ELECTRICMINE.COM

Electric mine simulation:

Where we are today and where we are going

STATE OF PLAY

Think & Act Differently Powered by BHP

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ELECTRIC MINE CONSORTIUM

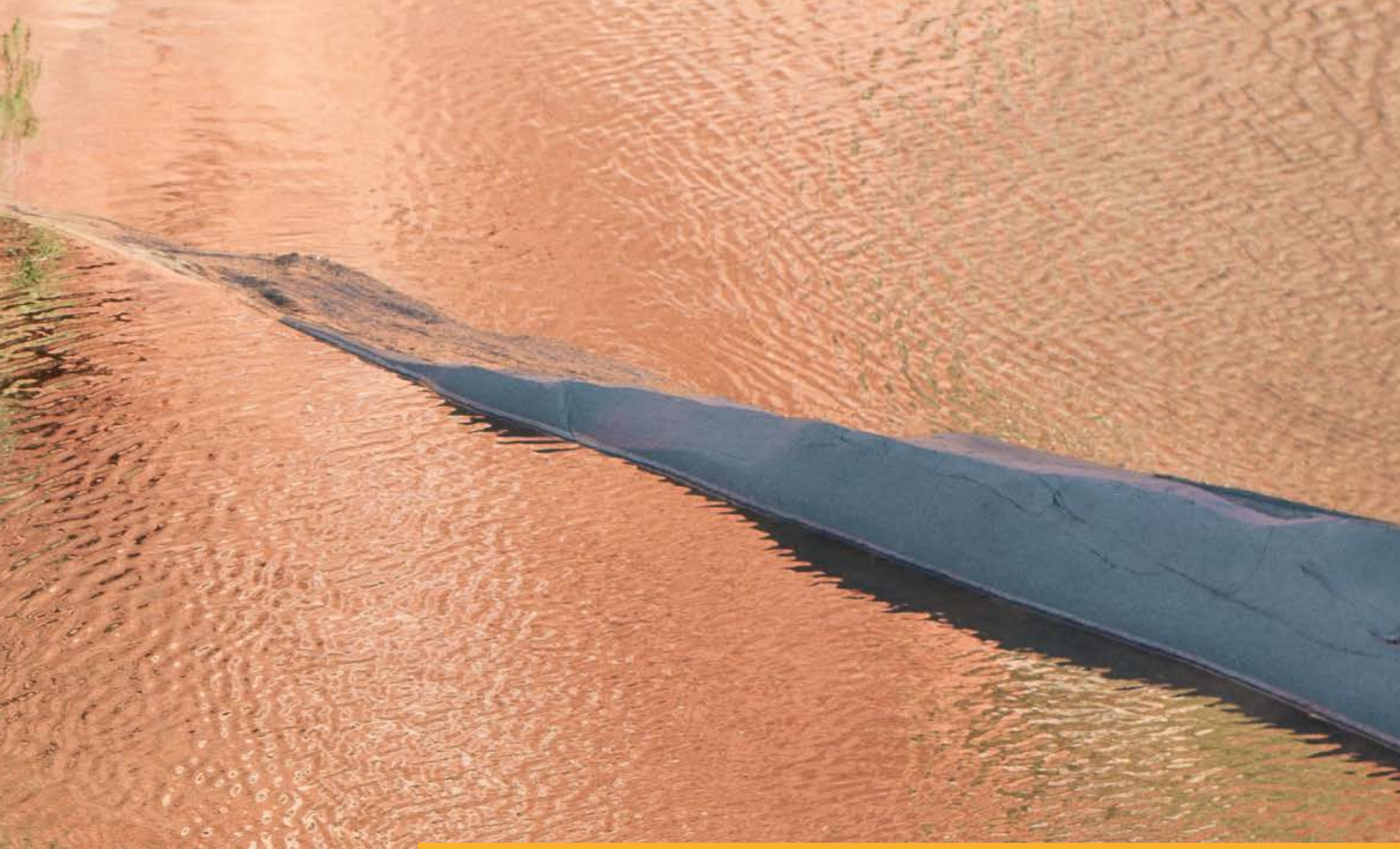


Table of Contents

Prologue 4

ELECTRIC MINE CONSORTIUM 4
THINK & ACT DIFFERENTLY 5

Executive Summary 6

Transition to Electric Mines 8

ELECTRIFICATION: A FOUNDATIONAL TECHNOLOGY WHAT 8
WILL CHANGE 9
OPERATING ELECTRIC MINES 9
THE COMPLEXITY OF SIMULATING ELECTRIC MINES 10
SIMULATING ELECTRIC MINES 11

Discussion of the project -EMC & TAD: Electric Mine Simulation Challenge 13

THE PROMINENT HILL CASE STUDY 14
THE BENEFITS: WHAT'S IN IT FOR EVERYONE? THE 14
SET & SIMGENICS COLLABORATIVE APPROACH 16

What we have learnt -A platform approach is required 17

Prologue

Electric Mine Consortium

The Electric Mine Consortium (EMC) has grown since its inception in late 2020 to become the world's leading mining decarbonisation initiative – it is, in effect, a case study in transformative collaboration.

Participants are driven by the imperative to meet their aspirations to decarbonise and in doing so to produce zero-emission products for their customers and to meet mounting investor expectations. Electrification is the rare trifecta that hits economic, environmental and health goals – this means that once it reaches a tipping point, the transition will accelerate.

"The objective of the consortium is to accelerate progress towards the zero-carbon and zero-particulates mine."

More than 70% of the world's emissions are now covered by net-zero pledges.[1] We expect that in the coming years company pledges will transition from statements to committed targets.

The Electric Mine Consortium's work is critical in achieving these emission reduction targets for our member companies.

Think & Act Differently (TAD) served as a founding member of the consortium and leads the Mine Design stream. In that role, TAD has led the development of the Electric Mine Simulation challenge that this report addresses.

1 The United Nations

Think & Act Differently

Founded in 2021, Think & Act Differently (TAD) is a human first technology and resource development ecosystem where curious minds come together from inside and outside the mining sector to tackle complex issues, challenge norms and find new ways to extract minerals that create value for all stakeholders.

In late 2023, TAD became Think & Act Differently, Powered by BHP. This project took place when TAD was part of OZ Minerals.

TAD is growing a resource development portfolio that operates in parallel with technology development pathways, recognising that traditional resource development frameworks can limit the ability to leverage technology effectively and achieve multi-stakeholder value.

In order to meet the growing demand for commodities required for the energy transition, we need to creatively identify options to convert mineral resources into ore reserves. TAD is developing an innovative approach to improve project evaluation, which involves combining different techniques and technologies to consider the interdependencies within the system and ultimately unlock these resources. TAD's ecosystem approach, comprising a diverse group of individuals, provides a unique advantage, allowing us to make informed decisions quickly and efficiently. Our design philosophy focuses our choices on autonomy, flexibility, data and the aspiration towards zero waste, water, carbon and closure liabilities.

The TAD operating model focuses on prioritising the human experience of bringing technology to market. By leveraging the ecosystem to drive innovation and success, TAD is committed to pushing the boundaries of what is possible and delivering innovative solutions to complex problems.

Developing a modern mine calls for a co-design approach that considers the lives and systems at play beyond the ore. We are empowering diverse stakeholder perspectives to shape our work and create mutual benefit for all involved. TAD believes that stakeholder value creation should be inherent in design from the onset, when decisions are still being made and architectures around project design can still be significantly shifted, when capability can be built.

Executive Summary

Current mine designs are constrained by existing diesel vehicles. Future mines will be designed around zero emissions technology.

New all-electric mines will fundamentally change a number of traditional mine design principles. Existing assets can also reap the rewards associated with the replacement of diesel fleets, upgrading of assets and adoption of new procurement procedures. Investment in these areas will create an inundation of new data, providing ample opportunities for optimisation and innovation.

Several consortium members are incorporating electric mine design learnings in their due diligence processes. There is currently no way to holistically demonstrate or validate the assumptions associated with these new design principles given the limited application of such technology at scale and within a single operation.

Despite many companies providing different aspects of the final product, the technology for the full integration and simulation of electric mines hasn't yet existed until the completion of this Electric Mine Simulation challenge.

The EMC's mine design working group, led by TAD, completed a global crowd challenge to attract companies and individuals from around the world to propose approaches for developing a scalable electric mine design simulation platform – a process that this report describes.

The final outcome developed by SET & SimGenics is, in concept, tantalisingly close to allowing for a large mitigation of the risk inherent in designing, building, and operating electric mines. It is able to:

- Complete full-scope, multi-vendor simulation of the demonstration mine
- Compare diesel and electric vehicles and their capabilities
- Consider all relevant interdependencies of a mine using a systems approach
- Simulate multiple energy supply and storage scenarios and technology mixes
- Test multiple scenarios to optimise mine designs
- Integrate continuous and discrete-event simulation tools from multiple other vendors

Recommendations available to the business, including mine managers and the executive, from this simulation technology are no less transformative:

- Recommendations for the operating strategy
- Discussion on the risks of the strategy and the mining system
- Graphical representation of outputs using graphs and animations
- Simulation system that is able to model various mine systems to identify potential risks with mine electrification
- Recommendations to support decarbonisation decisions

Across the Electric Mine Consortium, there are around 100 assets globally that require electrification and which collectively represent the carbon emissions of a medium-sized country such as Denmark.

The pipeline of future projects and greenfield developments is many times the size of the existing operating assets.

Together they represent many tens of billions of dollars of sunk and potential investment – an enormous risk and opportunity that will have a lock-in and legacy across decades.

Transition to Electric Mines

Electrification: A foundational technology

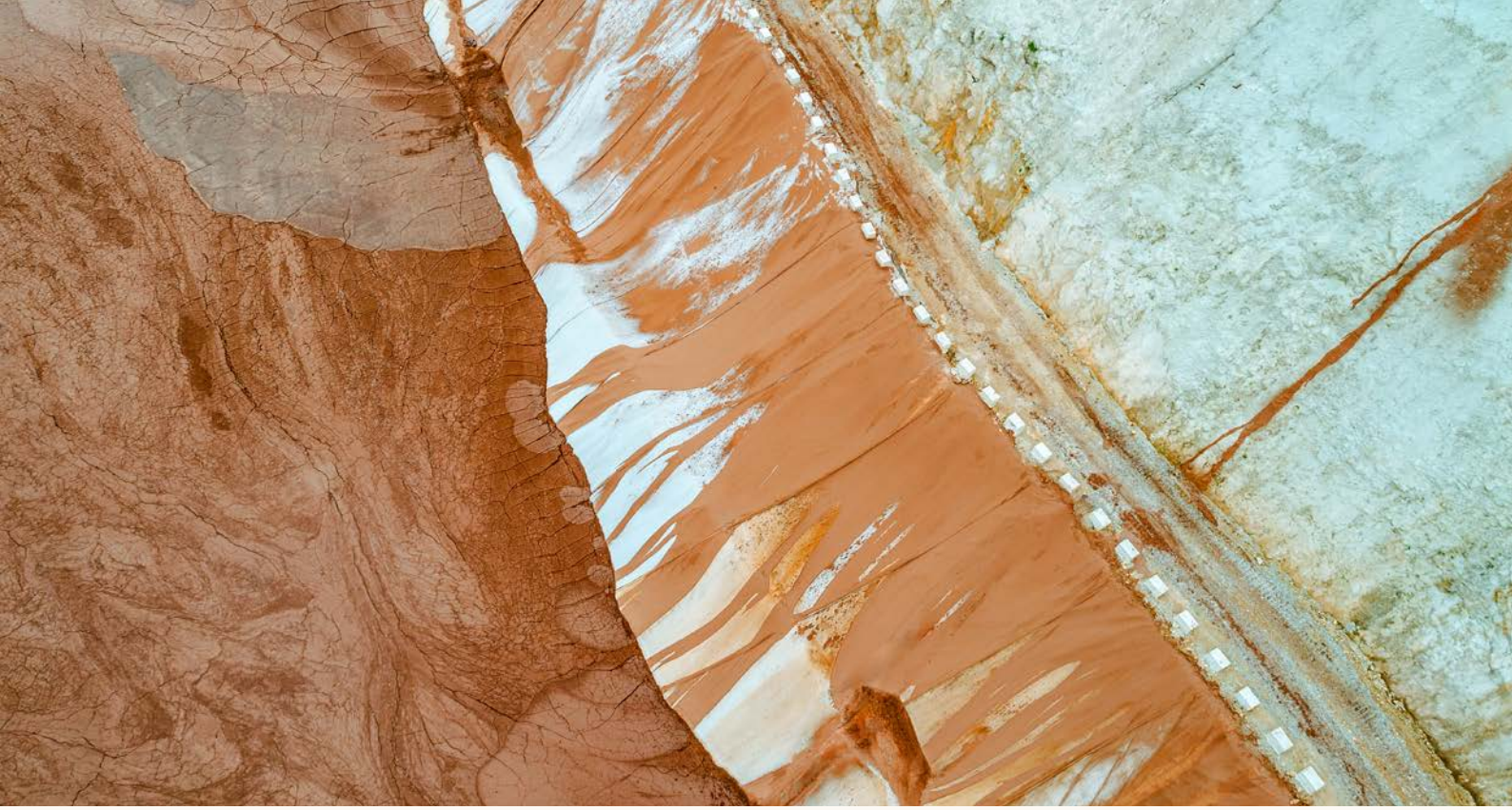
Electrification is the foundational technology for decarbonising the mining industry – as it is for the broader economy. The next generation of mines will be all-electric and leading companies are actively planning and preparing to realise this.

Electrification is the medium for consuming, transferring and optimising renewable energy. Its foundational role is similar to the internet in the digital economy. It is also synonymous with automation and digitisation for two reasons: the step change increase in data associated with electric equipment, and the increased controllability of electric equipment and precision operation required in an all electric mine.

For those mines globally that aren't grid connected – in Australia, around 35% of mines are remote[2] - there is the added challenge of building and managing clean electricity generation. In the case of renewables, this means adjusting to a variable source of electricity.

Shifting from a fossil fuel powered mine to an entirely electrically powered mine is a whole-of-systems shift from one energy technology to another. It is a challenge that hasn't been attempted in mining before, or anywhere else at the pace required.

2 Australian Bureau of Statistics



What will change

An all-electric mine will shift away from a number of traditional mine design principles. It casts away siloed operating assets and elevates systems thinking. New equipment will introduce an electric platform with available and seamless transfer of data, a capability not available on traditional equipment.

While retrofitting brownfields assets is somewhat constrained by sunk capital, existing assets can still replace diesel fleets, upgrade assets and adopt new procurement procedures. Investment in these areas will create an inundation of new data, providing ample opportunities for optimisation and innovation.

Greenfield assets offer an opportunity to capture the true value of full electrification through optimising the mine design – a great example being ventilation which accounts for around 35% of emission generation through energy use.

Electrification takes away the diesel emissions and heat generation that are key constraints to ventilation design, creating opportunities to adjust tunnel size, reduce vent fan size and flow, and reduce refrigeration. Ventilation cost reductions of 25 to 35% are achievable.

The improved productivity of electric equipment (driven by power transfer) will lead to potentially more efficient development design (for example, increased gradients, tighter turning circles).

In addition to lower operating costs, we may also see the economic viability of deposits change, unlocking marginal ore bodies, for example where depth, heat or development cost have created unviable costs. Consortium members are already beginning to incorporate electric mine design learnings in their due diligence processes.

Operating electric mines

One of the largest uncertainties mining companies are facing is the operating model for electric mines. Operations will need to simultaneously manage the energy budget and production for every piece of equipment at all times every day - based on an intermittent source of energy - in order to ensure continuous operations.

Even the most integrated and sophisticated mine sites today are not yet able to do this. The electric mine will demand a new level of operating precision. In practice, it will require greater automation and a greater emphasis on algorithmic based scheduling from automated operating systems.

An indication of this is how advanced contracting companies are pursuing both electrification and automation in parallel – Electric Mine Consortium member, Barminco, is a good example of this.

Digital comes of age

Once in place, an electric mine will allow for a degree of data driven decision making that has enormous value. This is a future that has been much predicted but that hasn't yet eventuated. Electrification will be the catalyst.

Where electric equipment produce hundreds of individual real-time data points, effectively gigabytes of data daily, the data intensity of today's telemetrics on traditional fossil fuelled equipment is far lower.

For example, fuel use for diesel equipment at many sites today can only be measured at a fleet level over a weeks-long timeframe because fuel tracking data is difficult to extract or non existent and can only be calculated by measuring the diesel stores of all fuel cards across several shifts.

The increased digitisation and automation of electric equipment will allow for a more decentralised workforce, not to mention the different electrician and electrical engineer based skills to supplement trades that are more common on mine sites today. The skill-set required to operate and manage a data-driven operating environment is likely to be vastly different to today's.

The Electric Mine Consortium has been actively collaborating to build towards such a capability – primarily through the electric mine simulation challenge, but also through the collection and sharing of large electric vehicle trial data sets covering supply, storage and equipment to build a real-world baseline.

The complexity of simulating electric mines

Mines are a complex assemblage of dependent systems. The electric mining value chain consists of:

1. **Mine design:** The layout of the mine in three dimensions will change as will the mining method itself in many instances.
2. **Energy:** The generation, distribution and storage of electrical energy is a key aspect of operating next generation electric mines in a way it isn't with fuels-based mines.
3. **Ventilation:** Underground mines are ventilated to remove diesel particulates, clear emissions and dust from blasting and manage heat loads from vehicles and host rock.
4. **Electrical infrastructure:** Charging infrastructure needed to keep BEVs operating will be installed and power supply to the underground workings will be increased.
5. **Mining:** The process of retrieving ore and waste from the ground, either underground or open pit.
6. **Vehicles & logistics:** Primarily loaders and trucks used to dig and transport ore, long haul trucks and shipping.
7. **Processing:** The process of recovering valuable minerals from ore at the mine site into concentrated products (copper, lead, zinc or nickel concentrates) or metal products (gold and silver).
8. **Marketing:** Transport and sale of products to market, either third party smelters in the case of concentrates or refiners and end users in the case of metal products.
9. Other supporting infrastructure; such as water supply, skills, accommodation, etc.

Simulating electric mines

An integrated simulation of the mining value chain and its sub-systems interacting over time is required to fully understand and communicate the value in transitioning from diesel powered equipment to battery electric equipment.

Simulation technologies have the potential to be far more effective at modelling electric equipment and mines due to the higher data density – a point reinforced by the Electric Mine Consortium data platform to share trial data among member companies.

From an operational perspective and vision for the future of simulation, there needs to be a tight link with the mine design process at all time frames (strategic, long, medium and short term) with feedback loops integrated to maximise learnings.

Whole of system simulation is optimum, yet hard to achieve, the Electric Mine Consortium has been a stepping stone to achieve this.

In addition to which, it is clear that one of the major value drivers for simulating electric mines is risk management. In fact, simulation arguably pays for itself as a risk management tool to better understand an uncertain transition.

The irony is that simulation in mining is widely seen as risky, not as risk mitigation. In a steady-state world in which fuels-based mines continue, then this is arguably true. But in an electric mine situation, simulation is an essential aspect of its design. There are simply too many variables that are different from conventional mines at a design and operational level to be able to account for and predict using more linear approaches.

Centrality of trials to simulation

The link between electric mines, trials and simulation is not widely appreciated. The design of electric mines today is based on a number of untested assumptions. These assumptions can only be made more accurate through physical trials.

Trial data is valuable to the simulation teams to calibrate the simulation models, build confidence and allow repeatability across diverse sites. However, trials are not widely used to support simulation.

In part, it could be argued that this is because the mining industry is not well-practiced in integrating major new technologies to its core process. The task of collecting real trial data to validate simulation assumptions further mitigates the risks of planning and designing electric mines.

To date, the Electric Mine Consortium has many dozens of trials either completed, in progress or planned in the near term. All of this data is being shared with the consortium's participants to further inform decisions, de-risking and accelerating their decarbonisation transitions.

Simulation costs remain a major barrier

Simulation is about helping make decisions but the perception, and often the reality, is that it is cost prohibitive to do so. This is despite a major aspect of the value proposition of simulation is that it reduces the time and cost of far more expensive physical technology deployment.

There is a development cost and a use cost associated with electric mine simulation – we haven't yet got over the development cost issue. The objective of simulation is to be able to test options in a repeatable and low cost way.

The development cost is repeated for every simulation. For each simulation project, the team must start from the start. Every simulation is ultimately bespoke which means that miners are unable to benefit from decreasing use costs over time.

This cost is also realised through long lead times from conception, negotiation, deployment and finally answering the question initially posed.

Mining industry skills and culture

Design work is not a central part of the mining industry's skillset – has been a long time since the industry has had to reconsider first principles design assumptions. Most engineering firms and studies teams lean towards re-using proven designs and mining methods.

As such, with the requirement to move quickly to electric mines, the industry does not have the embedded capability to quickly re-consider these first principles. And it certainly does not have the ability to do this systematically using modern simulation technologies.

Generally speaking, simulation is not a core capability in studies teams. It is used ad hoc in an outsourced manner. Miners are typically risk averse in bringing these skills in-house.

For example, we couldn't easily assemble a panel of industry experts to review the simulation challenge as few knew what they were talking about or the type of person we were looking for. No one had ever written a scope of work for this type of project.

The language of simulation itself is unfamiliar to most in operating mining companies. This needs to change in both directions – not enough simulation professionals speak the language of mining, and few miners speak the language of simulators. Both sides struggle to relate.

Those simulating professionals who do speak the language of mining, tend to come from long established mine planning companies using relatively dated technology.

Going forward, it will not just be about developing an application, it will be about developing the capability to build and run the capability. This capability will need to sit across the business, bridging both corporate and sites, in order for communication to be integrated and effective.

Mining companies will increasingly need to get into the mindset of simulations being a core capability in which DevOps-type skillsets are available at a site level.

Simulation industry context

Globally, there are a lot of sophisticated simulation platforms and products available across industries. Their penetration to the mining industry has, however, been low. Mining is a complex, yet relatively small, industry in which large investments by traditional simulation providers does not necessarily translate profitably.

There are closed source, proprietary simulation platforms able to cover one or two of these sub-systems but no single open source platform able to cover all aspects in an integrated way.

Moreover there has been no single platform that we are aware of that can flexibly add more sub-systems, expanding their scope beyond electrification and beyond underground mining to fully simulate all sub-systems and steps in the value chain.

Unfortunately the dominant weight of simulations companies is in the optimisation space, not the design space. Much of this has been used in the mine planning sphere for years and is well understood, but is also based on dated technology. A common complaint is that they also tend to be inaccessible for laymen, burdened with poor user interfaces.

The variability of mines and therefore their operations also makes the repeatability of simulation software difficult. Added to which, energy is also now increasingly site specific. The core assumptions underlying common mining methods themselves are coming into question as the cost structure of energy shifts – these methods are close to impossible to compare directly using current day mine simulation software.

Should there be an in-house development of software? Perhaps not. But it has been difficult to source from market to date. This sat at the core of the rationale for the mine simulation challenge. Done well, these simulations can be very powerful. And the increasing complexity of mining systems, compounded by the rapid rates of change in technology performance and cost, means the need for capable simulation platforms has never been greater.

Discussion of the project - EMC & TAD: Electric Mine Simulation Challenge

The electric mine consortium's six founding mining members, TAD, Blackstone Minerals, Barminco, IGO, Gold Fields and South32, identified five core technical challenges that needed to be resolved in order to realise their goal of developing all-electric mines. Each took the lead on one challenge.

For TAD, the priority was to identify and use sophisticated mine design simulation software to support the design and optimisation of the upcoming greenfield project at West Musgrave and the Promient Hill and Carapateena expansions.

The Prominent Hill case study

Prominent Hill reliably produces one of the highest grades of copper concentrate on the market. A high-quality, dependable asset, at some of the lowest production costs in the world.

The Prominent Hill mine's ongoing success has helped to grow sustainably and explore new areas of investment. The Antakirinja Matu-Yankunytjatjara peoples are the traditional owners of the land.

Prominent Hill

An ideal platform to increase our transition to electrification

Our Mine	Our Opportunity	Our Vision
"Prominent Hill: A high-quality, dependable asset"	*"A prospective ore zone decoupled from the main mine which enables us to innovate from day one"*	*"To be a fully electric mine from first cut to mine closure"*
▪ Long life, low cost, underground copper mine located in South Australia ▪ Transitioning from truck to shaft haulage by 2025 ▪ Established infrastructure including grid power	▪ Near surface ore zone with simple geometry and favourable mining conditions ▪ Resource delineation well advanced ▪ Independent but integrated, blank canvas for ideas and innovation	▪ Simulate an electric and conventional mine in parallel ▪ Identify roadblocks to electrification ▪ Target a lower $/ft compared to conventional

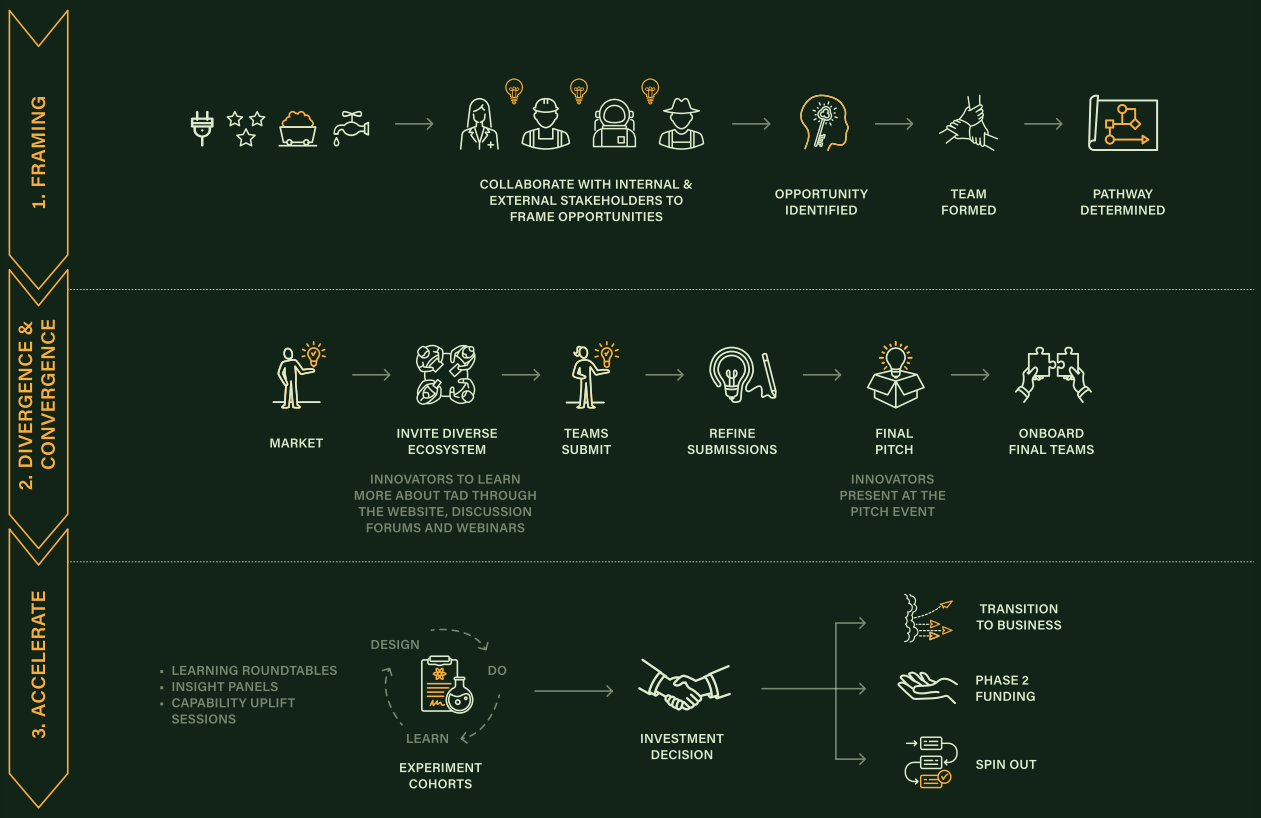
The benefits | What's in it for everyone?

Accelerating the transition	The impossible is now possible	A green mine is a sustainable
We aim to be early adopters and lead change in our industry. Electric mines are coming, and we want to push fast forward. An adaptable and effective simulation tool will help bring tomorrow closer.	Mining equipment manufacturers see the light and are rapidly developing BEVs. We would like to set the pace for electric mine design by identifying the roadblocks and designing them out.	The benefits of eliminating fossil fuels from underground mines are endless. We all know this, yet we wait for the first mine to take the lead. Well, we would like to be that mine and need your help to make it a reality.

The electric mine simulation case study focused on the Walawuru orebody located north of the existing Prominent Hill mine. The orebody is approximately 800m along strike and 600m height and between 5 and 30m wide. The proposed methods are Avoca and open stoping depending on the stope width.

Two haulage options are being considered with the ore being hauled to the pit, then to the ROM pad or being tipped into an orepass system with a transfer level to the lower orepass to the haulage level.

For TAD, the preference for building electric mines was clearly aligned with their modern mining design philosophy. TAD chose to run an open challenge to avoid repeating common approaches of the past, disrupt traditional procurement practices, accelerate the adoption of simulation and catalyse collaboration. TAD partnered with Unearthed to engage the global crowd in a search for possible solutions.



This open innovation challenge is likely one of the most exhaustive and collaborative efforts undertaken yet in the mining industry. Some simple high-level statistics:

Process	20 collaboration partners via EMC	12-months from start to finish	Dozens of design & evaluation sessions	50 - 60 individual participants from collaboration partners
Participation	190 participants	36 countries	23 submissions	2 use cases
Outcomes	8 shortlisted submissions	3 Q&A evaluation sessions	5 finalists	1 successful team with 2 companies in partnership

The SET & SimGenics collaborative approach

In a fantastic outcome, two finalists of the electric mine simulation challenge process – SET & SimGenics – decided to collaborate and put forward a joint proposal, and ultimately were successful in the challenge as a result. This step was due to their recognition of the complementarities of their respective simulation technologies.

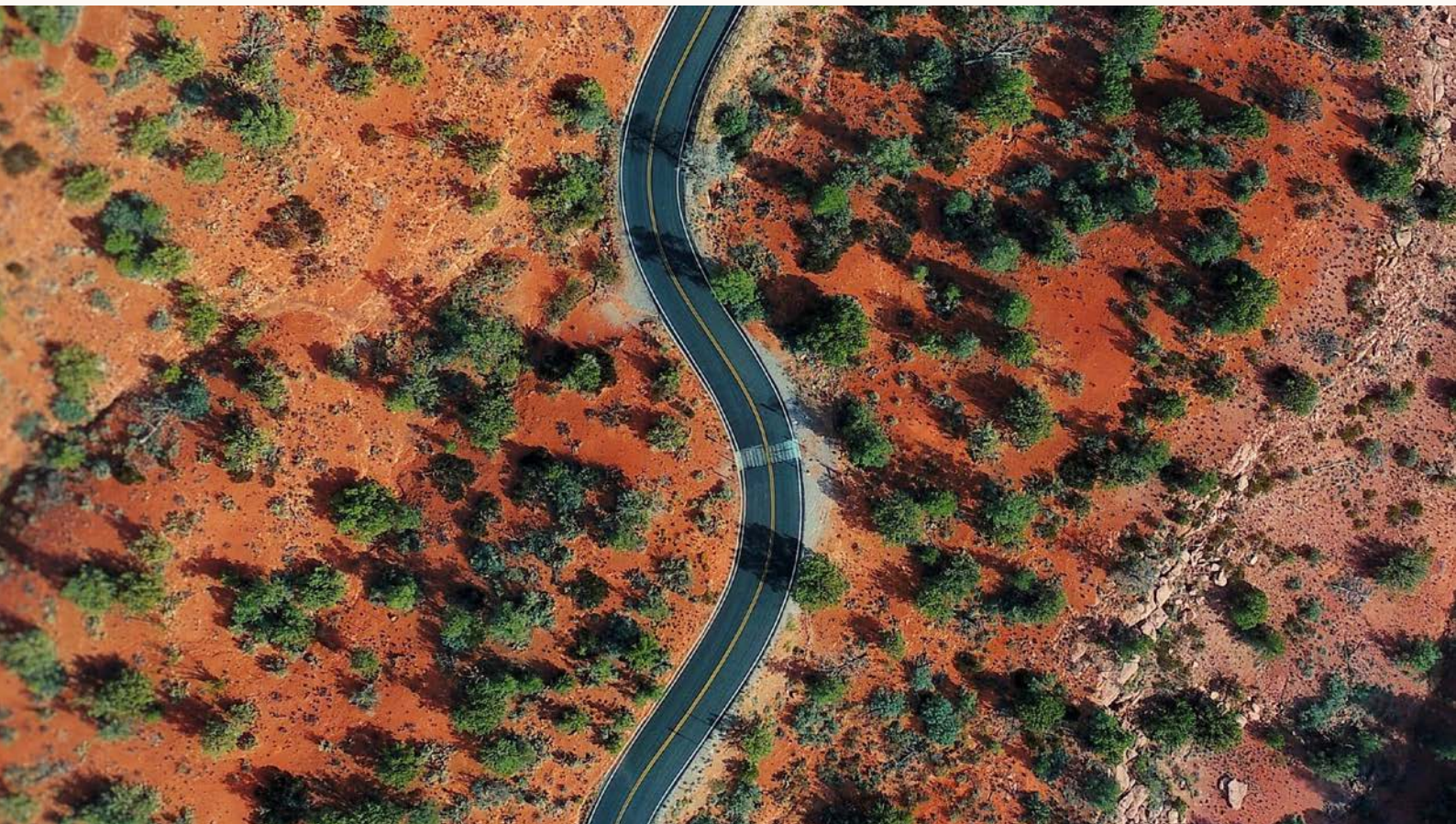
The platform is designed to be easily scalable, both in terms of its roll-out and its extension to include new capabilities.

A summary of near-term development steps include:

1. Extend the Prominent Hill pilot to the whole mine site, from the current new satellite deposit, which will build on the infrastructure and process interdependencies across the site. These include energy infrastructure and processes such as backfill consolidation.
2. Integrate the electrical infrastructure design with shaft, material handling, conveyors and automation design. Using the power of SimPac, we have a detailed real-time understanding of the load balance at site level.
3. Establish a formal post-pilot co-development feedback process between the Set & SimGenics team and the Prominent Hill team.
4. Extend the simulation comparison from electric and diesel equipment to include automated vehicles in an electric mine context, helping us to understand the design implications for major infrastructure and support services.
5. At a mine design level, the team will extend the simulation to allow for novel technologies, particularly different material movement options like vertical conveyors. Several of these have already been developed and form part of the simulation library, and others will be added.
6. Pursue greater integration with common mine planning tools such as Vulcan and Deswik, focusing on efficient coupling, common parameters and interface tools. This step will establish a feedback loop between the simulation and modelling processes.

Most importantly, simulation tools such as this are most valuable for their ability to socialise and support meaningful discussions to solve complex questions. The biggest thing for simulations is to be able to experiment and then discuss as a team.

Prominent Hill and the Electric Mine Consortium are committed to continuing to progress this co-development, and in so doing, supporting the broader industry discussion and understanding of the considerations when electrifying mines.



What we have learnt–A platform approach is required

One of the submissions to the electric mine simulation challenge proposed establishing an open source simulation platform. This was to be common to partners for integrating different parts of the value chain. The platform would have established a de facto industry standard for performing simulation.

The value of this approach is that mining company analysts can focus on value-add tasks, not on developing vendor locked or organisation specific simulation tools. Engineering teams would be seeking to answer the core mine design questions and supporting modelling work over building the tools.

Over time, the industry could build the ability to simulate hundreds of mines. Companies could leverage the modelling work performed by partners and vendors to accelerate technology adoption – reducing non value-add effort, saving both substantial time and money.

The simulation platform would establish a growing library of simulation components that can be used by teams throughout different analysis tasks. Service companies would have the opportunity to develop models and re-sell to create new revenue streams.

Reusing a common framework would allow faster time to value for simulation projects. If in place, service companies would also be able add custom features or to create unique offerings, developing new products to support the analysis ecosystem or through integration with other tools.

We would have created, and maybe still could, a democratisation of this type of capability, moving beyond simlulating very specific parts of the value chain through the use of siloed capabilities.

The business who proposed, and who subsequently argued convincingly for, this compelling model was First Mode. We chose not to go down this path due in part to the cost and the difficulty in convincing multiple mining companies to support the initiative given uncertain outcomes and long timeframes until value creation.

It required, in effect, more of a venturing type investment framework than how our challenge approach is structured and funded. The SET & SimGenics approach has been fantastic in supporting the Prominent Hill mine to understand its electric mine vision, and time will tell if they will be able to achieve the broader industry objectives potentially available from an open source simulation approach.

As the EMC and TAD, however, we will continue to ask ourselves the question - how can we support the ecosystem with more of a platform approach that will allow others to work with us on the systems view?

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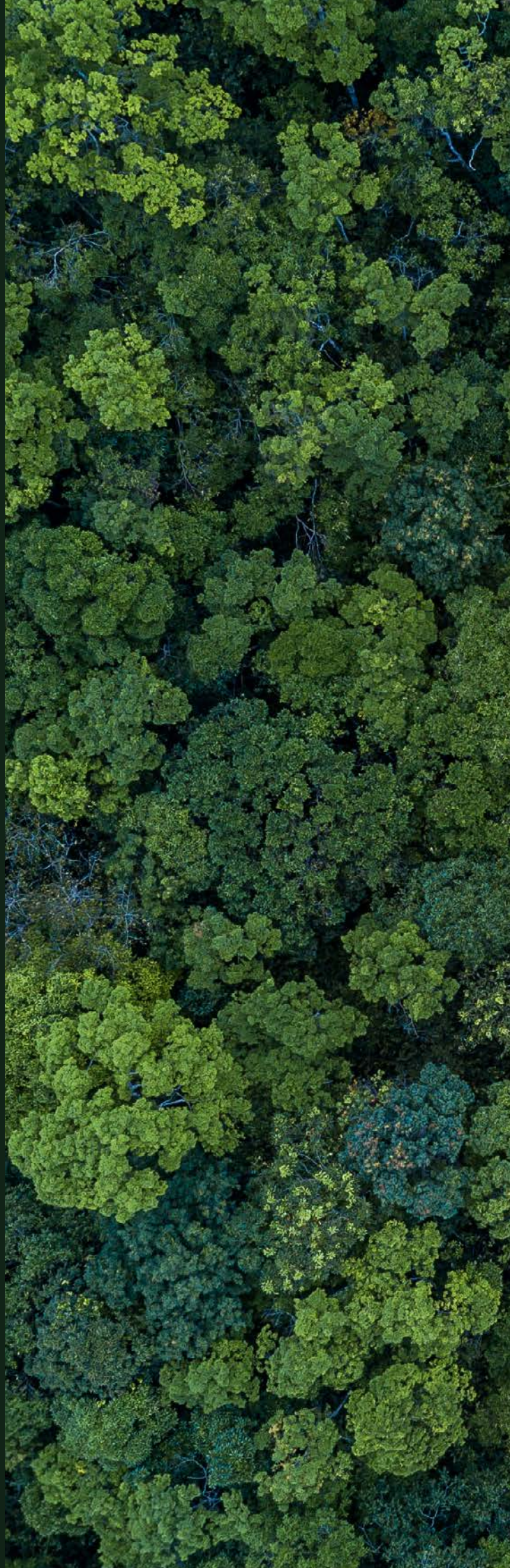

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