Reducing energy costs and environmental impacts of off-grid mines

ABB Microgrid Business Case

Executive Summary

Power systems in mining and other industries are seeing a major structural transformation as renewables and energy storage costs continue to decline and global pressure to mitigate CO2 remains strong. For off-grid mining in particular, renewable and storage technologies present an ideal opportunity not only to improve the mine's environmental footprint, but also to reduce energy costs while improving power quality.

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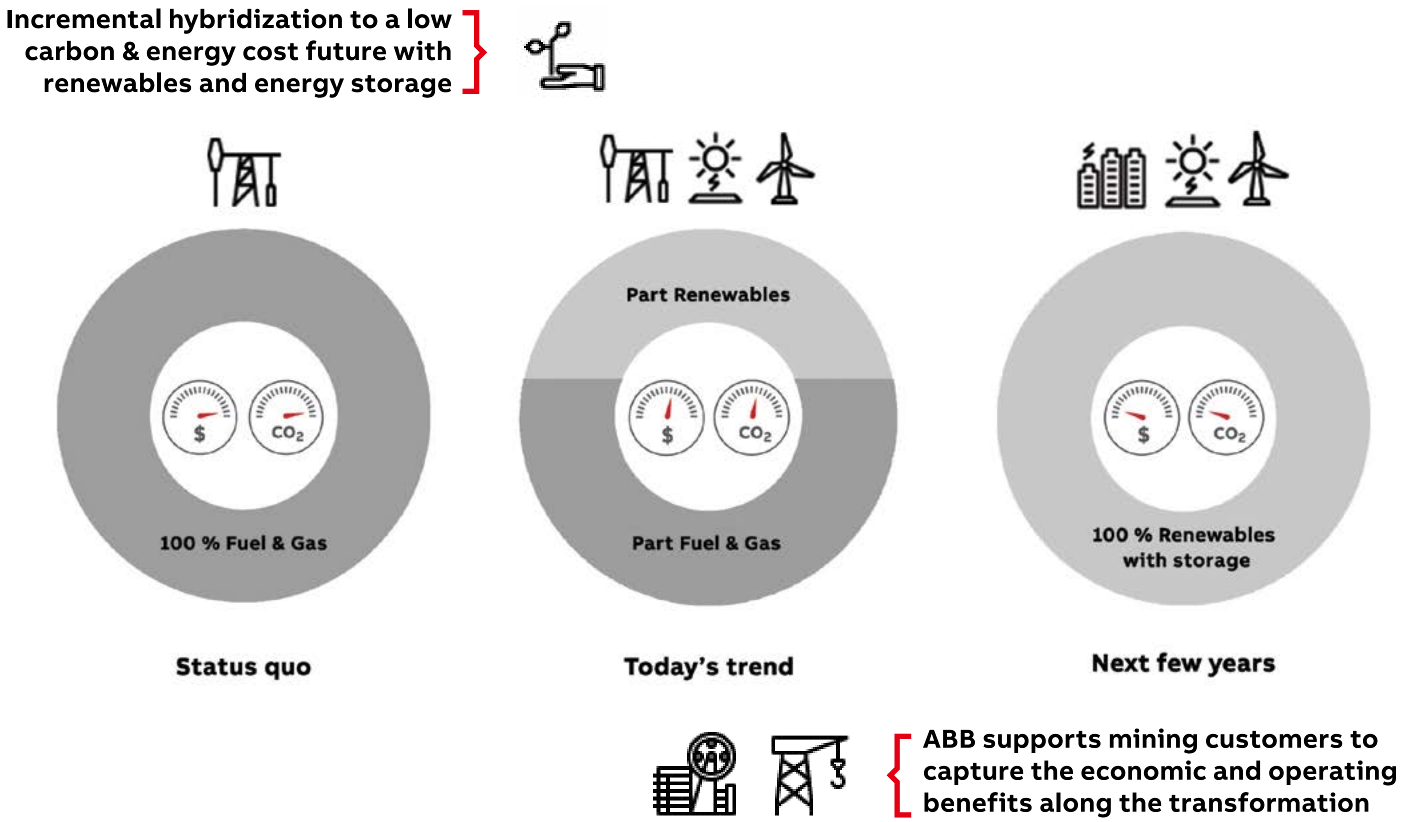

— **0 1** Electricity transformation of off-grid mining to battery energy storage and renewables already underway

For off-grid mines operating in remote locations, the cost of electricity can reach 300 USD/MWh[1] and consume up to 15% of mining revenues. Lowering energy costs will not only increase viability of mining operations today but also help future proof them against rising fuel costs.

To test the viability of storage plus renewables for brown field mining sites, we consider four scenarios that are optimized using HOMER Pro[2] microgrid modeling software.

The benefits compared include:

- Fuel saving (and associated reduction in CO2 emissions & maintenance costs)
- Reduced Levelized Cost of Electricity (LCOE) with an attractive Internal Rate of Return on investments (IRR)
- Improved power quality

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[1]ABB expert assessment and external references, e.g., Renewables for Australian Mines: Market Overview and Next Steps (Kate Dougherty, Energy and Mines)

[2]HOMER is an energy flow modelling tool that also takes the financial evaluation of a proposed hybrid system into account. HOMER Pro's modelling results are technology agnostic: the optimization is on the net present cost (NPC) of the system. The software is the global standard for rapid assessment of least cost solutions for clean, reliable, distributed power and microgrids (see www.homerenergy.com).

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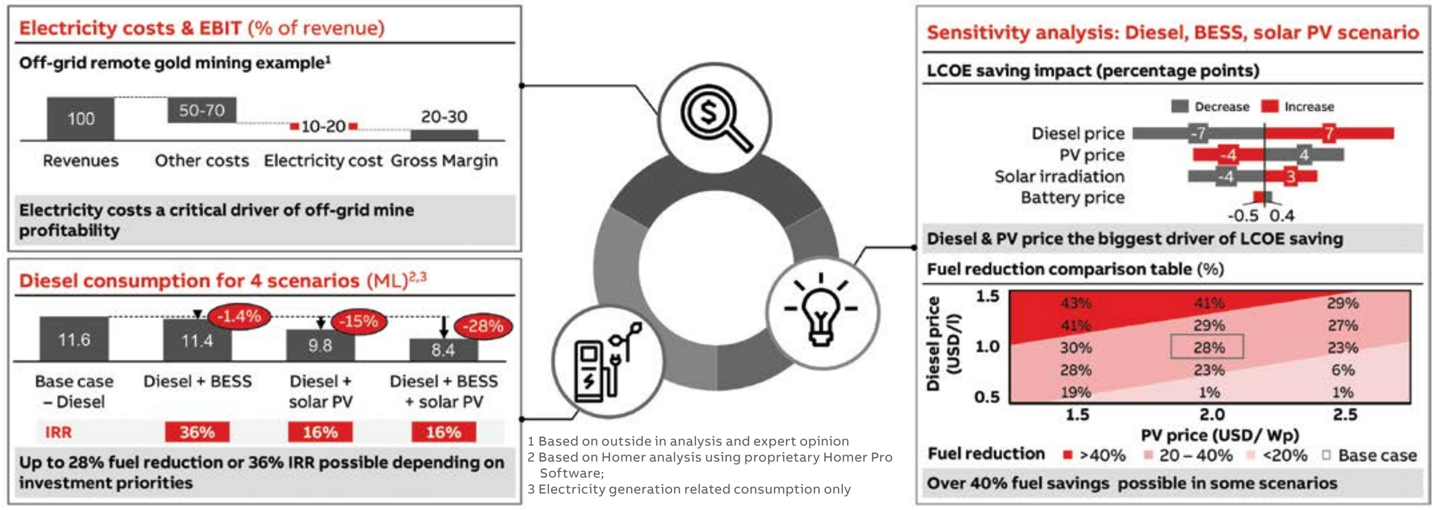

BESS + solar PV benefits for an off-grid remote brown-field mine (~5 MW demand example)

— **0 2** Over 40% fuel savings possible for some scenarios

The results (Figure 2) showed that the highest investment IRR of 36% was possible by installing a Battery Energy Storage System (BESS) where the main benefit comes from improved generator operational efficiency that results in a reduction in maintenance costs. Alternatively, by combining this with solar PV generation we can additionally substitute expensive diesel fuel with cost competitive solar PV thereby delivering the largest reduction in fuel consumption (28%) and LCOE (11%), while maintaining a healthy IRR (16%). Additional power quality benefits provided by a BESS such as reduced stress on the electrical installations across the mine site and associated reduction in maintenance cost and down-time have not been modelled in this study.

Finally, our analysis shows that the most important factor impacting system design is the price of delivered diesel followed by the cost of the installed solar PV system.

Two conclusions can be drawn from the business case:

- Mining companies have the opportunity to start transforming their mines today as solar PV now delivers a lower LCOE than diesel
- Deployment of solar PV + BESS is an excellent hedging solution against diesel price increases and/or future carbon costs

Benefits of storage and renewables in off-grid mining

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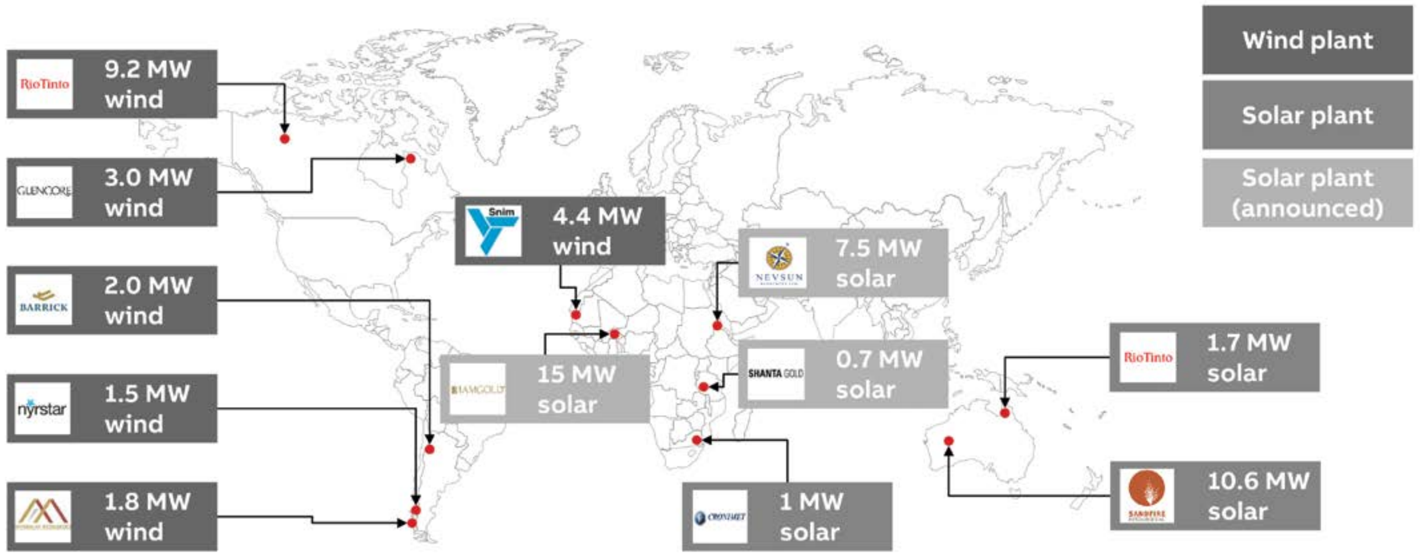

0 3 Selected mines with major on-site solar PV-diesel or wind-diesel microgrids

To date, diesel generation has a good track record in providing reliable power to off-grid mines. This traditional approach, however, also creates some well understood challenges:

- Power from diesel generators are high cost compared to energy supplied by a network
- Changes in diesel prices are difficult to predict and expensive to hedge long-term
- Additional carbon taxes on fossil fuels are likely to increase future diesel price
- Diesel deliveries can lead to logistical issues and additional transport and storage expenditure
- Electrification of mines and mobile plant increases demand over time

Renewables and energy storage systems have already proven themselves as an effective solution for generating high quality electricity. Figure 3 gives a global view of selected solar PV-diesel and wind-diesel microgrids[3], also known as hybrid plants, for powering off-grid mines[4]. Following the successful completion of numerous such projects, the focus is now on developing unsubsidized, profitable business cases that effectively reduce fuel dependency. Here a modular approach allows the hybridization process to be started with a smaller investment in either renewable energy or storage that can later by extended, for example, as framework conditions such as diesel fuel prices change.

The typical stakeholders in the path to hybridization include: the mining company itself, the project developer (internal or external), the financing company (debt versus equity), the EPC (Engineering, Procurement, and Construction), the technology suppliers and the O&M provider. Various business models among these players are possible, however an essential element across all models is the involvement of technology suppliers at an early stage of the design. Additionally, stakeholder management and commercial integration remains key in delivering a successful hybridization project.

[3] Microgrid can be defined as distributed energy resources and loads that can be operated in a controlled, coordinated way either connected to the main power grid or in "islanded" mode

[4] Hillig (2017), Mining Magazine, accessed online http://www.miningmagazine.com/man agement/water-environment/new-renewables-projects-for-mines/ on 19/05/2017

Four scenarios analyzed

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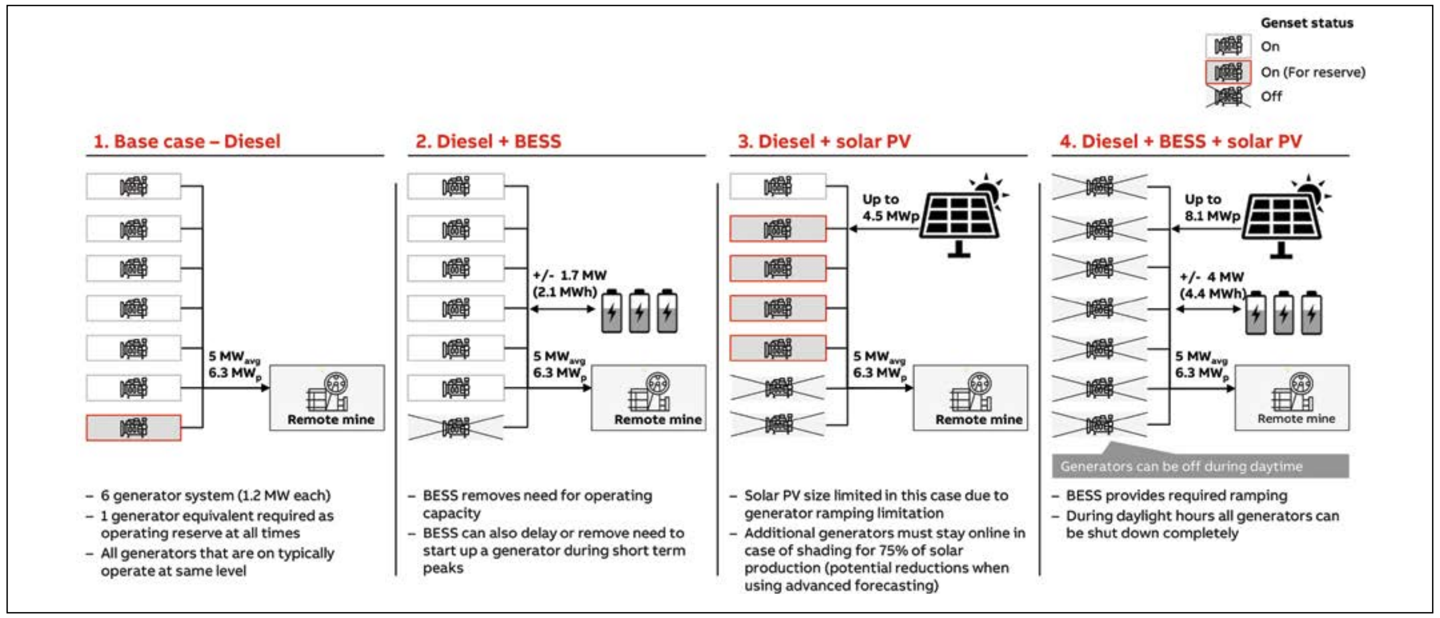

0 4 Overview of the 4 modelled scenarios

Background of simulated scenarios

The following scenarios consider various options for upgrading an off-grid mining operation with an energy storage system and / or a solar PV power plant. In total, four different scenarios are simulated and optimized to provide the lowest LCOE while achieving a minimum 10% IRR. As presented in Figure 4, these include:

- **Base case – Diesel:** Pre-existing diesel generators continue to supply power and operating reserve
- **Diesel + BESS:** BESS utilized to remove need for operating reserve as well as optimize the efficiency of the generators
- **Diesel + solar PV:** Solar PV plant without energy storage used to deliver fuel savings
- **Diesel + BESS + solar PV:** BESS now combined with solar PV to deliver improved diesel generator operating efficiency as well as increased solar PV integration

For all 4 scenarios, we assume a mine with a 24/7 average load of 5 MW with hourly (but no seasonal) variation. The peak load can reach a maximum of 6.3 MW. In addition to the load requirements, the minimum operating reserve of the power system is 1.2 MW - an entire generator's capacity. The generators are all a standard model benchmarked on a leading manufacturer. Each generator has a capacity of 1.2 MW and operates on diesel fuel. The minimum load ratio for the generator is 30% and the minimum run-time is 2 hours.

This case study only considers new investment costs for the hybrid system as the generators are already installed on-site. For comparing each scenario an all-in fuel price of 1 USD/L is used, which is inclusive of transport, taxes etc. The total CAPEX of the installed solar PV system, including inverter, is 2 USD/Wp[5]. In the simulation, the assumption for the solar irradiation[6] is 5 kWh/m^2. To account for cloud cover 75% of the PV's power output must be covered in the operating reserve by the diesel generators or the BESS. The BESS uses Li-ion batteries and the roundtrip efficiency is assumed to be 90%. The assumptions are rather conservative in that they reflect, for example, higher construction costs at remote locations.

[5] Solar PV installations costs vary significantly based on region and remoteness. 2 USD/Wp is a conservative estimate to take into account remoteness of a typical off-grid mine

[6] Typical solar irradiation level for much of Australia and South Africa

To assess LCOE and annualized costs, a 10% nominal discount rate is applied and project lifetime is assumed to be 10 years, after which the solar PV modules, BESS and inverter are assumed to have a salvage value worth a third of the original purchase price.

The HOMER Pro simulation tool combines the operating requirements (e.g., electrical and thermal demand, reserve requirements), to the physical assets (existing + additional) and key financial inputs (including investment, maintenance and replacement costs). Based on this, HOMER Pro runs generation dispatch analysis for a range of scenarios, and determines the most economic system to meet the operating requirements.

Base case - Diesel

The base case refers to the mine continuing to run the existing diesel generators as before. Six diesel generators with a 1.2 MW nominal rating are required to serve the load with one additional generator always online as an operating reserve in case any one of the six generators unexpectedly fails.

All generators operate in proportional load sharing which means each generator has the same capacity factor. The sum of spinning reserve[7] carried by all generators allows one generator to trip or the load to instantly increase without the need for load shedding. This operation leads to additional O&M costs from additional generator runtime as well as lower fuel efficiency due to a lower capacity factor.

At a diesel price of 1 USD/L, the base case has annual fuel costs of 11.6 MUSD and maintenance costs of 1.7 MUSD which results in an average annual operating cost of USD 13.3 MUSD and a LCOE of 304 USD/MWh[8] . The following scenarios are benchmarked to the base case.

Diesel + BESS

A BESS (e.g., ABB PowerStore[9]) is able to replace the diesel generator that serves the 1.2 MW operating reserve requirement as well as smooth certain demand peaks with battery storage (an additional 0.9 MW) thereby delaying or avoiding the start of a generator.

Total investment costs for a BESS solution meeting the modelled size requirements of 2.1 MWh/1.7 MW are estimated to be 1.5 MUSD. The simulation output shows a fuel reduction of 0.16 ML and an annual cost savings of 0.4 MUSD leading to a payback period of 2.7 years and IRR of 37%. The LCOE is reduced from 304 to 295 USD/MW, mainly due to a reduction of generator maintenance costs.

[7]Spinning reserve is the extra generating capacity that is online and available by simply increasing the power output of generators

[8]LCOE excludes capital cost of generators (pre-existing) and transmission and distribution as this is the same for all scenarios

[9]PowerStore™ is a reliable containerized plug-and-play microgrid solution, available in various ratings with a standardized specification for installations including remote villages as well as industry and utilities. Its "Virtual Generator" can form the grid, and integrate up to 100% of renewable energy

Diesel + solar PV

This scenario pursues an alternative path to hybridization initiated by a PV-only upgrade without energy storage. Here we replace diesel fuel by cost competitive solar PV. In this configuration, the integrated solar PV system is limited by the minimum loading of the diesel generators in combination with their step load capabilities.[10]

As the ideal solar PV generation capacity exceeds the step capability of the generators, the PV capacity is limited to 4.5 MW. Installing this PV system requires a CAPEX of 9.0 MUSD. As a result, the LCOE is reduced from 304 to 289 USD/MWh with fuel savings the primary value-driver for this system at 10 times the level of the diesel + BESS scenario. The payback time is 5.2 years and the IRR is 16%, somewhat lower than the diesel + BESS scenario that had an IRR of 36%.

Diesel + BESS + solar PV (Maximum Savings)

In this scenario, the two technologies are combined. An investment of 19.4 MUSD is required to add a solar PV system of 8.1 MWAC and a BESS of 4.4 MWh/4.0 MW.

The solar PV plus BESS system reduces annualized costs from 13.3 MUSD down to 12.0 MUSD, a saving of 1.3 MUSD annually, primarily due to 3.2 ML of fuel reduction. The solution offers maximum value stacking from the storage component as it substitutes the diesel generator as operating reserve, smoothing demand peaks, and also allowing maximum solar PV integration.

The investment returns an IRR of 16% with a payback period of 5.2 years and is easily the best option from the perspective of lowering LCOE. In this case, an advanced BESS has the additional benefit of effectively managing the fluctuations caused by renewable energies, e.g., cloud cover[11] , while continuing to deliver high quality power.

Recap

The transformation to a solar PV + BESS microgrid can be achieved through incremental hybridization investments thereby lowering investment risk and effectively responding to changing market conditions such as increased delivered fuel price or decreased solar PV price. Depending on the business objectives, it is possible to either maximize investment IRR by adding only a BESS, or alternatively reduce diesel consumption and associated carbon emissions and delivery risks by investing in a solar PV + BESS solution. The summary of all scenario results are presented in Figure 5.

0 5 Simulated results across four scenarios

Scenario		Additional investment			Operation costs						Economic benefit	
		BESS (MWh)	PV (MWp)	Initial inv. (MUSD)	Gen. use (1000h/yr)	Fuel use (ML/yr)	Fuel cost (MUSD/ yr)	Mtce cost (MUSD/ yr)	Total cost¹ (MUSD/ yr)	LCOE (USD/ MWh)	IRR (%)	Payback (yr)
1 Base Case – Diesel only	Output	-	-	-	50.1	11.6	11.6	1.7	13.3	304		
2 Diesel + BESS	Output	2.1	0	1.5	37.6	11.4	11.4	1.3	12.9	295	37%	2.7
	Change (in %)				-12.5 -25%	-0.16 -1.4%	-0.16 -1.4%	-0.4 -24%	-0.4 -3%	-9 -3%		
3 Diesel + solar PV	Output	-	4.5	9.0	48.3	9.8	9.8	1.7	12.7	289	16%	5.2
	Change (in %)				-1.8 -4%	-1.8 -15%	-1.8 -15%	- -	-0.60 -5%	-15 -5%		
4 Diesel + BESS + solar PV	Output	4.4	8.1	19.4	28.6	8.4	8.4	1.1	12.0	273	16%	5.2
	Change (in %)				-21.5 -43%	-3.2 -28%	-3.2 -28%	-0.6 -35%	-1.3 -11%	-31 -11%		

NOTE: Numbers may be affected due to rounding
1 Includes annualized investment costs

Optimized results for each scenario (as modelled using Homer software)

0 5

[10]Step load capacity is the maximum amount of power a generator can produce within a certain time to recover PV output lost due to cloud shading of the array

[11]Similarly relevant for other intermittent resources such as wind power

Evaluation of assumptions

06

Diesel price the largest single driver of LCOE savings, followed by solar PV price

06 Tornado chart shows the LCOE savings impact by driver

To better understand the drivers of LCOE savings, the full hybridization scenario, diesel + solar PV + BESS, is analyzed for a range of input factors. This sensitivity analysis includes diesel fuel price, installed solar PV price, battery price (excl. converter) as well as solar irradiation.

As presented in Figure 6, diesel costs are found to have the highest impact on LCOE savings with an increase in fuel price from 1.0 to 1.5 USD/L leading to an increase in savings of 6.5 percentage points versus the base case. To further assess the impact of diesel and solar PV prices, Figure 7 shows the recommended microgrid system configuration, resulting fuel saving and LCOE saving as diesel and PV prices vary. Under the majority of the conditions evaluated, a mine would achieve an IRR of above 10% for the upgraded systems adding both BESS and solar PV.

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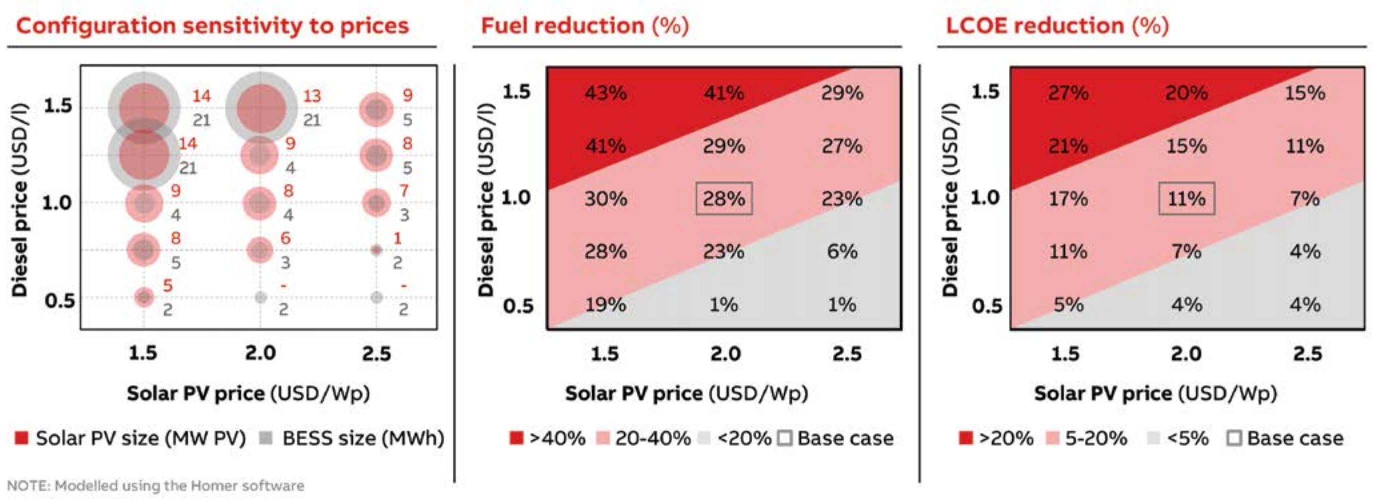

Low solar PV price and high diesel price leads to large systems with up to 40% fuel saving

07 Bubble chart showing optimal solar PV and BESS size as solar PV price and diesel price vary

As diesel prices increase, or PV prices decrease, the size of the optimized solar PV and BESS becomes larger. Under some scenarios, when diesel is very cheap and PV is very expensive, it no longer makes sense to install PV purely from an economic perspective. Under these conditions, it may be best to first install a BESS and add solar PV as their price decreases, or the price of diesel increases.

Conclusions and next steps

Powering remote mines with diesel generators provides a proven and reliable energy source, but leaves the mine operator vulnerable to diesel price fluctuations, fuel supply risk as well as uncertainty around future carbon taxes. It also fails to capitalize on the economic and operating benefits that BESS and solar PV offers today and potential cost savings from carbon taxes in the future. Figure 8 presents an overview of the economic benefits and capital requirements of the four scenarios tested.

In some cases, mine operators may prefer the incremental hybridization route as it allows more gradual changes to the operating system and strategy. This analysis shows that it makes sense to consider BESS in the first step without additional renewable energy capacity as this offers the highest IRR. Ideally, the use of a flexible BESS, such as the ABB PowerStore would allow the storage capacity to be increased if renewable energy systems are later added.

In terms of renewable options, wind has also proven itself to be effective in the mining sector, particularly in those areas with high wind resource and low solar resource. Due to historically lower costs, high scalability and relative ease to gain approvals in remote locations, wind has accounted for 59% of installed renewables in mining to date[12]. Where mine lives are shorter than 10 years new business models[13] allowing for relocatable solar PV to be installed could be considered. Once you have found the right renewable choice for your location, combining with a BESS can provide additional cost-savings that mining operators can benefit from today.

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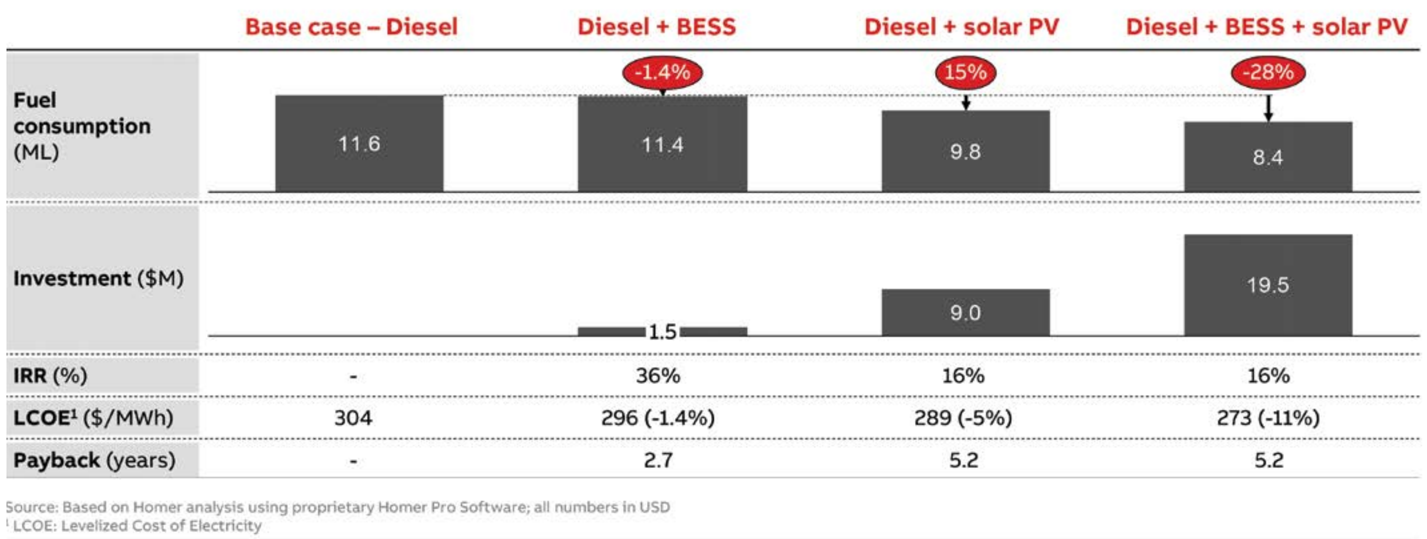


Up to 28% reduction in fuel and CO_2 possible when combining diesel with BESS and solar PV

08 Overview of results

[12] 552MW wind versus 391MW solar thermal and solar PV (Source: "Energy and Mines Global Rankings 2016")

[13] For example, see www.sunshift.com

ABB Microgrid Solutions

ABB provides expertise and experience in designing optimized microgrid solutions with a proven track record of hybridizing mining power plants with BESS and renewable energy. The flagship product and solution for the mining sector is ABB's PowerStore™ (Figure 9). It is a standardized, containerized solution which can be easily transported to any mine site. Together with ABB´s remote portal, customers have 24/7 support by ABB experts allowing them to further optimize their mine's operations.

09

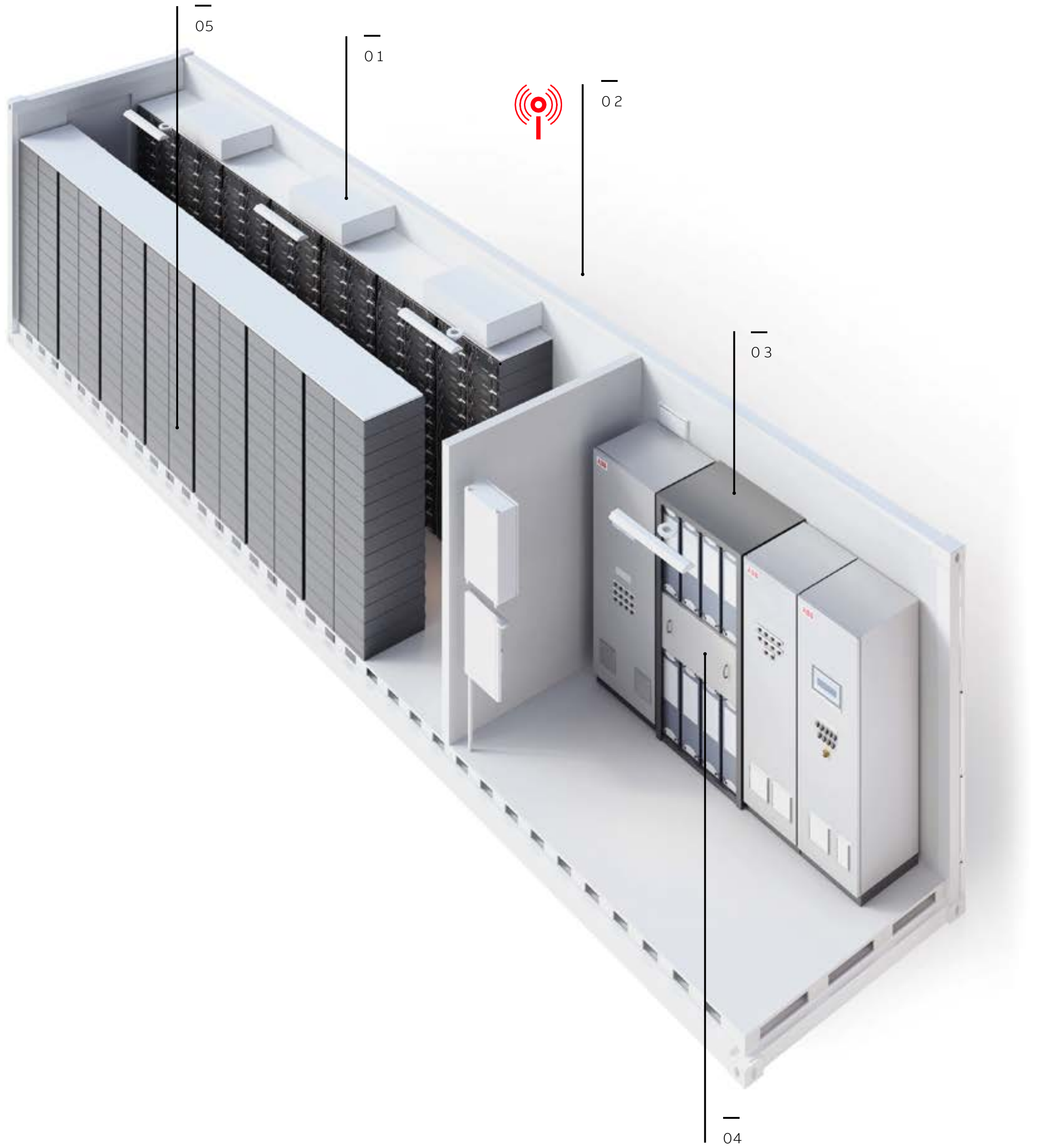
01 Climate Control
Maintaining temperature inside the container within an acceptable operating limit at all times

02 Remote Monitoring
Comprehensive solutions for unattended sites to increase productivity.

03 Built-in PowerStore™ Automation
Dedicated Microgrid plus control system delivered pre-programed to meet the application needs

04 PCS100
PowerStore™ Conversion System
- Scalable
- Modular
- Grid Forming
- Virtual Generator

05 Lithium Ion Batteries
Battery module, Racks, and Battery Management System (BMS) Interface
- Easy maintenance
- Online replaceable
- Hot-swappable



09 ABB PowerStore™ solution

[14]For further information, please see http://new.abb.com/microgrids

ABB's product range[14] covers the entire microgrid portfolio, starting with the 60kW to multi-megawatt PowerStore™, using ABB's broad range of string and central solar PV inverters in modular, containerized solutions. Additionally ABB provides low and medium voltage switchgear, protection relays, transformers and electrical balance of plant.

Whatever your mining electricity needs, ABB can assist you to design and implement the best strategy for mining energy and technology upgrades, saving you money while ensuring delivery of reliable and high quality power. We are a leading provider of microgrid products and solutions that offer a complete end to end approach from initial consultancy through to remote monitoring.

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ABB India Contact Center

Tel **1800 420 0707**
Toll free number within India
+91 80 67 143 000
International number

E-mail contact.center@in.abb.com

www.abb.com/microgrid

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