players. It is no surprise that we have recently seen more developments in segments of smaller PV plants and wind turbines.

In summary, renewable energy has become very competitive during the last decade. The technology has become mature and, in the meantime, very reliable. Many wind and solar parks already feed energy into the grid. Most grid-connected renewable energy plants, however, were highly incentivized. Many incentive schemes expire after a relatively short time. This has been a major challenge for many renewable energy players, as they had to deal with many different markets and the unpredictability of their business.

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[6] http://renewables.seenews.com/news/update-abu-dhabi-confirms-usd-24-2-mwh-bid-in-solar-tender-540324 (retrieved on 10/18/2016).

[7] http://cleantechnica.com/2016/08/18/new-low-solar-price-record-set-chile-2-91%C2%A2-per-kwh/ (retrieved on 10/18/2016).

[8] Schmela, M., et al. (2016), *Global Market Outlook for Solar Power*, 2016–2020, p. 3.

In the grid-connected context, renewable energy must often compete with subsidized conventional energy. In the end, successful business depends to a large extent on the energy policy, which can hardly be influenced by smaller players.

Off-grid projects typically depend less on subsidies. Framework conditions are much more straightforward. However, the falling oil and diesel prices are also factors that cannot be influenced by renewable energy suppliers. The renewable energy business case for many off-grid applications consists of replacing expensive diesel power with inexpensive power from renewable energy. This gap is closing because diesel prices have decreased; however, it still exists in many cases. Renewable energy investments are typically long term. In the end, it can be expected that the current prices will not be representative throughout the investment period.

However, the long-term character of investments in solar and wind plants presents a severe issue for off-grid applications. The installations have to operate for numerous years in order to make the investment profitable. In off-grid applications, two requirements must be fulfilled:

1) The renewable energy plants must generate reliable energy during their expected lifetime and beyond.
2) It must be ensured that the electricity demand will be there for a certain minimum time. In the case of external investments, it must be ascertained that the off-taker is able to pay for the electricity.

In the case that the off-taker does not pay for the electricity, it is typically impossible to find alternative off-takers in remote locations. In certain applications, it is a priori obvious that operating life is not long-enough for justifying economical investments into renewable energy. Traditional solar and wind power plants are difficult to remove. With off-grid electrification, we see growing requirements for mobile solar and wind installations.

4.2 Barriers to Making PV Systems Mobile

Traditionally, solar and wind installations are designed in a way that they remain in a single location throughout their lifetime. A major quality aspect has been to make them robust for all kinds of weather circumstances. They are not conceived in such a way that they can be dismantled and rebuilt.
We can see limitations regarding the following aspects:

- The foundation,
- Absence of portable modular designs, such as:
    - Mounting systems,
    - Cabling,
- Dismantling of parts, and
- Integration into existing conventional energy systems.

In traditional solar plants, foundations are often concrete and cannot be dismantled. Recently, new concepts have been evolving that are more mobile than concrete. They can be almost fully reused in other locations. Simultaneously, they have a lower environmental impact. As they can be completed with less material, it can be expected that these concepts might even have a positive influence on the costs.

In traditional PV plants, each module is individually connected with cables. In addition, each module is mounted individually at the construction site on sub-structures. Few systems use a modular design, which may have considerable advantages if the plant is dismantled. Thus far, it has been rather difficult to dismantle a PV plant because it was not conceived for that purpose. Sometimes, the dismantling process has caused damage to components.

In wind energy, the situation is similar. Making wind turbines more portable requires constraint regarding the size of wind turbines. In addition, there must be a focus on the dismantlability of large parts (e.g., the rotor or the tower). For smaller turbines, even new concepts with respect to the foundation could be considered.

Traditional PV systems and wind have not been integrated into the electricity consumption processes. Grid connections through inverters and transformers must only be done once. The integration of remote hybrid applications is often far more difficult. The mobility concept involves a quick connection of existing diesel gensets, as this connection must be done more than once.

4.3 Mobile PV Application With Storage for Mineral Exploration

The mining industry is often regarded as the best target industry for solar-diesel hybrid applications. The main reasons are the following:

- High electricity consumption,
- Scale and duration of operation,
- Remote locations with high diesel prices owing to transportation, and
- Mining groups are considered a reliable partner.

The first PV-diesel installation on the MW scale was built in 2012 at a chromium mine in South Africa. Since then, many experts have been expecting a boom in this specific market segment, but progress has been slow. The global mining industry has been in crisis lately, as commodity prices have fallen considerably. Many projects that were underway have been postponed. Electricity was often not the main priority in this situation.

It took three years until First Solar commissioned the second MW-scale PV-diesel hybrid project. After the insolvency of the original EPC, First Solar recently finished a 1.7 MW installation at Rio Tinto’s Weipa mine in Australia. Several other projects have been announced and commenced in the meantime. For example, JuWi has announced a groundbreaking 10.6 MW installation with 6 MW storage at Sandfire’s Degrussa mine in Australia.
Many other companies have reported a substantial project pipeline for solar-diesel hybrid projects in the mining industry. In the meantime, renewables play an important role in the mining press, and several conferences with a focus on renewables and mining have been established.

In addition, PV prices have fallen considerably in the last years and mining companies see renewable energy an alternative to reduce energy costs. Furthermore, innovative business models are evolving, and several external investors are offering to finance off-grid PV installations. They either rent or lease back the PV plant to the mine or sell the electricity via a long-term PPA to the mine.

However, in this market-diffusion process, falling oil and diesel prices have slowed the development at a certain stage. Most often, the business cases for PV-diesel hybrid applications are still positive. Therefore, it is no surprise that the low oil prices have slowed the development but did not stop it and that many companies have reported a serious pipeline for solar-diesel hybrid projects.

The requirements for portability of solar and wind installations are much greater during the mineral exploration stage. Under normal circumstances, this stage lasts less than six years. With today's oil and diesel prices, solar and wind energy are hardly profitable in remote applications that are diesel powered. If the mineral exploration stage is successful, the solar or wind plant could also be used for mining activities. Especially for greenfield exploration, the probability that the exploration is successful and that the mining stage follows is not particularly high. That means that profitable solar and wind installations for mineral exploration require concepts for making the installations more mobile.

The German company PFISTERER Holding AG has developed such a portable system, called CrossPower. It is transportable as required. The entire CrossPower system can be housed in standard ISO containers. Quick connection of the system (plug and operate) is one of the main advantages. The pluggable terminals from PFISTERER allow fast assembly onsite without qualified personnel. Even when operating, the system is fully autonomous and can be maintained remotely if required. The CrossPower system offers scaled power outputs ranging from 25 kW to 5,000 kW.

Figure 3: PFISTERER's CrossPower System

According to local requirements, the system can combine solar, wind, and diesel energy and storage. Typically, renewable energy has the highest priority. In addition, the PFISTERER energy management system allows for prioritizing different consumers. If there is not enough power available, uncritical applications are shut down automatically while relevant safety applications receive the highest priorities. The container is also a major part of the mounting system for the wind turbine and parts of the solar plant. The systems also minimize the wear in the case that the installation must be dismantled. A modular design minimizes the effort for removing the plant and building it up somewhere else.

PFISTERER’S CrossPower system is ideally suited for integrating solar and wind energy to mineral exploration. The system has already been applied in military applications for the NATO Energy Security Centre of Excellence. This system has a rated output of approximately 150 kW (or up to 3,600 kWh per day), a storage capacity of 100 kWh, and comprises a control unit, high-performance batteries, wind turbine, solar panels, and two diesel generators. All components can be transported in two 20 ft. ISO containers for mobile use.

Other possible applications are power generation for geographical islands, such as for hotels and resorts, building construction, or rural electrification. In addition, the CrossPower system targets power generation for refugee camps and remote communities.

5 Summary and Outlook

Based on the literature and expert interviews, the study analysis indicates that, in the mineral exploration stage, there are exceptionally high requirements regarding the integration of solar and wind energy. Energy requirements in general are rather low during this stage of the mining process. In addition, one of the main obstacles is that the mineral exploration stage typically last less than six years. The combination of these two factors and the currently low oil and diesel prices are severe economic challenges. Under these framework conditions, it normally is necessary to reuse the solar and wind plants after the first years at the first mineral exploration site.

The study shows that a portable concept could make power generation with solar and wind energy profitable. Time and costs for dismantling and rebuilding the system must be considerably reduced. With CrossPower, PFISTERER has developed such a system, which ideally fits the requirements of mineral exploration. The energy management system, storage, wind and solar plants, and generators can be housed in standard containers. Then, the containers can simultaneously serve as parts of the mounting system for the solar and wind installations. The PFISTERER system allows integrating solar, wind, and storage according to the specific site needs. As the marginal costs for solar and wind energy are typically almost zero, renewables have priority in the system in comparison to power from diesel gensets, which leads to a reduction of fuel consumption of up to 80%.

The potential in mineral exploration and other remote applications, such as small islands, hotels, resorts, rural electrification, building construction, refugee camps, or military applications is huge. It can be expected that this kind of mobile renewable energy system will systematically develop in the market. This not only has a direct effect due to carbon dioxide reductions but also could change the mindsets in key industries, such as the mining industry. Mineral exploration, with its sometimes exorbitantly high electricity costs, could familiarize the mining industry with solar and wind power. In normal mining processes, the energy needs are even higher. Mobile solar and wind systems that are used from the very beginning of the mining process could increase the involvement of mining companies in switching their main mining processes toward renewables. This indirect effect could have an even larger impact.

About PFISTERER

PFISTERER is a leading independent manufacturer of cable and overhead line accessories for sensitive interfaces in energy networks. The Group is headquartered in Winterbach, near Stuttgart in southern Germany. PFISTERER develops, produces, and sells internationally successful solutions for 110 V to 850 kV voltage levels. With its end-to-end range of products for application in energy networks, consulting, installation, and training, the manufacturer is a valued partner to companies specializing in power supply, plant construction, and electrified rail transport around the world. PFISTERER operates production plants in Europe, South America, and South Africa, as well as sales offices in 18 countries across Europe, Asia, Africa, South America, and the USA. The Group employs around 2,700 employees following the recent acquisition of LAPP Insulators Holding. You find additional information regarding PFISTERER's containerized renewable energy solution at http://www.pfisterer.com/crosspower/.

About Dr. Thomas Hillig Energy Consulting ("THEnergy")

THEnergy assists companies in dealing with energy-related challenges. Renewable energy companies are offered strategy, marketing and sales consulting services. For industrial companies THEnergy develops energy concepts and shows how they can become more sustainable. It combines experience from conventional and renewable energy with industry knowledge in consulting. In addition to business consulting, THEnergy advises investors regarding renewable energy investments in changing markets. It is also active in marketing intelligence and as an information provider in select fields, such as renewables and mining, through the platform th-energy.net/mining or renewables on islands through the new platform th-energy.net/islands. For more information, have a look at www.th-energy.net.

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