GOLD FIELDS AGNEW GOLD MINE

HYBRID MICRO-GRID PROJECT

KNOWLEDGE SHARING FINAL REPORT

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 PROJECT OVERVIEW

The Agnew Renewable Energy Microgrid Project demonstrates a new type of hybrid microgrid at Gold Fields Australia's Agnew gold mine in Western Australia. It is located in Leinster, Western Australia.

Agnew's hybrid microgrid consists of an 18 MW wind farm with 5 wind turbines, a 10,710-panel, 4 MW solar farm, a 13 MW / 4 MWh Battery Energy Storage System (BESS) that underpins the security and reliability of the microgrid, and an 18 MW gas and diesel engine power station as back-up – all managed by an advanced control system. The security of the microgrid is further supported by predictive solar forecasting technology and demand-side load management.

Figure 1: Aerial View Microgrid Components

The Agnew hybrid microgrid is forecast to deliver an annual average of 54% renewable energy to the Agnew mine and reduce the mine's carbon emissions by some 40,000 t CO_2 e/year, the equivalent of removing 12,700 cars off the road[1]. In favourable weather conditions, the power station has delivered over 85% of the mine's power requirements with renewable energy.

ARENA provided the project with $13.5 million in funding under ARENA's Advancing Renewables Program.

This project is providing a blueprint for organisations to deploy similar off-grid energy solutions and demonstrate a pathway for commercialisation of low emissions technologies by de-risking the technical and commercial integration of high renewable energy fraction power solutions.

When constructed in 2020, the Agnew Hybrid Renewable Energy Microgrid was Australia's largest hybrid renewable energy microgrid. It is also the first in Australia to utilise a large-scale wind farm as part of a mining microgrid.

Developed, constructed and operated by EDL, the microgrid comprises five components, as listed on the following pages.

"When constructed in 2020, the Agnew Hybrid Renewable Energy Microgrid was Australia's largest hybrid renewable energy microgrid.

[1] https://edlenergy.com/wp-content/uploads/2021/10/EDL-Fact-Sheet-Agnew-Hybrid-Renewable-Microgrid.pdf

Component 1 – 18 MW Wind Farm

The wind farm is constructed from five, 110 m-high wind turbines, each with a rotor diameter of 140 m and a combined capacity of 18 MW.

Parameters include:

- 5 Goldwind GW140 3.57 MW permanent magnet drive with full converter system;
- 110 m hub height;
- 140 m rotor diameter.

At full power, blades rotate at a rate of only 12 rpm but the tip of the turbine blades are moving at a speed of 320 km/h.

Figure 2: Agnew's five Goldwind 3.57MW wind turbines

Component 2 – 4 MW Solar Farm

The solar farm is made up of 10,710 solar panels, generating 4 MW.

Parameters include:

- 10,710 x Suntech 370 W panels;
- 5 MVA SMA centralised solar inverter;
- Nextracker single axis tracking system;
- Steadysun cloud forecasting camera system.

Figure 3: Solar Farm Array

1 PROJECT OVERVIEW (CONTINUED)

Component 3 – BESS

The BESS has a capacity of 13 MW/4 MWh.

Parameters include:

- SAFT Li-ion NMC/NCA battery storage;
- 6 x 2.5 MVA SMA centralised storage inverters.

Figure 4: Inside the Battery Energy Storage System

Component 4 - 21 MW gas/diesel engine power plant

The thermal power plant is primarily fuelled by natural gas with a small amount of diesel as backup in case of a gas shortage.

Parameters include:

- 9 x 2 MW Cummins QSV91 reciprocating gas engines
- 2 x 1.6 MW Cummins QSK60 reciprocating diesel engines
- 25 km gas lateral pipeline.

Figure 5: Gas and Diesel Plant (foreground)

Component 5 – Microgrid control system

The overarching control scheme responsible for the interface between each microgrid components is hosted on a PLC based platform and was supplied and commissioned by Entura. The microgrid controller is programmed to dispatch the various energy sources according to the following order of priorities:

1. Ensuring the security and quality of supply of electricity
2. Maximising the utilisation of available renewable energy
3. Maximising the efficiency of gas generation.

2 HOW THE PROJECT OUTCOMES WERE ACHIEVED

ARENA's funding of the Agnew microgrid project contributed to the delivery of the specific outcomes, including:

- increased industry knowledge;
- increased understanding of:
  - the business case for hybrid microgrids;
  - the operation of microgrids;
  - predictive wind and solar technology; and
  - the scope of investment decisions; and
- assessment of strategies to utilise curtailed renewable energy.

These project outcomes are further detailed in the sections below.

2.1 Increased Industry Knowledge

Increased industry knowledge regarding the technical and commercial effectiveness of hybrid microgrids involving solar, wind and storage.

Since completion, the publicity and awareness around the success of the Project has reached far and wide, through press releases, media articles, social media and conference presentations *(refer to Appendix 1: Media Examples, page 36)*. This awareness has given industry a measure of confidence that projects of this nature are viable and that the 'guinea pig' for high-penetration microgrids has survived.

2.1.1 Reduction in Commercial Cost

The Project demonstrates a pathway to a reduction in commercial cost of renewable microgrids, by promoting a reduced perception of risk with microgrids (coupled with new commitments to Environmental Social Governance (ESG)) which will increase supplier competition (reducing risk premiums) and tease out alternative, lower-cost financing solutions.

Challenges do remain. For example, small-scale wind farms will continue to be a challenge due to the logistics of mobilising large cranes and concrete batching plants. It is noted in particular that the availability of cranes of sufficient size to erect wind farms, is limited.

However, the cost of solar, wind and battery projects are on their own continuing to approach commercially-competitive levels through economies of scale. The Project has demonstrated that where wind and solar resources are complementary (wind predominantly after sundown), they are an effective combination.

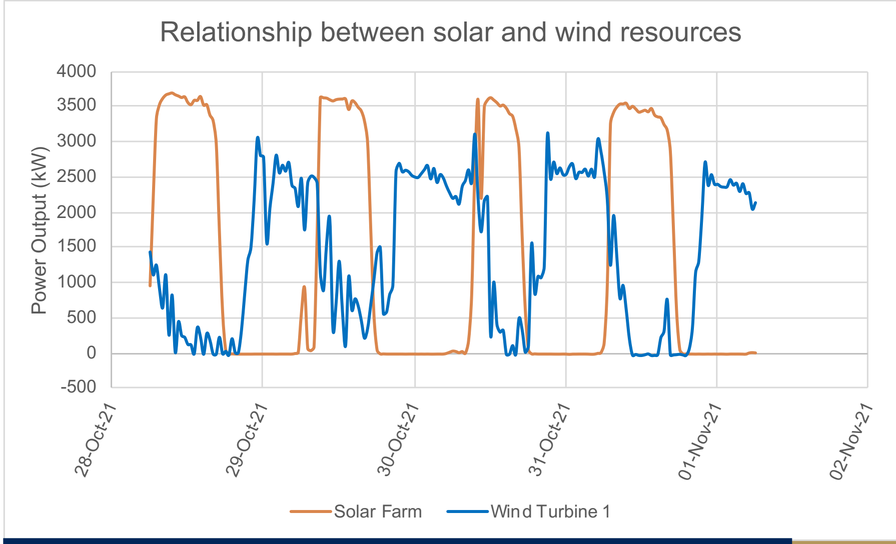

Figure 6: Relationship between solar and wind resources

The Diurnal Effect

Figure 6: Relationship between solar and wind resources, above, illustrates how wind and solar are complementary, in that the wind is present at night when solar is not and vice versa. Source: Data from Agnew. It is noted that each site will differ, in terms of availability of wind and solar, depending on local climatic conditions.

2.1.2 Improved Procurement Processes

The Project has aided the procurement process by demonstrating that the each of the Project's technologies can be broken down into discrete projects (wind farm, solar farm, thermal power plant and battery storage), with the microgrid controller integrating each project into a single power solution. This opens up the market to competitive tendering for each technology and the ability to access green leasing finance, which will reduce the overall commercial cost.

2.1.3 Allocating Risks Throughout Project Development and Deployment

The Project model for equitable risk allocation remains appropriate after commissioning and has ensured a sound working relationship between the off taker and energy supplier. Commercially, it demonstrates that there are opportunities for the off taker to allocate more risk to the energy supplier while there is competitive tension in the procurement process, through more onerous renewable energy guarantees. However, the wind and solar resource datasets provided to the energy supplier at tender must be more robust than what was made available by the Project. The Project highlights that investing in renewable energy is effectively 'prepaying' for energy but by prepaying, the mine must be able to amortise all of the expenditure over its life. So it is currently only feasible to decarbonise with traditional wind and solar if the underlying asset (the mine) has the reserve to sustain it long enough to amortise the expenditure effectively.

It is anticipated that more redeployable technologies will become available to mitigate this risk for assets with shorter lives, such as 5B's Maverick solar system[2] and Cambridge Energy Partners for solar.

The following tables expand upon the concept of risk allocation. They illustrate how various risks within the Project were apportioned either to the independent power producer (IPP) or to Gold Fields. This is of course simply an example. Each project will include project-specific risks and a project-specific method of risk apportionment.

[2] https://5b.co/solutions

Table 1: Example Allocation of Construction Risks

Construction Items	EDL Responsibility	Gold Fields Responsibility
Flora and fauna and heritage surveys		✓
Drainage studies		✓
Mining proposal and clearing permit		✓
Site offices, ablutions (including effluent disposal), crib room, construction power, potable water, internet, phone	✓	
Clearing and levelling of site		✓
Construction of access road		✓
Site drainage		✓
Site fencing	✓	
Supply of road base material / gravel	✓	
Supply of bedding sand	✓	
Supply of concrete	✓	
Supply of construction water		✓
Supply of diesel fuel	✓	
Freight to minesite	✓	
Unloading of freight	✓	
Construction waste disposal	✓	
Flights between Perth WA and minesite and accommodation in mine camp in accordance with the construction schedule		✓
Power and communications interconnection between mine and power facility		✓
Permanent water and effluent connection to power facility and effluent disposal		✓

Table 2: Example Allocation of Operating Risks

Operating Items	EDL Responsibility	Gold Fields Responsibility
Power facility operations, capacity and supply security	✓	
Power facility maintenance	✓	
Thermal fuel supply		✓
Renewable resource availability (wind and sun)		✓
Solar and wind generation availability	✓	
Flights between Perth WA and minesite and accommodation in mine camp during operations		✓
Permanent water an effluent connection to power facility and effluent disposal		✓

The general principle of allocation of risk (between a buyer and a seller) is that the risk is managed by the party which is in the best position to manage that risk. In the wind risk example, it is the mine owner which bears that risk, as they selected the location for the wind turbines (the minesite). Latent conditions risk generally goes to the mine owner as well, as they own the land.

2.1.4 Economic Costs and Benefits

The Project has demonstrated that investing in renewables is a change in risk profile for miners. Prepaying for energy (via the capital cost of building a renewable energy power generating facility) requires a significant, upfront investment, which tests the strength of the balance sheet and may not be feasible for small cap miners with smaller capitalisations. The long-term benefits, however, are compelling for mining assets with longer lives, as the marginal cost of renewable energy is very low; creating opportunities for improving the resource evaluation and possibly extending mine life.

Figure 7: Amortisation Comparisons, below, illustrates the marginal cost of energy after amortisation of the capital outlay, for several configurations, as an example of how alteration of the project components can change the LCOE. In all three scenarios as illustrated, the capital outlay is 'paid back' by year 10.

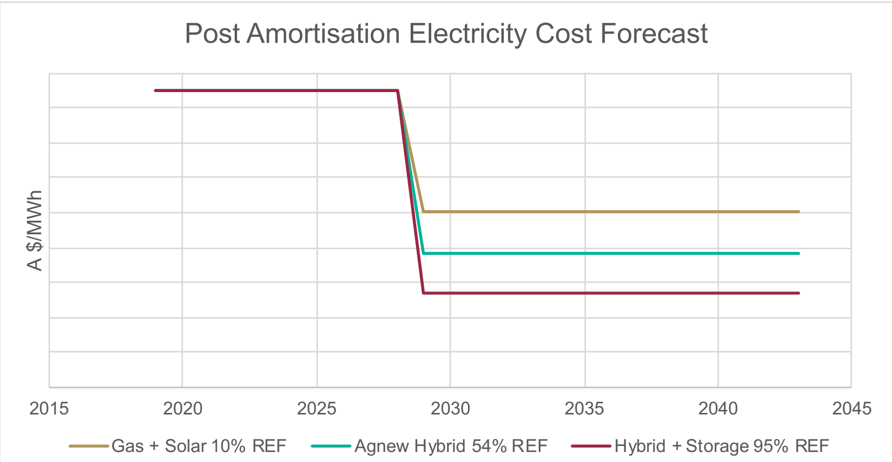

Figure 7: Amortisation Comparisons

2.2 Increased Understanding of the Business Case for Hybrid Microgrids

Increased understanding of the business case for hybrid microgrids supplying energy to mines in Australia.

In the last 12 months, Gold Fields (and its peers) have seen an increase in investor interest in the handling of ESG matters by the mining industry. There have been comments made that many investors are currently more focused on ESG matters than they are in the profit being made. In 2020, Gold Fields released its first dedicated 'Report to Stakeholders' with an accompanying CEO ESG presentation detailing how Gold Fields is integrating ESG in the business. Gold Fields' renewable energy projects featured regularly as part of these communications. In December 2021, Gold Fields followed this up with the announcement of a range of 2030 ESG targets, headlined by the company's commitment to reduce its Scope 1 and 2 carbon emissions by 30% by 2030 and to achieve net zero emissions by 2050[3]. About two-thirds of the planned 2030 emission reductions will derive from replacing traditional carbon-based electricity with renewable energy sources. By 2050, all of Gold Fields energy is scheduled to derive from renewable energy. The success of the Agnew Microgrid provides investors and stakeholders with a level of comfort that these targets are indeed achievable.

Although the issues described above do not directly relate to the business case for hybrid microgrids (as an operating cost), the value for the Project is reflected in the ability of Gold Fields to retain investors and attract new investors. This in turn drives up the share price via increases in the market capitalisation, providing an increase in value to all investors.

This component of the business case was anticipated in the Gold Fields request for the board's approval of the Project. However, the benefit described above could not be quantified. Even now, the value cannot be properly quantified.

At a purely commercial level, the business case becomes more compelling, the longer the amortisation period (at least 10 years, with 25 years most desirable) and offers an increase in power generation diversity, a reduction in exposure to fossil fuel price volatility, supply risk and carbon pricing. As has been discovered more recently, the cost of solar PV is continuing to decline (larger panel output reducing construction materials and labour) which ensures a lower LCOE (Levelised Cost of Electricity) and encourages higher renewable fractions.

[3] https://www.goldfields.com/pdf/investors/presentation/2020/gold-fields-report-to-stakeholders-new.pdf

2.3 Increased Understanding of the Operation of Microgrids

Increased understanding of how control and integration design and operation (in hybrid microgrids) can improve issues related to intermittency and reliability for energy supply to a mine.

Aside from ensuring adequate power generation is available to match the load (as is typical with a regular power station control scheme), the Project's microgrid control system (MCS) ensures there is a minimum level of frequency regulation support from synchronous generation (gas engines) and measure the state of charge in the BESS (Battery Energy Storage System) before determining the maximum renewable energy setpoint. If there is more renewable energy available than the setpoint, it will curtail renewable energy. If there is not enough renewable energy, it will supplement with gas generation from the thermal power station.

The intermittency of renewable energy is buffered by the battery, with gas generation able to be brought online before the battery loses its charge. When levels of renewables are high (above renewable energy setpoint), the intermittency is absorbed by curtailment in conjunction with the BESS. When renewables are low, the scale of the intermittency is much smaller and is managed through thermal station spinning reserve.

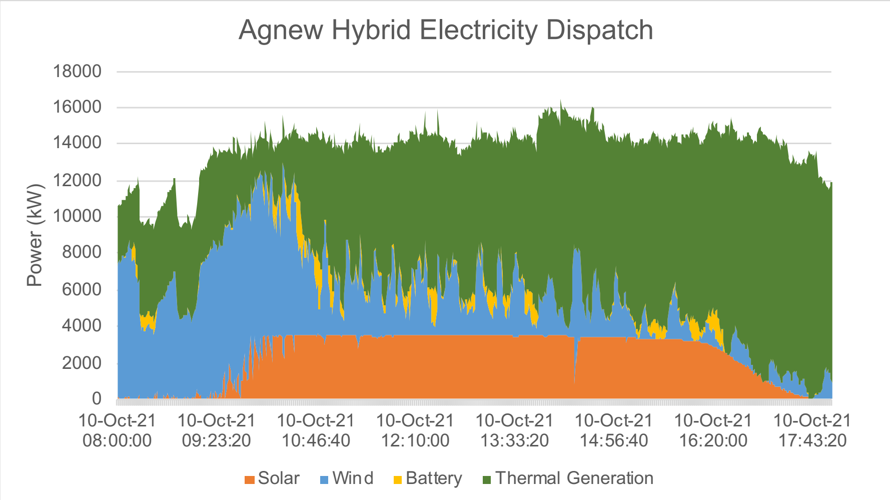

Figure 8: Variation in energy sources over time

Figure 8: Variation in energy sources over time, above, illustrates the concept of buffering. When the wind drops off, the battery provides power and then either the wind picks up again or gas power takes its place. Battery buffering lasts 15 minutes and while it is buffering, the gas engines start up. The gas power station can meet the full mine demand on its own, so if there are no renewables for hours or days, there is gas in the pipeline to keep the mine running. In the future, this would ideally change, to reduce overall emissions.

Over a year, the mine gets 54% of its energy from renewables, so the other 46% is from gas. There is not one single gas generator, there are 9 gas units (2 MW each) and we run a minimum of 2 gas units at all times. As the sun goes down or the wind drops off, units will be brought on incrementally, to ensure there is enough capacity of gas engines online.

Thanks to the large power output sizing of Agnew's BESS (13 MW, near to full mine load), the intermittency of renewables does not affect the reliability of electricity supply to the mine. In fact, Agnew has 99.99% reliable energy supply due to its diversity in power generation technologies and the seamless integration of the battery with the other generation sources.

Explainer

Renewables for a mine are sized depending on economics and the mine's ambition for achieving a renewable fraction. The battery is sized depending on the responsiveness/ capability and size of the mine's thermal generators and how much spinning reserve the mine wants to keep running. Battery cost feeds back into the overall economics, which may adjust the mine's ambition for achieving a target renewable fraction.

Figure 9: Construction of wind turbines

2.4 Increased Understanding of Predictive Wind and Solar Technology

Increased understanding of how the implementation of predictive wind and solar technology and demand side dynamic load shedding can improve the performance of hybrid microgrids for mine energy supply.

To date, only predictive solar technology has been implemented in the Agnew microgrid. A commitment has been made to consider day-ahead wind forecasting by June 2024 and this will be reported on at a later date.

Agnew's predictive solar technology utilises a Steadysun sky imager[4] to feed forecasts of cloud coverage approaching the solar farm into the MCS. This can give the MCS time to schedule gas generation ahead of the loss of solar energy (to ensure adequate power generation is available to match the load), thereby assisting to provide the mine with secure and reliable electricity.

However, as the Agnew microgrid has adequate instantaneous power available from the BESS and the solar has a relatively low penetration, the benefit of predictive solar technology to Agnew is not significant. Theoretically, forecasting technologies would allow a microgrid designer to reduce the output power sizing of the BESS (reducing capital cost) however this will increase use of fossil-fuelled thermal generation (from increased pre-emptive scheduling of generators). As the end game is to reduce the use of thermal generation (ideally to zero) a BESS with a minimum state of charge is a more effective tool for managing the variability of renewables in a low-carbon microgrid.

Demand-side dynamic load shedding has been implemented at Agnew but its use is limited to 'last resort' and with the reliability offered by the BESS, to date it has not been initiated. The use of dynamic load shedding protects the microgrid from total blackout. However, the impact of a blackout to the mine's production can be significant and may trigger an underground mine evacuation due to loss of power to ventilation systems. Agnew's investment in a robust power solution is 'paid back' by the potential production losses that are imagined if dynamic load shedding was the first line of defence against power station blackouts.

[4] https://www.steady-sun.com/swx-series-sky-imager-for-steadyeye/

2.5 Increased Understanding of the Scope of Investment Decisions

Increased understanding of the minimum scope of resource tests required to inform investment decisions (specifically related to wind resource availability VS feasibility study assessments).

Gold Fields took the Agnew project to the IPP (Independent Power Provider) market for tender after collecting only 3 months of wind resource data, sourced from a rented, onsite measurement unit (trailer-mounted SODAR (Sonic Detection and Ranging)). Historically, wind farms have been designed using datasets from met masts (tower structures) with a minimum 12 months of data in order to be bankable. Financiers typically need at least 3 years of data to capture variability of seasons year to year, so it was uncertain how the limited data set would be received.

The rationale for the Project using the SODAR rather than a met mast was the simplicity of the logistics of deployment, offering cost and time savings. Additionally, the SODAR measures wind speeds at a height of 200 m above the ground and DNV will certify SODAR data as bankable where DNV-certified instruments are used[5].

The reason for taking a short data set to market was the need to have an IPP selected to meet the project deadline. In their tender, the IPPs were able to extrapolate Agnew's 3-month data set by correlating with other wind resource data from the region. This enabled wind turbine selection, wind farm sizing and modelling of wind farm output, including the microgrid's expected renewable fraction. Agnew took the risk on the wind resource, so the IPPs were not exposed to providing a wind generation guarantee, only the equipment availability and performance guarantees.

Post IPP selection and during detailed design, the SODAR at Agnew continued to collect wind data until a full 12 months of data had been collected. The complete data set was then used to validate the extrapolated dataset. Wind turbine selection and wind farm sizing did not change between the 3 month dataset and the 12 month dataset.

Learning:- For new projects, having no wind data shouldn't mean a 12-month delay before any assessment of the viability of a wind project can be made. Work can start using freely-available datasets

Meterological towers ('met' towers) have a standard height of 60 m, although taller towers are possible. Cup anemometers are mounted to the towers to measure wind speed.

However, the hub height and rotor diameter of wind turbines are now very large and increasing.

SODAR (Sonic Detection and Ranging) can measure wind speed as a function of height – up to 200 m above ground. They are reasonably easy to assemble and transport.

Measurement uses the Doppler shift phenomenon, where a fixed observer perceives an apparent change in frequency of an acoustic signal, relative to a moving source. This apparent frequency is calculated at several points in the area, to deduce the vector wind speed. High frequency (e.g., 4500 Hz) acoustic signals are emitted from the SODAR in three directions, one beam in the vertical and two orthogonal beams tilted approximately 17 degrees from vertical.

Moving layers of air in the atmosphere reflect the acoustic waves, resulting in some of the signal to return back to the SODAR, which measures them.

[5] https://www.fulcrum3d.com/2015/08/05/fulcrum3d-sodar-achieves-bankable-status-dnv-gl/

2.5 Increased Understanding of the Scope of Investment Decisions (continued)

such as AREMI or NASA. Assumptions made using these datasets can then be validated using localised instrumentation and as more data is collected, more assurance can be given.

The scope of resource testing required really comes down to the project financier's required level of certainty to make an investment decision. Prior to obtaining this level of certainty, the engineering and procurement side can be progressed and refined over time.

Figure 10: SODAR compared to a meteorological (met) tower below, illustrates the comparison of meteorological ('met') towers compared to SODAR. The figure is from the University of Massachussets Amherst.

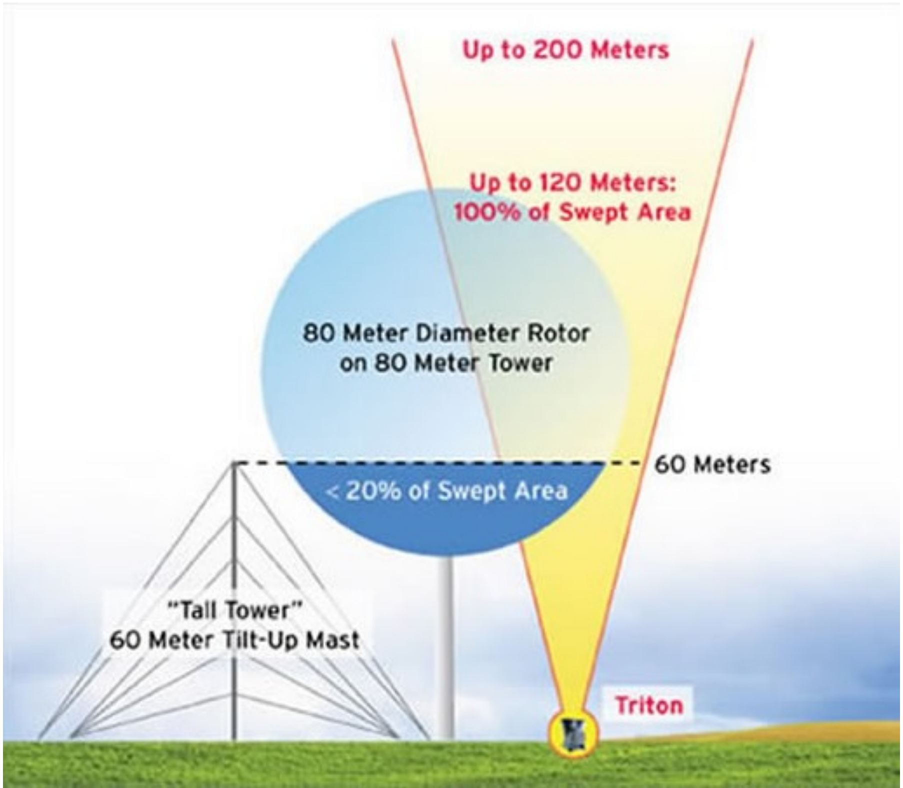

Figure 10: SODAR compared to a meteorological (met) tower [6]

[6] SOURCE: https://www.umass.edu/windenergy/research/topics/tools/hardware/sodar

2.6 Assessment of Strategies to Utilise Curtailed Renewable Energy

Assessment of strategies to utilise curtailed renewable energy

Being an islanded microgrid, with more installed wind generation capacity than mine load, Agnew is unable to utilise the excess energy produced by the wind farm (or spill it into another grid) and so it is curtailed by limiting the output of the wind farm. The reason for installing more wind generation is to maintain a high level of wind penetration, even at lower wind speeds.

Although curtailed energy is an inefficiency for the Project, the fact is that due to the variable nature of renewable energy and the synchronous stability requirements of microgrids, then designing a microgrid with a factor of curtailment is currently the lowest cost method of achieving a mid to high level (50% – 80%) of renewable fraction. That is, the economic cost of procuring incremental renewable generation is lower than procuring the equivalent level of output from energy storage. Above this level, there are diminishing returns for renewables and adding storage will improve LCOE. The Figure 11 illustrates this.

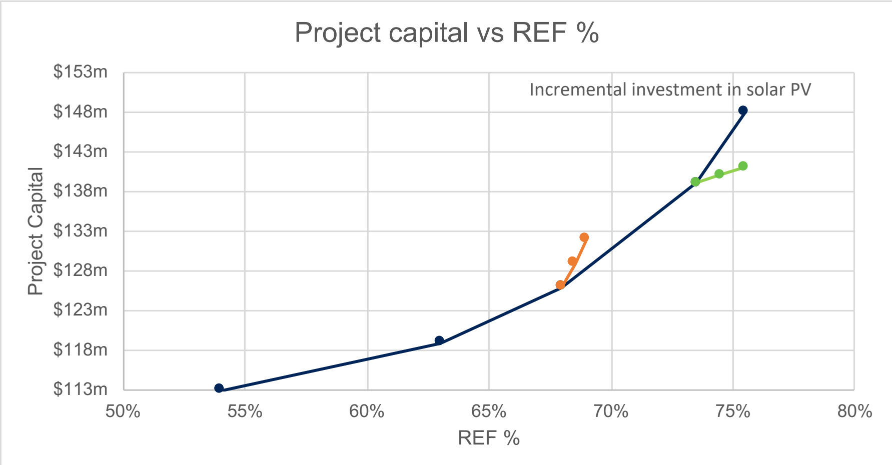

Figure 11: Project capital vs REF (%)

While the above is currently the case, it is anticipated that as the cost of energy storage comes down and other forms of non fossil-fuelled synchronous or non-synchronous inertia decrease in cost (e.g., synchronous condensers), microgrids will be designed to capture excess renewable energy and time shift this energy to when renewable energy production reduces to below the load.

The strategies being explored at Agnew to utilise curtailed energy are (1) relieve the minimum thermal generator operating constraint (currently 2 generators, displacing 2 MW of renewable energy) and (2) store excess renewables (time shifting).

To relieve the minimum thermal operating constraint, the BESS must be able to prove that it can replicate the grid support functionality of the thermal generators and the renewable generation must prove its FRT (Fault Ride Through) capabilities. Modifications may also need to be made to the gas supply pipe and valve network to allow for a zero gas flow condition. This would require a full gas outage for 24-48 hours and may require temporary diesel generation to be installed during the outage to avoid impacting gold production. Relieving this constraint would reduce curtailment from 7.3% to 3.4% and increase renewable fraction (REF) from 54% to 57%.

2.6 Assessment of Strategies to Utilise Curtailed Renewable Energy (continued)

The efficiency of energy storage at Agnew will be higher with solar generation (daily cycles) than with wind generation (seasonal cycles). However, the efficiency of solar generation with storage drops off over winter when the output from solar reduces. As Agnew's microgrid is supplied predominantly from wind, the potential efficiency of energy storage is relatively low.

Current analysis shows that to utilise Agnew's curtailed energy by employing energy storage, a 100 MWh lithium battery would reduce curtailment from 7.3% of consumption to 1.0% and increase renewable fraction (REF) from 54% to 59%.

In 2019 at Lake Bonney in South Australia, a 25 MW/52 MWh battery was installed for a capital cost of $38 m[7], so a 100 MWh battery will cost far more than this. In comparison, an additional 6 MW of solar power installed at Agnew will increase the renewable fraction at Agnew from 54% to 60%, increase curtailment from 7.3% to 11% and cost approximately $10 m.

Gold Fields is working to understand the various storage technologies available and the associated deployment cost but at this point in time, the economics suggest ratcheting up solar generation first and then investing in storage once the costs improve.

[7] https://arena.gov.au/blog/infigen-new-tesla-battery-lake-bonney-wind-farm/

3 PERFORMANCE OF THE MICROGRID AND SUPPORTING TECHNOLOGY

The performance data to date is a close match to the forecast and it is expected that performance will vary year to year, due to seasonal variation and mine load. During the months of December 2020 and January 2021, wind turbine 3 was offline due to a cable fault (now resolved) which explains the RE Contribution being below forecast for these months.

Table 3: Forecast v. Actual Energy Production

		Forecast Production					Actual Production			
Month	Mine Load (MWh)	Forecast Wind (MWh)	Forecast Solar (MWh)	Total Re-newables (MWh)	RE Contribution	Mine Load (MWh)	Actual Wind (MWh)	Actual Solar (MWh)	Total Re-newables (MWh)	RE Contribution
Sep	9,399	4,917	506	5,423	57.7%	9,563	4,746	565	5,311	55.5%
Oct	10,454	5,250	614	5,864	56.1%	9,574	4,929	659	5,588	58.4%
Nov	9,960	5,200	707	5,907	59.3%	10,035	5,046	737	5,783	57.6%
Dec	10,468	5,361	662	6,023	57.5%	10,238	4,585	863	5,449	53.2%
Jan	9,955	5,399	607	6,006	60.3%	10,069	5,173	754	5,927	58.9%
Feb	8,995	3,768	591	4,359	48.5%	8,974	4,633	494	5,126	57.1%
Mar	10,098	5,105	575	5,681	56.3%	9,633	4,128	565	4,693	48.7%
Apr	10,040	4,149	521	4,670	46.5%	9,386	4,627	590	5,217	55.6%
May	9,538	4,991	413	5,404	56.7%	9,597	4,796	384	5,180	54.0%
Jun	9,580	4,578	321	4,899	51.1%	9,585	4,110	410	4,520	47.2%
Jul	9,739	3,767	394	4,160	42.7%	10,022	4,787	330	5,116	51.0%
Aug	9,775	4,881	423	5,304	54.3%	10,040	5,133	499	5,632	56.1%
Total	118,000	57,365	6,335	63,700	54.0%	116,715	56,695	6,849	63,543	54.4%

Agnew's performance in its first year of operation exceeds expectations, considering new plant generally has a ramp up phase before it is fully optimised. Year-to-year performance will vary due to seasonality but it's not yet known to what extent this will influence Agnew's REF.

4 KEY LESSONS LEARNED

4.1 Design Criteria

The Agnew microgrid has met all of its performance criteria and despite being constructed during the beginnings of a global pandemic, was delivered on time and on budget.

There are also key lessons in relation to advancing the Agnew project to achieve a higher renewable energy fraction and further decarbonise the mine. Some of these learnings cannot be retrofitted, as it is uneconomic to do so but will be considered in future designs.

Table 4 : Key Design Lessons

1	**Gas Supply Infrastructure**	For projects connected to a gas pipeline, at 100% renewable penetration (thermal generators off), the gas supply pressure regulators may pass gas over to the low pressure side and trigger an emergency shutdown of the gas supply (high pressure on low pressure side / regulator failure trip mode). In a remote location it may take a long period of time to manually reset this condition and during this time, if thermal generators are required they are without a gas supply. The learning for future projects that utilise gas for backup is to design the gas supply system for a no flow condition by having automated isolation valves upstream of the regulators, controlled by a signal from the power station when thermal generation is not being called for.
2	**Thermal Fuel Choice**	Depending on how high the renewable fraction is, the economics of the firming thermal fuel supply options (i.e. pipeline gas, trucked LNG, diesel) will change. The biggest barrier to increasing the renewable fraction at Agnew now (post construction) is the amortisation of the capital invested in the gas pipeline. If the long-term goal for a project is to get to as near to 100% renewable energy as possible, then all thermal fuel options should be considered, even a higher emissions fuel such as diesel, as it will not produce a significant amount of emissions if it's only used as a contingency.
3	**Inertia**	Although the instantaneous REF has reached 85%, the long term REF at Agnew is currently limited due to its physical capacity in renewable energy generation but also the requirement to run a minimum level of thermal generation to provide system strength or inertia. Relieving this inertia constraint would allow further displacement of gas power with curtailed renewable energy and increase Agnew's renewable fraction from 54% to 58%. There are also other technologies that can be considered such as synchronous condensers and flywheels. However, they are an additional cost and are a parasitic energy consumer.

4	**Energy Storage**	Given the variability and non-dispatchable nature of renewable energy, it is not possible to get to 100% renewable energy without bulk energy storage. The lithium-ion battery at Agnew only provides enough energy storage to bring the thermal generators online and is not capable of high-frequency cycling without premature cell degradation. At present, due to the higher cost of energy storage, the most cost effective method of increasing renewable fraction is building more renewables with increasing levels of curtailment. In time, energy storage will become viable and will assist in taking a microgrid's renewable fraction closer to 100%.
5	**Battery Sizing**	The power (MW) and storage (MWh) rating of Agnew's BESS was sized to be able to power the entire mine load for a short duration while gas generators started up and synchronised to the grid. In Agnew's case the power rating is short of the total load as there is a minimum of two thermal generators online (inertia constraint). This sizing has been critical to ensuring reliable supply at Agnew and will be maintained by Gold Fields in future high penetration projects, including increasing the power sizing to full load when the inertia constraint is relieved.

4.2 Challenges

The key challenge was derisking the project to satisfy the tests applied by Gold Fields Board and management and prove that a project of this nature could be delivered. A high penetration renewable energy project represents a **change in mine power supply risk profile from low capex / high opex to high capex / low opex** and so a mine must have the life to support a much larger upfront capital investment. For Agnew this meant aligning the business case with geological data that supported the potential for the Agnew mine life to continue to be extended long enough to see out the 10-year power contract.

The ARENA funding assisted with overcoming this challenge in part (reducing the headline capital number), with Gold Fields taking on the residual risks to progress the project as part of its vision to be a global leader in sustainable gold mining.

4.3 Environmental Impacts

There were zero significant environmental incidents during construction. The site used for the Agnew microgrid was either previously disturbed mining tenure or sparsely vegetated, level ground. Agnew's mine closure plan has been updated to include rehabilitation of Project land after mine closure.

The grid emissions factor was reduced from approximately 0.59 to 0.27 tCO2-e/MWh on completion of commissioning of the Project.

4.4 Deployment / Installation

The deployment of Agnew project was completed with no significant safety incidents recorded and all works completed in accordance with the project schedule.

The key learnings from deployment were:

1. Cost estimates for solar tracker foundations in hard rock (like at Agnew) should be costed at the higher end of PV plant benchmarks.
2. Wind farms in remote areas need large volumes of suitable sand, cement and aggregate trucked in for concrete foundations which can be expensive. 2 x mobile batch plants are required in case one batch plant has a failure during a foundation pour. Suitable quality water for the batching of concrete foundations is not always available in remote areas such as those with high salinity groundwater.
3. There are a limited amount number of cranes available in Australia that capable of performing wind farm duties. Mobilising these cranes can be a challenge, including the logistics of transporting the crane to the project (over 50 truck loads) and the supporting cranes required to construct the high-lift crane. These cranes then require roads built to their specification if they are to move between wind turbine construction sites on their tracks, otherwise they must be dismantled, transported and reassembled at each site, which adds to the total hire time and labour requirements for the crane.

Figure 12: Lifting Blades onto Nacelle

4.5 Gas Engine Performance

Some tuning of control schemes has been required to allow the gas generators to work with the wind turbines and the battery to ride through high kVAr events (500 kW+ motor starts). At high renewable fractions, the gas engines are maintaining minimum load factor (50%) without any issues.

4.6 Battery Capacity Performance

The BESS performs a number of functions at Agnew:

- maintains site power quality, increasing the reliability of power to the mine;
- static spinning reserve, allowing a reduction in the requirement for online gas generation capacity;
- ability to form a grid if the last gas generator trips, taking over responsibility for voltage and frequency management;
- providing fault current contribution during contingency events.

4.6 Battery Capacity Performance (Continued)

Agnew's BESS maintains a minimum state of charge, to ensure there is enough storage in the event of a sudden loss of renewable generation to carry the station during the 10 minute start-up time of the gas generators (gas purge cycle, ignition, synchronisation and ramp up).

Agnew's BESS maintains a maximum state of charge to give the BESS the capacity to accept additional charge in the event of a loss of a large load. In this event, the BESS absorbs the power that was supplying this load, limiting frequency overshoot and the subsequent tripping of other loads.

The BESS is continuously charging and discharging in the +/- 100 kW range during normal operation, while it is making a contribution to maintaining power quality.

4.7 Dynamic Load Shedding and Mine Load Control Capabilities and Performance

Demand-side dynamic load shedding has been implemented at Agnew but its use is limited to 'last resort' due to the reliability offered by the BESS. To date, it has not been initiated. The use of dynamic load shedding protects the power station from total blackout. However, the impact (of load shedding) to the mine's production can be significant and may trigger an underground mine evacuation due to loss of power to ventilation systems.

Agnew's investment in a robust power solution (including the BESS) is 'paid back' by the potential production losses that would potentially be incurred, if dynamic load shedding was the first line of defence against power station blackouts.

4.8 Disconnection and Reconnection of the Microgrid from the Nickel West Northern Grid

The disconnection from the Northern Grid was well planned and the cutover was staged to limit disruption of power to the Agnew mine.

It is understood that the equipment between the Northern Grid and Agnew has been decommissioned by its owners, making reconnection impractical.

4.9 Impacts on the Microgrid Security, Reliability and Spinning Reserves

The microgrid security and reliability has improved, as it is no longer affected by exposure to 50 km of powerline (which can be subject to pole collapse events and lightning strikes). The mine's ability to expand its power supply has also improved, as the generation is now local to the mine, relieving the capacity constraint of the powerline.

Spinning reserve can in theory be zeroed, with the battery providing a 'virtual spinning reserve'. However, operationally, this is impractical, as the mine's load varies at a rate faster than a gas generator can be started and shutdown, and relying solely on the BESS would cause premature ageing. It is more cost-effective to utilise the spinning reserve capability of the online gas generators, in conjunction with the BESS.

5 PROCUREMENT PROCESS

5.1 Overview and Context

Gold Fields Australia Pty Ltd (Gold Fields) owns and operates the Agnew Gold Mine in the northern Goldfields of Western Australia. The mine is situated in a remote location, approximately 330 km from the nearest grid supply. The mine received 12 MW of electricity from the neighbouring nickel mine near Leinster through a Power Purchase Agreement (PPA) which was due for renewal through an extension option in April 2019. Agnew at the time had an average power demand of 13.5 MW, with the extra energy being self generated from rental diesel gensets. Agnew was also considering a mine expansion which would increase average loads to 16 MW, with a peak of up to 20 MW.

While considering the PPA's extension, Gold Fields commenced its due diligence on alternative supply options to power the Agnew mine, which would include an evaluation of renewable energy solutions.

Gold Fields engaged an energy advisory consultancy to complete a technical and economic study to assist with configuring the renewable energy solution and structuring the procurement process.

5.2 Business Case

The business case for the Agnew project was based around the following metrics.

1. Expandable and reliable power supply to meet the growing energy demands for the mine;
2. Consideration of the non-financial benefits of renewable energy; and
3. Break even against the current energy cost.

Considering the increase in supply risk with the variable nature of renewable energy, a thermal power station was necessary to provide the power reserve and a battery to bridge the startup time of the thermal generators. These additional costs were higher than the break even test.

ARENA funding was sought in order for the project to proceed, bringing energy cost back to break even. The procurement process sought to bring the four construction projects (thermal, wind, solar and battery) and operation and maintenance of the microgrid to a single point of accountability from an independent power producer (IPP). Gold Fields preference for a single point of accountability was determined by a risk assessment which focused on minimising complexity of commercial arrangements, technical interfaces and simultaneous operations (SIMOPs) during construction.

To do this, Gold Fields and its advisors engaged IPPs and their partners through an EOI process, to pull together a list of technically and financially-capable IPPs or IPP consortiums which had expertise with leading generator technologies and microgrid control systems.

At the end of the EOI process, Gold Fields had a shortlist of 4 IPPs to invite to tender.

In compiling the tender pack, Gold Fields engaged legal counsel to assist with drafting a PPA to include the necessary terms and conditions to facilitate the operation of the microgrid, as well as a construction development agreement.

After tender closure, Gold Fields selected EDL as the preferred supplier and commenced detailed negotiations to form a balanced PPA. EDL backed into the development agreement their milestones, with their appointed EPC contractors for the gas power station, solar farm, battery storage and wind farm.

5.3 Early Risk Minimisation Activities and Clarity of Residual Risk Sharing

Gold Fields engaged an energy consultancy to undertake the initial feasibility and risk studies for the project. As part of Gold Fields' process, a risk register (developed by the Energy Consultancy) for the design, procurement, construction and operation of the microgrid was developed, to identify and understand which minimisation activities (mitigants) were required to de-risk the project to an acceptable level.

The risk minimisation activities included:

- early vendor consultation prior to tender;
- geotechnical drilling of the land upon which solar and wind plants would be constructed, to assist with accuracy of tendered construction costs;
- engagement with regulators and early commencement of the regulatory approvals process;
- deployment of SODAR at the wind plant site to gather localised wind resource data;
- GIS mapping to select suitable locations on the minesite to construct the power generation facilities; and
- engagement with ARENA to assist with funding of the project.
- residual risk allocation similar to a typical thermal PPA.

EDL accepted operating and maintenance risk for the renewable plant and Gold Fields the renewable resource risk (availability of wind and sun).

The Agnew project was not treated differently to any other mining construction project by the regulators. The Agnew mine is in a remote area, a long way from populous areas. The project was constructed on already disturbed or near to disturbed land, with very low levels of vegetation.

The two key approval documents produced for the project were the Mining Proposal and Land Clearing Permit. Both documents were lodged for approval with the WA Government Department of Mines, Industry Regulation & Safety (DMIRS).

The Mining Proposal demonstrated that the project had:

- been designed to comply with Australian Standards and the Mining Safety and Inspection Regulations;
- consulted with traditional owners and native title holders, had completed lands surveys and that no sites of cultural significance would be disturbed;
- completed native flora and fauna surveys and that no habitats of protected species would be impacted;
- completed hydrology studies and that any localised flooding would be mitigated using flood controls;
- been added to the mine's closure plan.

In addition, the Mining Proposal addressed the construction of the wind farm by referencing the 'Best Practice Guideline for implementation of Wind Energy Projects in Australia', June 2018, from the Clean Energy Council, which called for additional studies such as land and visual, noise, bird and bat ecology, electromagnetic interference and aircraft safety.

The clearing permit is required where land clearing on a mining tenement exceeds 10 ha and includes a period of public consultation.

5.3 Early Risk Minimisation Activities and Clarity of Residual Risk Sharing (Continued)

There are a number of barriers that have stood in the way of commercialising renewable energy in the mining industry. Key are:

1. the mismatch between mine life and renewable energy asset life;
2. lack of successful, large-scale renewable energy projects attached to mine sites, to give the perception that the technology and integration risk has been solved;
3. pre-existing, fixed take or pay contracts.

The Agnew project was required to address items 1 & 2 in order to be successful, with ARENA funding targeted at item 2.

To address item 1, Gold Fields has taken on the full residual risk of the hybrid power assets if the mine closes prior to the end of the PPA term. As a result of this, Agnew's monthly leasing charge (the fixed cost paid for energy) is higher than a grid-tied merchant project or a long-life mining asset. The assets that are least redeployable (wind turbines and PV array) present the highest commercial risk. Recent technological developments are attempting to address this barrier by making renewable energy redeployable.

Item 2 is a mixture of mine production and 'white elephant' risk. The mine production risk includes the following.

- The Agnew mine is a continuous 24/7 operation and its operating efficiency relies on having a reliable power supply to match.
- At the process plant, a brief power outage may mean a production outage of up to 4 hours while various systems are reset and readied to bring back online.
- The disturbance may also result in gold being sent to tailings, reducing recoveries.
- In the underground mines, a power outage may trigger a mine evacuation due to the loss of ventilation systems with production lost to re-entry times.

The white elephant risk is if any of the elements of the microgrid did not perform. If the integration platform or the battery didn't perform or if the wind resource did not exist as expected, the large amount of capital invested would have been wasted.

Between reaching construction completion in 2020 and the time of writing this report, Agnew has demonstrated that both of these risks (mine production and white elephant) were mitigated through careful technology selection, good engineering practice and quality assurance / quality control (QA/QC).

The ARENA funding enabled Agnew to increase the size of the battery up to the full mine load, so the mine effectively has a UPS backing up the power supply. As a result, the Agnew hybrid has proven to be an extremely reliable source of electricity, which has consistently produced a renewable energy fraction of more than 54% since construction was completed.

As a contemporary, operating project, other operators of off-grid power supplies and microgrids are able to witness renewable technologies in operation (by visiting the plant by prior arrangement) and understand the key components needed to get comfortable with making their own investments.

6 FORMATION OF THE IPP CONSORTIUM

IPP consortiums were encouraged through the project EOI process, either by the head IPP involving partners of their own or by the Gold Fields consultant making introductions between suitable parties. The IPP consortiums were formed to bring all the relative components and technologies (operator, solar, wind, thermal, BESS and integration) together under a single umbrella. This provided Gold Fields with a counterparty with a single point of accountability during both construction and operations.

6.1 Development of Contractual and Partnership Structures Between Key Stakeholders

After reviewing the knowledge shared from the ARENA-funded Sandfire DeGrussa solar and battery project (e.g. multiple contracts and complex counterparty arrangement), Gold Fields set a preference for a single contract, single counterparty arrangement for the supply of electricity to Agnew. This structure was in place at Gold Fields Granny Smith mine and the contract had recently been successfully amended to include IPP ownership of solar and BESS facilities.

With assistance from a Gold Fields energy management consultant, a list of potential suppliers to the project was drafted from local and international sources, including:

- wind turbine OEMs;
- solar PV system integrators;
- hybrid system integrators;
- thermal (gas) generation IPPs;
- power systems hardware manufacturers;
- conglomerate IPPs / energy companies;
- constructors;
- financiers.

With this list in hand, Gold Fields and its consultant made some assumptions as to which parties would be a logical fit to bring together to deliver the scope of work, with a balance sheet strong enough to be able to finance the project. Gold Fields then approached those that would be leads, to participate in an Expression of Interest (EOI) process and made suggestions to the leads as to who they could partner with to form a consortium.

At the end of the EOI process, Gold Fields had shortlisted 4 potential IPPs or consortium IPPs that had the technical and financial capability to deliver and operate the hybrid microgrid at Agnew. These four IPPs were then invited to tender on the project.

The nature of the contractual and partnership structure varied between IPP consortiums. The prevailing structure that delivered the project was EDL as the sole counterparty to Gold Fields and EDL with EPC subcontractors Cummins South Pacific, juwi (group), SAFT, Goldwind/Nacap JV, Entura and SCEE.

6.2 Development of the Scope of Work for the Consortium

The scope of work was developed by Gold Fields and its consultants based on a common scope for a gas-fired, reciprocating engine power station with the wind, solar, BESS and integration elements added in. Gold Fields intended to apply limited resources to the Project, so it was up to the IPP to supply all materials and labour.

6.3 Development of Agreement and Electricity Supply Agreement

The construction development agreement (DA) and electricity supply agreement (ESA) were based on documents from previous Gold Fields thermal generation projects. Gold Fields took these documents to external legal counsel. Through a series of workshops, counsel revised these documents to apportion the hybrid construction and operating risks between Gold Fields and the IPP and to structure the principles for renewable fraction, metering, charging and environmental rights according to Gold Fields logic.

During shortlisting of the tender, departures from the DA and ESA were negotiated. After EDL was selected as the preferred bidder, outstanding departures were negotiated and agreed and the DA and ESA were finalised for execution.

6.4 Risk Management

The ESA requires EDL to supply reliable electricity up to a contracted capacity of 18 MW to the Agnew mine, with a minimum renewable energy fraction of 54%. Gold Fields free issues fuel (gas) to EDL at the power station boundary and in line with this principle, Gold Fields is also responsible for the wind and solar resource. While the wind and solar resources are not specifically in the company's control, the availability of resources are determined by the location of the mine site, which is designated by Gold Fields.

The ESA is a capacity-based contract, to ensure EDL recovers the capital invested with variable charges to cover consumables at the thermal power station. EDL guarantees the renewable energy fraction on the basis that the renewable resources are available (referenced against wind speed and irradiation instrumentation) which implies an availability guarantee of the renewable energy generation.

While the creation of LGCs (Large-scale Generation Certificates) rests with the generator, Gold Fields has rights to receive the LGCs and takes price risk on trades in the LGC market.

In the DA, EDL assumed construction risk with exceptions limited to latent conditions, delays caused by Gold Fields and force majeure.

6.5 Managing the Process from Financial Close Through to Practical Completion

Managing this process was one of the more challenging components of the Agnew project, as not all timelines lined up to be achieved by financial close. The most critical timeline driving the financial close date was the expiry of the existing power supply agreement and the need to have the new microgrid commissioned (to practical completion) ahead of this expiry date.

The key issue at financial close was that the process to obtain ARENA funding was still progressing through its channels and hadn't yet made it to the ARENA board for approval. Gold Fields and EDL agreed that to meet the Gold Fields timeline, the project would have to be broken into two phases:

- Phase 1: thermal station and 4 MW solar;
- Phase 2: wind farm and BESS; with Phase 2 being subject to the approval of ARENA funding.

The delay to Phase 2 created several, significant commercial challenges for the Project, including the cost escalation of some equipment purchases, which Gold Fields had to absorb. The delay also caused a reduced amortisation period for EDL's capital (approximately 9 years instead of 10) leading to higher, fixed, monthly charges to Gold Fields. In addition, Gold Fields had to secure additional gas pipeline capacity for the thermal power station for a 12-month period, which eliminated the LNG option, locking in the Project's sunk costs and making it less feasible to go to higher renewable fractions in the future. This also meant higher emissions for the Project over its life and less revenue from LGCs (Large Scale Generation Certificate).

Cost issues aside, the phasing of the delivery gave EDL more time to focus on delivering the thermal plant to schedule and ensuring that the quality of the build was to the required standard. The quality of the construction standard for the thermal station was critical, given that once the supply lines from the old power supply were disconnected, there was no turning back.

The construction process was managed by EDL by excising the site for the microgrid assets out of the mining lease, to be under EDL's safety management and control. EDL also had access to the project directly off the main road, without having to traverse the mine site. This allowed for a good segregation between mining and construction activities and reduced the risk of plant and equipment interactions.

At a management level, Gold Fields and EDL met weekly to discuss progress and resolve issues.

Prior to thermal station practical completion, EDL tested all thermal generators using load banks, offline from the mine. Once all generators were signed off, the feeders from the thermal station main switchboard were connected to the mine and the process of cutting over the power supplies began.

The solar, wind and BESS all connected into the thermal station main switchboard, which allowed each of these elements to be commissioned against the mine load, with the thermal station running as backup. The microgrid control system was also commissioned as part of this process.

Practical completion of the Agnew microgrid was achieved by EDL once Phase 2 (wind and BESS) had passed their performance tests.

6.6 Onsite Operating Protocols and Management

The Agnew mine is a 24/7, 365 day-per-year operation and so the hybrid microgrid needs an availability to match. The mine can run 100% powered by the gas thermal station, such as if there is no wind and it is night time. Therefore, each or any of the solar inverters, wind turbines and BESS are able to be taken offline for maintenance, without affecting gold production. The thermal station is modular by nature (9 x 2 MW gas gensets and 2 x 1.5 MW diesel gensets) which means individual generators can be shut down for maintenance. As a result of this configuration, the mine is not dependent on the maintenance of the power station and operates according to its production schedule.

To assist with the reliability of the power supply, the mine must request permission from the power station before starting any large motors. This is an automated process involving requests and handshaking between control systems as part of a large motor start sequence. The power station will assess available spinning reserve and reactive power and if necessary, start up additional thermal generation before granting permission to start.

The power station has two operators on a day shift roster and on call during the night while on roster. The power station is also monitored by EDL at their remote operating centres in Perth and Brisbane. Additional resources are brought in for major maintenance activities.

Gold Fields and EDL meet monthly to discuss and resolve any operational issues.

6.7 IPP Consortium Challenges

The traditional IPP model that specialises in thermal generation has not historically had to form consortiums in the past to bring multiple technologies together. As a result, there were some challenges in finding the right mix of organisations to form consortiums and bid for the Agnew project.

The challenge of finding IPPs that had both the capability and experience to deliver, integrate and operate the Project was overcome through the use of both Gold Fields' and the energy consultant's networks.

The next challenge was getting the risk balance right so that IPP consortiums would take an interest in the project and put a competitive offer on the table. Generally where there is competitive tension, the mine will push more risk onto tenderers however, in this situation the volume of risks (particularly in integration, renewable resource and construction) was much larger. So it was important for Gold Fields to absorb as much risk as was reasonably feasible to limit the stacking of risk premiums and encourage competitive tendering.

And lastly, getting the consortiums comfortable with Gold Fields as a counterparty such that their return on capital invested was secure. Some of the mechanisms to support this include demonstrating the strength of the Agnew mine company balance sheet, credit support from other members of the Gold Fields group of companies and other forms of financial guarantees.

7 DATA SETS COLLECTED

The primary sources of data collected in the development phase of the Agnew Hybrid Microgrid included:

1. mine power demand (historic);
2. mine large load data;
3. solar POA irradiance (Homer / PVsyst);
4. wind resource (SODAR based at Agnew).

This data was adequate for the preliminary work done by Gold Fields and for EDL to design the system to achieve a 54% renewable energy fraction.

8 CONCLUSION

The Agnew hybrid microgrid has demonstrated that a remote mining operation can be powered by high penetration renewable energy and that wind power is a mature and reliable technology for use at mines. Further, where wind and solar resources are complementary (wind at night and solar during the day) as they are at Agnew, there is a strong economic case for high penetration renewable projects.

Due to the variable nature of renewable energy and the synchronous stability requirements of microgrids, designing a microgrid with a factor of curtailment is currently the lowest cost method of achieving a mid to high level (50% – 80%) of renewable fraction. Above these levels there is a business case for storage which makes use of zero marginal cost curtailed renewable energy.

With a much higher capital outlay than traditional diesel fired power solutions, high penetration renewable microgrids have an inherently different risk profile that can be difficult to fund when there are capital constraints, a lack of balance sheet strength or a short mine life. At executive and board level the implications of this change in risk profile will be weighed up against the risk of not accepting the risk (and going diesel) versus other business risk such as investor backlash and challenging financing markets from lack of ESG initiatives.

Figure 13: The Agnew microgrid captured during a thunderstorm. Image: Ryan Kelly

9 GLOSSARY

Acronym/Term	Definition
AREMI	Australian Renewable Energy Mapping Infrastructure
BESS	Battery Energy Storage System
Curtailment	Limiting (not using) the power that is generated from renewable sources. In terms of a microgrid system, this is done to avoid overloading the grid.
DA	Development Agreement
DNV	www.dnv.com - this is a certification and assurance provider. On 1 March 2021 DNV GL became DNV.
Dynamic load shedding	Reducing demand on a power generation system by tripping loads when there is insufficient generation.
EDL	EDL: https://edlenergy.com
EOI	Expression of Interest
ESA	Electricity Supply Agreement
ESG	Environmental, Social and Governance
FRT	Fault Ride Through
High-penetration microgrid	A microgrid with a high proportion of renewable energy generation sources
IPP	Independent Power Provider
kVA	Kilovolt amp
kVAr	Kilo volt-ampere reactive. Is equal to apparent power times sine of power angle (φ).
LCOE	Levelised Cost of Electricity
LGC	Large-scale Generation Certificate
MCS	Microgrid Control System
REF	Renewable Energy Fraction
SODAR	Sonic Detection and Ranging
Spinning reserve	The provision of online ‘spinning’ generation, ready to ramp up to meet a load in the event of a fault with other generation.
UPS	Uninterruptible Power Supply
WTG	Wind Turbine Generator

10 APPENDIX 1: MEDIA EXAMPLES

This Project has been widely published in the media. Examples include the following:-

1. Official media release: Agnew leads the way in decarbonising Australian mining with wind and hybrid power https://bit.ly/3uba4dw
2. Energy & Mines virtual summit presentation 4 August 2020: https://bit.ly/3KTXiXQ
3. Australian Mining's Blueprint for Renewable Energy: https://bit.ly/3qgjzXE
4. Agnew hybrid micorgrid completed: https://bit.ly/3qfRXIA
5. Australian miners moving the dial for decarbonisation: https://bit.ly/3wgUfEO
6. Gold Fields at Energy and Mines virtual conference: https://bit.ly/3JzYb7m
7. Energy and Mines Australia Summit 2021: https://bit.ly/3ig7Gg7
8. Renewable Energy: Q & A with James Koerting: https://bit.ly/3ua5hZP
9. Global gold miner sets sights on "realistic" 99% renewables share on mining projects: https://bit.ly/3L0GHSh
10. Agnew gold mine: a vision for green power at mines? https://bit.ly/3KVPkgJ
11. VIDEO CONFERENCE | Energy & Resources Series: Powering Australia's next Gold rush https://bit.ly/3CV9ULf
12. Agnew hybrid microgrid powering greener mining: https://bit.ly/3u6Z94E
13. Official media release: Gold Fields Agnew mine to be powered by renewables in industry-leading project: https://bit.ly/3ltw4Ws
14. Official media release: First stage of landmark Agnew hybrid renewable project powers up: https://bit.ly/36vEE9x
15. Official media release: Agnew leads the way in decarbonising Australian mining with wind and hybrid power: https://bit.ly/3lzD3gB
16. Official media release: Australia's largest hybrid renewable microgrid takes top honours in international awards: https://bit.ly/34RdLMT
17. A renewable energy revolution is powering Australia's $720bn mining and resources industry: https://ab.co/3MVwckV
18. Agnew gold mine could run off 95 per cent renewable energy in 12 months, owner says: https://ab.co/3JuwqgQ
19. From China to the outback: Logistical nightmare behind transport of gigantic wind turbines: https://ab.co/3llHc7I

11 APPENDIX 2: AWARDS WON

2020

Winner (EDL):
S&P Global Platts Global Energy Awards – Engineering Solution of the Year

Winner (EDL):
Asian Power Awards – Innovative Technology of the Year (Australia)

Winner (EDL and Gold Fields):
Australian Engineering Excellence Awards: Western Australia Division

2020/2021

WA winner (SCEE) – National Electrical and Communications Association (NECA) Awards:
Industrial – Medium Project

2021

Winner (Gold Fields and EDL):
Department of Mines, Industry Regulation and Safety's Resources Sector Awards for Excellence – Golden Gecko Awards

Finalist (Gold Fields and EDL):
United Nations Association of Australia – WA Division Excellence in Environmental Action Award

Listed (EDL):
2021 Australian Financial Review Most Innovative Companies List – Agriculture, Mining and Utilities

Finalist (EDL and Gold Fields):
Western Australia Energy Awards – Energy Innovation of the Year (Company)

Winner (Gold Fields and EDL):
Australian Mining Prospect Awards - Excellence in Environmental Management

EDL CEO James Harman, Gold Fields EVP Stuart Mathews, and Bill Johnston, Western Australia Minister for Mines and Petroleum, Energy and Industrial Relations

EDL

GOLD FIELDS