Think & Act Differently
powered by OZ Minerals

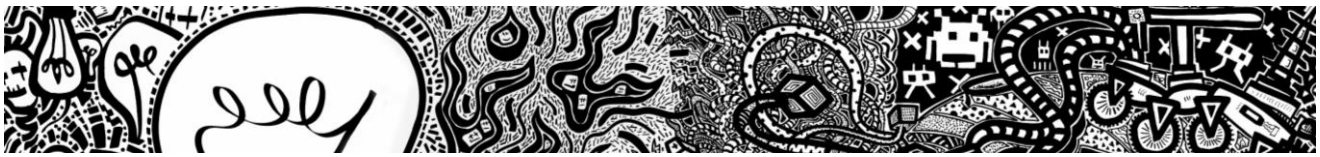
CHALLENGE
WHITE PAPER

OZ MINERALS

March 2022

HYDROGEN HYPOTHESIS

Accelerating OZ Minerals to zero emissions



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PURPOSE AND ACKNOWLEDGEMENTS

This document captures the current and potential future state of green hydrogen and summarises the outcomes of the Hydrogen Hypothesis challenge

Purpose of this document

The purpose of this document is to capture the current and potential future state of green hydrogen at the global, industry and OZ Minerals levels and to summarise the outcomes of the Hydrogen Hypothesis challenge within this context. The document outlines the next steps that will be taken based on the momentum created through the challenge and how this supports OZ Minerals in the achievement of our zero emissions aspiration and Decarbonisation Roadmap.

Acknowledgements

Acknowledgement of Country

From the past, to today, and for forever into the future: these are the Lands of the Traditional Owners. Always have been, always will be.

Terry Burgess, Hydrogen Hypothesis mentor

The Think & Act Differently team would like to acknowledge the invaluable role that Terry Burgess played in sourcing, selecting and mentoring the innovators throughout the challenge. The role of the mentor in each of our challenges is to help innovators connect the dots by providing industry context, access to networks and subject matter expertise.

The Think & Act Differently team

Katie Hulmes
Challenge Sponsor

Terry Burgess
Hydrogen Hypothesis Mentor

Brett Triffett
Challenge Host

Burkhard Seifert
Challenge Framing

Rachel Eaves
Challenge Marketing & Communications

Jessica Doherty
Innovator Experience

Leidy Alvarado
Insights Panel Host

Debbie Alexander
Hydrogen Hypothesis Cohort Facilitator

Collaborators

The Think & Act Differently team would like to acknowledge the input received from the companies and teams in imagining, delivering and running the Hydrogen Hypothesis crowd challenge, including the composition of this document.

Unearthed Deloitte. LarkinSykes MINING | INNOVATION | ADVISORY

> **To achieve decarbonisation of the minerals and mining sector we need to work together with all our Stakeholders taking a "why not" or a "How Might We?" approach to unlocking technology and mutually creating value.**
>
> **- Katie Hulmes**

Mike Bellemore
Monitor Deloitte

Jacob Herman
Monitor Deloitte

Kate Fahey
Monitor Deloitte

Emily Ong
Monitor Deloitte

EXECUTIVE SUMMARY

The Hydrogen Hypothesis challenge, run by Think & Act Differently, has demonstrated the value of hydrogen as a potential key enabler for decarbonisation at OZ Minerals

Hydrogen is gaining momentum

Green hydrogen is expected to play a key role in the decarbonisation journey of the mining industry and has been gaining increased attention over recent years. Advances in production, reduced distribution costs and rapid technology development are accelerating the commercial viability of hydrogen as an energy source. One of OZ Minerals' strategic aspirations is to emit zero Scope 1 emissions and strive to systematically reduce Scope 2 & 3 emissions across the value chain and we have released our Decarbonisation Roadmap in our sustainability report. OZ Minerals has recognised that the emerging hydrogen industry is a material opportunity for the miner to explore, lead and collaborate on solutions that could accelerate the application for this energy source and deliver its Decarbonisation Roadmap.

Identifying innovators

To explore the potential for green hydrogen, Think and Act Differently launched the Hydrogen Hypothesis challenge in March 2021. The aim was to find innovators both inside and outside the mining industry who could help OZ Minerals learn more about the potential role hydrogen could play in a transition to zero emissions mining. A cohort of seven innovators from across the globe were selected to test their hypothesis about safe and cost-effective use cases for hydrogen in mining through experimentation. Innovators were strategically selected across all stages of the value chain to ensure a holistic understanding of the role hydrogen could play in supporting OZ Minerals reach its emissions ambition.

A systems approach to hydrogen

Through this process, Think & Act Differently and the cohort learned that there is a need for a systems approach to implementing hydrogen solutions within mining; that is, an approach that considers how all the pieces of the hydrogen value chain fit together and integrate with the demand side of the equation. Many promising use cases were validated that could create value for mining operations, including options for achieving zero scope one emissions in off-grid assets, long-distance haulage options for concentrate and freight (alongside the development of batteries), and novel options for concentrate treatment.

Australia is early in the adoption journey

While technology exists for the production and storage of green hydrogen, there are many barriers preventing its large-scale adoption. It is still relatively niche and there is a lack of hydrogen infrastructure in Australia to support its adoption. Additionally, electrolysis and pressurised storage is expensive, the low energy density of hydrogen presents operational challenges and hydrogen-based mine and haulage solutions are still very much in development, with no networks supporting offsite haulage solutions.

Will Hydrogen play a role in OZ Minerals' decarbonisation toolkit?

Understanding these issues has enabled OZ Minerals to narrow its focus on start-ups with the potential to unlock cost, storage, and diverse applications. The company is continuing to support the work of innovators to explore lower cost green hydrogen generation and safe and efficient storage options that can facilitate the transition from diesel. It is likely that future assets will be remote and off-grid; therefore, having hydrogen as a flexible option within the OZ Minerals decarbonisation toolkit could be advantageous in maintaining decarbonised assets.

A collaborative innovation endeavour

The Think & Act Differently Team would like to acknowledge the time and effort of all participants and innovators that have contributed and will continue to contribute to the hydrogen hypothesis challenge.

THINK & ACT DIFFERENTLY

Think & Act Differently is a discovery-driven incubator powered by OZ Minerals; established in 2021, its purpose is to accelerate the achievement of the company's strategic aspirations

Think & Act Differently provides a unique approach to innovation, attracting the best minds from both inside and outside the mining industry, connecting the dots in new and exciting ways.

Central to its success is the active participation of a network of thousands of people from across multiple industries, organisations, community groups, governments, research organisations and others who want to play a role in solving complex mining challenges.

The incubator provides these stakeholders with access to tools, skills and processes to help identify new, low impact ways to mine and process minerals and create valuable opportunities for society.

At the core of Think & Act Differently is a unique human-driven process where the ecosystem works together to **Frame** opportunities, **Diverge** in our thinking to generate ideas, **Converge** experiments that we can use to test the best ideas and then **Accelerate** these ideas by providing funding, technical expertise, access to sites and support.

Think & Act Differently powered by OZ Minerals

Value Created by Hydrogen Hypothesis

Employees

- Employees actively working with early technology learning pathways for commercial products
- Over 100 employees attended the pitch event
- 151 employees present at the insights panel on hydrogen with mentor Terry Burgess

Suppliers

- 158 registered innovators from around the world as a part of the crowd challenge
- Cohort have upskilled their understanding of mining and 40 suppliers attended the mid-challenge webinar
- 40% of cohort currently raising capital with $10m collectively raised during the Accelerate stage

Government

- Participation in SA H2H Hydrogen Cluster supporting development of a hydrogen Industry in South Australia
- Active promotion of hydrogen infrastructure in the Upper Spencer Gulf

Community

- Five companies expressed interest in a consortium for hydrogen transport
- Potential for increased investment into regional and rural communities for hydrogen developments

Shareholders

- Accelerated focus on Scope 1 and 3 Emissions through Hydrogen Highway
- Demonstration of operating model against all available technologies, not reliant on just hydrogen or battery electric vehicles (BEV)
- Increasing clarity and certainty on roadmap to 2040 and opportunities to accelerate

THINK & ACT DIFFERENTLY

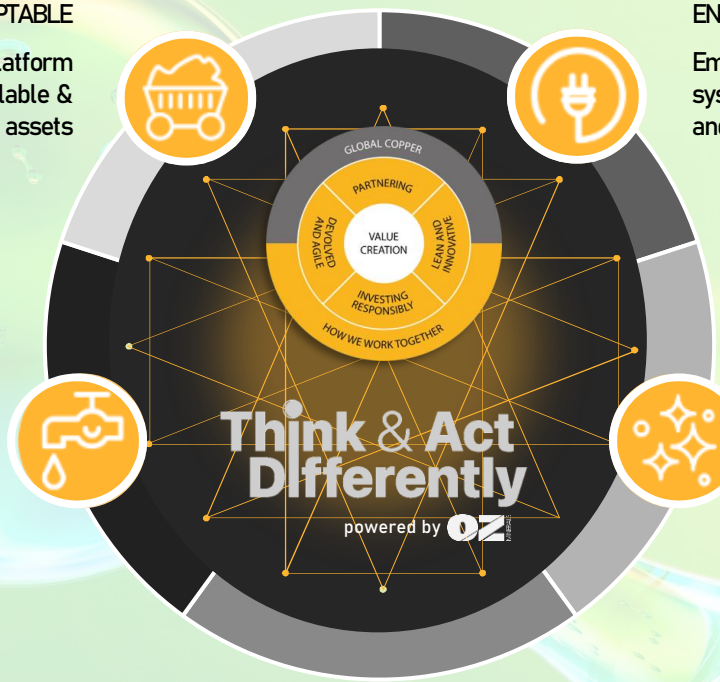
Think & Act Differently focuses on four transformation themes which are delivered using a humanistic systems-driven approach to innovation

SCALABLE & ADAPTABLE

Leverage modular/platform solutions for scalable & adaptable assets

ENERGY & EMISSIONS

Emit zero Scope 1 emissions, and systematically reduced Scope 2 and 3



WATER & WASTE

Minimise water use and generate zero net waste

CLEAN PRODUCTS

Produce clean valuing adding products in a transparent manner

Humanistic systems driven innovation, Sustainable Development Goals and TAD

OZ Minerals' Strategic Aspirations are aligned with specific United Nations Sustainable Development Goals (SDGs). Also aligned to this is TAD's humanistic, systems-driven approach to work which acknowledges the complexity of our challenges and prioritises the interests, needs and welfare of people, in synergy with the OZ Minerals purpose of 'Going beyond what is possible to make lives better'.

SDGs are addressed through TAD themes of clean products, energy and emissions, water and waste, and scalable and adaptable. TAD is committed to demonstrating the impact of technologies developed through the incubator process towards the SDGs and their associated targets. In partnership with Wicked Lab, innovators will be able to demonstrate to the broader community how their technologies, both individually and combined, are contributing to SDG progress. Wicked Lab assists change-makers to address wicked problems through mapping and strengthening solution ecosystems.

01

CLEAN PRODUCTS THROUGH A SUSTAINABLE VALUE CHAIN

In collaboration with:

Clare Sykes
Managing Director,
LarkinSykes Advisory

LarkinSykes
MINING | INNOVATION | ADVISORY

> The global energy sector is undergoing significant change and it is increasingly accepted that hydrogen, with a range of applications, will be a catalyst to reach global decarbonisation ambitions. It is timely that OZ Minerals should explore a future that includes hydrogen including practical pathways to overcome technology barriers and leading models to accelerate applications.
>
> - Clare Sykes

1.1 Hydrogen Context

The emerging hydrogen industry is a material opportunity for OZ Minerals to explore, lead and collaborate on solutions that could accelerate the application of green hydrogen

What is Hydrogen?

Hydrogen, the most abundant element in the universe is receiving attention world-wide as an enabler to arguably the most ambitious undertaking in industrial history; a redesign of the way the world is powered to achieve emission reduction and mitigate the impact of climate change.

Hydrogen, when produced from renewable energy, is known as green hydrogen. It does not emit any greenhouse gases when produced or used. The flexible and broad nature of hydrogen represents a significant opportunity to contribute to decarbonisation efforts across a range of applications including hard to abate sectors. This includes mobility and transport, power, heat, chemical feedstock for industrial processes and materials. According to the World Energy Council[1] a comparative assessment of worldwide hydrogen demand scenarios shows hydrogen could reach up to 25 percent of global energy consumption by 2050 depending on how hydrogen is balanced with other solutions such as battery storage.

A National Hydrogen Strategy

Australia is well placed to participate in the global hydrogen economy, with exceptional wind and solar resources supported by resource development expertise.

Investment is increasing in hydrogen projects and technology developments. According to the Australian Hydrogen Council,[2] announced hydrogen projects have grown from 228 to 359 in the first six months of 2021 and more than 32 governments across the world have announced net zero commitments, with over 100 countries considering it, resulting in an estimated $108B to mature hydrogen strategies and projects.

According to the World Energy Council, the drivers behind key hydrogen commitments include emission reduction, diversification and security of energy supply, fostering of economic growth, and integration of renewables.
In November 2019, the Council of Australian Governments (COAG) Energy Council endorsed a National Hydrogen Strategy demonstrating a commitment to advance a hydrogen industry. The past two years have seen a number of significant milestones by Australian and State governments to progress and support hydrogen projects and related activities, with further momentum anticipated in the coming years.

According to HyResource[3] there are currently 18 projects that are operating or under construction in Australia and a further 11 projects at an advanced stage of development planning.

Although announced projects are increasing in Australia, and a number of projects are progressing to construction, the technology is still in its infancy. Further research and development will be required to drive hydrogen adoption. Stimulus measures are required to drive a virtuous cycle of private investment, scale and technology advancement which will all work as levers to enhance the competitiveness of hydrogen as a clean fuel.

The first six months of 2021 has seen:

57%	increase in announced hydrogen projects in Australia
30+	countries commit to net zero hydrogen projects
US$76b	public funding for mature hydrogen projects and research

1.1 Hydrogen Context (cont.)

Green Hydrogen is increasing in potential and competitiveness in the new energy ecosystem and is expected to be commercially viable in Australia for a range of applications by 2030

Hydrogen is gaining competitiveness for energy transition

A global shift towards decarbonisation, structural policy directives from governments, and private investments are all driving efforts to deliver Australia's National Hydrogen Strategy including a target of $2/kg for green hydrogen that would put it within reach of commercial applications across many industries.

In 2021, the Clean Energy Finance Corporation (CEFC) commissioned a study into the competitiveness of green hydrogen. It is anticipated that advances in production and distribution costs plus ongoing technology development will be key to accelerate the commercial viability of green hydrogen. Large scale project development is also critical to drive economies of scale and bring down installation and commissioning costs. CEFC predicts commercial viability across transport and mobility sectors could be possible by 2030 .

Why is hydrogen storage so important for the energy transition?

To enable widescale deployment of renewables to replace coal, gas and diesel, long-duration energy storage is critical to transition to a zero-carbon economy. As a long duration media for storage, hydrogen can support energy system resilience. Electrolysers can respond to variations in generation output and generated hydrogen can be stored for later use in generating electricity.

Transporting fuel over longer distances and secure storage are also critical factors for the mobility sector to replace diesel and fossil fuels. Hydrogen as a clean and sustainable energy vector for renewable energy can fulfil this role.

The colours of hydrogen

Hydrogen is already used in a wide range of industrial applications including petroleum refining, ammonia and methanol production. The International Energy Agency (IEA) has identified around 70 Mtpa of demand worldwide for "pure" hydrogen that is commonly used for refining oil and the production of ammonia for fertilizer. There is a further 45 Mtpa of hydrogen that is used in a mixture of gases, such as synthesis gas, for fuel or feedstock for producing methanol and steel. Hydrogen can be produced by steam methane reforming (SMR), gasification or through the electrolysis of water. Hydrogen production is often referred to as a 'colour" indicating the method of production:

Black or brown hydrogen is formed through coal or lignite gasification, with a by-product of CO_2 released.

Grey hydrogen is formed through methods such as Steam Methane Reforming (SMR) or gasification, with CO_2 released as a by-product.

Blue hydrogen is formed the same as grey and black hydrogen, but with CO_2 captured via Carbon Capture Utilisation and Storage (CCUS) technology.

Green hydrogen is formed via the electrolysis of water using renewable electricity source(s). There is no process-related carbon emissions.

Currently, 95% of the world's hydrogen production could be described as black or grey and is associated with fossil fuels. The most widely applied technology for hydrogen production is steam methane reforming (SMR) which is considered a mature technology and is widely used across the refining and petrochemical industries.

It appears very likely that green hydrogen will play a role in global decarbonisation and Australia is well placed to take advantage of this. As technology improves and moves to mass production costs will decline and this will support the development of infrastructure. With this backdrop, there is an opportunity for OZ Minerals' zero emissions aspirations to benefit from further exploration of hydrogen.

1.2 Hydrogen Supply Chain

The hydrogen supply chain comprises three key stages: 1) generation, 2) storage and transport, 3) utilisation

Hydrogen does not typically exist by itself in nature, rather, it is a component of numerous substances including water and various petrochemicals.

Hydrogen generation

The hydrogen value chain begins with production. There are three main processes for hydrogen production, all of which require significant energy input. These are:

- Coal gasification involves the reaction of coal with oxygen and steam to produce black hydrogen, carbon monoxide, carbon dioxide, methane and water vapour. The levelised cost of hydrogen (LCOH) for this method of hydrogen production is $2.02/kg - $2.47/kg[4]. The carbon emissions produced by coal gasification mean this is not a viable option for OZ Minerals.
- Steam reforming of hydrocarbons to produce grey hydrogen and carbon monoxide. The LCOH for this method is $1.88/kg - $2.30/kg[4]. Given the carbon emissions associated with steam reforming, it is not considered a viable option as it is unable to assist OZ Minerals in achieving its ambition of zero Scope 1 emissions.
- Electrolysis of water is a method of producing green hydrogen if the energy used in the process comes from renewable sources. The LCOH for this method is $4.78/kg - $5.83/kg[4]. This process involves using an electrolyser to pass an electrical current through water to decompose it to hydrogen and oxygen gas. Given it is the only method that can produce green hydrogen, this process can assist OZ Minerals in achieving zero Scope 1 emissions.

Hydrogen storage and transport

Hydrogen at ambient temperature and atmospheric pressure is a gas that has a low volumetric energy density (kWh/m^3) resulting in challenges in storing adequate supplies. Due to this challenge, hydrogen is often stored in other forms. The three key forms of hydrogen storage include:

- Compression: Gaseous hydrogen is compressed and stored at higher pressures to increase the volumetric energy density.
- Liquefaction: Hydrogen is both pressurised and cooled to -253^{O}C so that it is in a liquid state.
- Chemical: Hydrogen can be stored in other compounds such as, but not limited to, ammonia and metal hydrides.

Although hydrogen can be transported by any type of vehicle, including truck, trail or ships, the form of transport is dependent on several factors including quantity, distance and safety considerations. For large quantities of hydrogen, pipelines can also be used to transport the pressurised gas, provided the infrastructure is available.

Hydrogen utilisation

There are numerous applications for hydrogen, the key one being:

- Electricity: Hydrogen, along with a fuel cell or turbine, is able to produce electricity.
- Heat: Similarly to electricity, a fuel cell or turbine can produce heat.
- Hydrogen fuelled transport: Vehicles can be powered for transport by either fuel cells or internal combustion engines.
- Chemical feedstocks: Hydrogen is used as an input into several chemical processes including for the Haber process to produce ammonia.

Source: **(4) International Journal of Hydrogen Energy (2020)** Renewable-powered hydrogen economy from Australia's perspective

02

HYDROGEN HYPOTHESIS

In collaboration with:

Lizzie Brookman
Unearthed Marketing & Collateral

Unearthed

Connecting bright minds from across sectors and building global communities of innovators to help solve problems, harnesses the power of the crowd and accelerates our industry towards positive, sustainable change.

With few hydrogen players present in the resources sector, Hydrogen Hypothesis provided the opportunity to connect innovators outside the industry and demonstrated the potential for applying their technology to mining.

It is by working with the crowd we facilitate the transfer of knowledge and expertise and identify solutions to progress the use of hydrogen in mining, helping us to take critical steps closer to a greener future.

- Lizzie Brookman

2.1 Challenge Framing

The Hydrogen Hypothesis challenge is part of a broader exploration of the Energy and Emissions theme by Think & Act Differently

Think & Act Differently has chosen Energy and Emissions as one of its five key themes as it aligns with OZ Minerals' aspiration to emit zero Scope 1 emissions and strive to systematically reduce Scope 2 and 3 emissions across our value chain and our Decarbonisation Roadmap.

In 2020, Think & Act Differently ran the Capture the Spark crowd challenge in collaboration with the West Musgrave Project team, with an aim of identifying opportunities to increase penetration of renewables to 100%. The use of an open crowd challenge was prompted by a business priority to experiment with crowd sourcing as a means of identifying new ideas. Hydrogen was strongly represented amongst the submissions, however these solutions were not prioritised due to perceived cost and technology risks.

OZ Minerals' asset Decarbonisation Plans place a strong emphasis on the introduction of renewable generation and battery-electric mining and haulage equipment. However, plans at this stage have discounted onsite (behind the meter) renewables as cost prohibitive compared to the grid. To support this effort, Think & Act Differently is running the Electric Mine Simulation challenge focused on building simulation capability that will allow a holistic systems view of electrified mines.

Our Decarbonisation Roadmap is not risk free. Opportunities exist to accelerate technology uptake, create more optionality and ensure that assets are able to truly claim to be zero emission.

This company specific context has an additional overlay of hydrogen receiving considerable attention globally as an enabler to full decarbonisation and a strong hydrogen economy narrative emerging in Australia. For this reason Think & Act Differently chose to launch Hydrogen Hypothesis.

Research by the team during challenge framing identified Currently, there are very few examples of hydrogen being used in a mining context. While technology exists for the production and storage of green hydrogen, it is still relatively niche and therefore expensive. Added to this is a lack of hydrogen supply chain infrastructure in Australia.

With this in mind, Think & Act Differently framed a broad, unconstrained crowd challenge inviting innovators to propose use cases for hydrogen in a mining context, as well as experiments that could be performed to derisk these use cases.

In an increasingly complex world, an important piece of Think & Act Differently's purpose is to help build our workforces' capability in dealing with volatility, uncertainty, complexity and ambiguity. We are approaching this challenge by encouraging a systems view to problems, practical experimentation, just getting started and being curious. That is what Hydrogen Hypothesis is all about.

2.2 Challenge Process

Hydrogen Hypothesis was a global crowd campaign to attract the world's best hydrogen innovators

Curating the crowd

Research conducted by Unearthed for the challenge identified Europe, Asia and to a lesser extent Australia and the United States, as the regions with the highest number of projects, centres of excellence and investment in hydrogen. While many projects are government funded infrastructure, the challenge outreach focused on identifying technology companies and hydrogen experts.

Diverging

Over a 10 week period, the challenge attracted 158 participants from 25 countries, with 34 teams putting forward a submission.

Organisations that expressed interest in the challenge were diverse, with start-ups, early-stage technology companies, and consultants. Their technology focus was evenly distributed across electrolysis, combustion, storage, fuel cells and distribution, with a smaller number of companies focused on compression. Many organisations were focused on the consumer and commercial transportation sector and were typically unaware of the opportunities in the mining industry. The Think & Act Differently team hosted a mid-challenge webinar, promoted widely on social media, which was attended by 40 people from across the globe.

Converging

In selecting a cohort to support through the experimental Acceleration stage, Think & Act Differently focused on ensuring a spread of technologies across the supply chain, as well as selecting innovators that were highly collaborative, willing to share their learnings and had expressed interest in building whole of system solutions. It was particularly surprising that prior to entering the challenge most innovators with point solutions within the supply chain had not considered teaming up with complementary innovators to provide more holistic solutions. By progressing through to the Acceleration cohort innovators have grown their networks and met others with complimentary solutions. Ultimately, seven experiments were funded from a group of nine finalists.

Accelerating

The seven members of the Acceleration cohort (presented on the following pages) have spent three months completing their experiments. They have met every two weeks to share learnings and experiment progress in a Learnings Roundtable. Additionally, they have shared insights with OZ Minerals via Insights Panels and a Pitch Event attended by over 100 OZ Minerals employees. With experiments now complete, or nearing completion, each innovator will have a personalised roadmap developed, providing a recommended future direction. In some cases this will involve Think & Act Differently investing in further development of their concept while in other cases their work will finish but they will continue to stay connected to the ecosystem through our Alumni program.

The Think & Act Differently team would like to acknowledge the time and effort all participants and innovators that have contributed and will continue to contribute to the Hydrogen Hypothesis challenge.

2.3 Innovator Overview

A global cohort of innovators with diverse technology applications were selected for the incubator

	Technology	Potential Impact	Experiment
Supercritical Start-up	High pressure and temperature electrolyser for the production of green-hydrogen	Lower cost production than other available methods, especially when coupled with waste heat	Determine the cost of hydrogen produced when coupled with roaster technology for concentrate treatment
Carbon 280 Start-up	Atmospheric pressure storage solution using proprietary mineral oil and magnesium solution	Lower cost storage than pressurised solutions. Safety benefits by operating at atmospheric pressure.	Simulation of a holistic hydrogen based power generation solution for remote bore field application at Carrapateena
Hydrogen Highway OZ Mineral Partnership	Hydrogen based concentrate haulage	Reduction in Scope 1 Emission by 20% by 2026 for South Australian assets	Investigate Collaboration opportunities to bring together H_2 supply, demand and OEMs for a Hydrogen Highway in the Upper Spencer Gulf.
Carnot Start-up	Ultra-efficient ceramic engines that runs on diesel or hydrogen	An alternative to hydrogen fuel cell technology for power supply in generators or for haulage.	Simulation of a remote borefield generation solution at Carrapateena and hydrogen based concentrate haulage using a Carnot engine
$FlyH_2$ Aerospace Start-up	Hydrogen powered drones for remote monitoring of infrastructure	Enable significantly longer range and flight-duration than battery powered options	Simulation of drone operation at an OZ Minerals mine site and investigation of potential sensor arrays
Avid Group Company	Hydrogen powered lighting towers for remote operations	Removal of diesel towers with a clean, hydrogen powered alternative	Testing of light-tower as a pilot to determine reliability and suitability
YaKum Queens Partnership	Hydrogen based reduction of copper solutions as an alternative to electrowinning	Significant reduction in cost and emissions created using traditional electrowinning method for concentrate treatment	Bench scale testing to validate the proposed approach as a valid alternative to the existing method

03

ACCELERATE LEARNINGS

In collaboration with:

Terry Burgess
Facilitator & Mentor,
Hydrogen Hypothesis

Developing a "grand vision" for hydrogen as the "Fuel of the Future with Game Changing Technologies" is much easier than working through the multiple steps required to successfully map out and progress the journey from a concept to a potentially feasible and economic hydrogen solution.

The Think & Act Differently™ Hydrogen Hypothesis Challenge has enabled a number of different groups, previously unknown to each other, to work both individually and collaboratively on their hydrogen experiments and studies. The Challenge has helped to progress their concepts and plan their next steps. These plans will increase scale and reduce the burden of the high upfront costs associated with introducing any technology for decarbonisation.

For a Zero Carbon mine to be feasible, it will likely require a combination of renewable technologies with one being focused on hydrogen and be driven by a consortium of like-minded companies across the supply and value chains.

- Terry Burgess

3.1 Supercritical

Luke Tan
Supercritical

Gemma Cusworth
Supercritical

Company and Innovator Overview

Supercritical is a UK based, seed start-up that is developing the worlds first high pressure, ultra-efficient electrolyser for the production of green hydrogen from water.

Luke Tan – Chief Product Officer

Luke has lived and breathed hydrogen for his entire career, driving innovations into new markets globally with a world leading catalyst company. Always looking to solve the problem, Luke is the person to talk to about Supercritical's technology.

Gemma Cusworth – Senior Process Engineer

Gemma is a chartered process engineer, innovative thinker and agile researcher. The focus of Gemma's career has been driving new technologies and approaches to energy production processes.

The Opportunity

The current levelised cost of hydrogen (LCOH) of green hydrogen produced through a conventional polymer electrolyte membrane (PEM) electrolyser producing hydrogen at 35 bar has been benchmarked between $6.08/kg and $7.43/kg.

By exploiting the benefits of supercritical water[1], hydrogen gas can be delivered more efficiently and at a lower cost than this conventional method. As water is pressurised and heated prior to being electrolysed, the hydrogen gas can be delivered at pressure, removing the need for complex and expensive multi-stage compressors after electrolysis. Reducing the cost of green hydrogen production removes one of the biggest barriers to its adoption at OZ Minerals.

> It was also great to understand the back drop of other innovations that are happening in the Australian hydrogen space... - Gemma Cusworth (Senior Process Engineer)

Experiment summary

Supercritical investigated three different applications of their electrolyser for producing green hydrogen at Carrapateena to determine the financial and environmental impacts of each.

- Case 1 used approximately 7MW of waste heat available from a theoretical downstream copper concentrate roaster being investigated by the Ingenious Extraction cohort. The waste heat was able to reduce energy demand during electrolysis by 25%, delivering a levelised cost of hydrogen (LCOH) of $4.99/kg.
- Case 2 supplied hydrogen for site trucks in partnership with the Hydrogen Highway experiment. It was found that meeting the demand of 350 bar of hydrogen while using a 10MW electrolyser resulted in an LCOH of $6.17/kg. This would be accompanied by a reduction of 16,496 tonnes of CO_2 per year compared to diesel.
- Case 3 supplied green hydrogen as a feedstock for the copper sulfate reduction process being developed by YaKum Queens. It was found that to meet the demand of 2,000 tonnes of hydrogen per annum, the LCOH would be $6.05/kg. This would be accompanied by a reduction of 12,129 tonnes of CO_2 per year when compared to natural gas.

Based on these results, it appears that the Supercritical technology has the potential to reduce the LCOH by 20 – 30% compared to conventional PEM technology with further reductions possible as the product scales.

[1] Water that has been heated and highly compressed such that it has properties of both gases and liquids.

3.2 Carbon 280

Mark Rheinlander
Carbon 280

Company and Innovator Overview

Carbon 280 is a Perth based seed round start-up who are commercialising the Hydrilyte™ hydrogen storage system, which is an innovative solution for the low-cost, safe, storage of hydrogen.

Mark Rheinlander – Founder and CEO

Mark is a geologist and technology entrepreneur. As the founder of two high-tech companies Mark has a broad range of commercialisation skills and experience covering all aspects of bringing a deep technology product to market and a new company to profitability. Mark also brings techno-economic modelling expertise to the team.

The Opportunity

The capital cost for pressurised storage of hydrogen at scale can range from $500 - $1000/kg of stored hydrogen. Hydrilyte™ offers the potential to reduce this by a factor of 10x. The technology stores hydrogen within a mineral oil suspension containing magnesium particles, which bond with hydrogen to form magnesium hydride.

In contrast to pressurised options, chemical storage offers the opportunity to increase stored energy density whilst operating at ambient temperature and pressure, making it a safer option within the mining context. Hydrilyte™ can be charged and discharged, through a hydrider and dehydrider, to store and release hydrogen when required – a process that can occur thousands of times before it needs to be replaced. Hydrilyte™ is non-toxic and can be pumped, transported, and stored at low cost through using existing diesel fuel infrastructure.

Hydrilyte can store 54kg of hydrogen per cubic metre at atmospheric pressure

The opportunity for OZ Minerals is to integrate this technology with renewable energy and hydrogen production capability to provide a fully decarbonised off-grid solution at a lower total cost of ownership compared to the base case renewable solution combined with battery storage. This could potentially be applicable at smaller scale (1MW) for remote borefields such as at Carrapateena or at larger scale (60MW) for whole of site generation such as at West Musgrave, should the project proceed.

Experiment summary

Carbon 280 conducted a simulation to determine the financial viability of replacing the diesel generators used to power transfer borefield pumps 1 & 2 at Carrapateena with a green solution combining Hydrilyte™ with solar and wind energy. Currently, these diesel generators emit approximately 713 tonnes of carbon dioxide per year. The study found that Hydrilyte™ combined with solar and wind energy could reliably power the transfer pumps for the same cost as diesel (both have a levelised cost of energy (LCOE) of $0.31/kWh). This is a significant finding as it highlights a financially viable and environmentally friendly solution for OZ Minerals to significantly reduce Scope 1 emissions.

> We wouldn't have got the chance to work with other companies in the supply chain if it wasn't for OZ Minerals' Think & Act Differently Accelerator Program.
>
> – Mark Rheinlander (CEO)

3.3 Hydrogen Highway

Steve Day
OZ Minerals

Company and Innovator Overview

Hydrogen Highway is a collaboration between OZ Minerals, a logistics provider, hydrogen supplier and a manufacturer of hydrogen fuel cells prime movers with support from the Hydrogen Hypothesis mentor, Terry Burgess. The objective of the collaboration is to investigate options to decarbonise heavy road transport.

Steve Day - OZ Minerals' Concentrate Logistic Manager

Steve had been investigating options to decarbonise concentrate haulage for OZ Minerals. He had developed a roadmap for a collaboration among multiple stakeholders to establish a Hydrogen Highway in the Upper Spencer Gulf.

The Opportunity

The Hydrogen Highway represents a pathway to replacing heavy diesel road transport with a hydrogen option in the Upper Spencer Gulf and surrounds. Heavy road transport requires a large amount of power over a long range. Batteries are currently constrained for heavy haulage over long distances (>250km) as battery weight impacts the total transport load. To overcome this, smaller batteries can be used which are swapped out at dedicated swapping stations along a route. The opportunity was evaluated for OZ Minerals is to employ hydrogen as an alternative to batteries, testing the hypothesis of achieving ranges up to 1,000km and faster refuelling compared to batteries. While the initial focus of this work was for Carrapateena, this will be particularly advantageous for remote sites such as West Musgrave, should the project proceed.

Experiment summary

This experiment aimed for a strategic collaboration between key players in the supply of hydrogen or alternative fuel, original equipment manufacturer (OEM) and a logistics provider all sharing the ambition to decarbonise haulage within the next 5 years.

- The **logistic provider** showed a strong willingness to collaborate
- A US **manufacturer of hydrogen trucks** expressed interest, however was not able/willing to continue as design was not able to meet the scoped duty requirement. A Canadian based hydrogen fuel cell (HFC) company was identified and up for the challenge.
- A **hydrogen supplier** was identified that is willing to establish a hydrogen hub in South Australia and produce sufficient hydrogen at $8 - $11/kg H_2 including storage in the Upper Spencer Gulf. Significant underpinning of offtake (30% of output) would be required by OZ Minerals to facilitate this investment. Not a good option, given the identification of a better suited BEV solution for the South Australian assets.

While these key players have expressed interest, achieving full commitment to trial a solution will require considerable investment and an agreement to share risks amongst the parties. Meanwhile, Carrapateena has decided to pursue a battery-based trial appropriate to the shorter haulage distance (<300km) required. Battery swapping will be required for this solution. This is also a good option for Prominent Hill. For West Musgrave, there is no technical solution currently available that can cover the distances necessary (up to 1,000km).

> This opportunity would have taken much longer to investigate without the Think & Act Differently team. - **Steve Day**

3.4 Carnot

Francis Lempp
Carnot

Company and Innovator Overview

Carnot is a UK based pre-seed start-up working to decarbonise markets through the development of ultra-efficient ceramic engines with a net zero capability.

Francis Lempp – Co Founder

Francis is the co-founder and director of fund raising, sales and marketing at Carnot. With a background in applied physics Francis also heads up the control systems and thermal-mechanical modelling. Carnot has successfully gone from concept to prototype in under a year.

The Opportunity

Modern engines waste on average 1/3 of their fuel to cooling systems that stop metallic components from melting from combustion, leading to poor efficiency and high emissions. Carnot has patented a design that uses advanced technical ceramics, able to withstand combustion temperatures and eliminates the need cooling systems and bringing efficiencies up to 70%. With double efficiency Carnot engines can halve emissions and reduce the total cost of ownership by ~35%.

Carnot's fuel agnostic design can ensure net-zero capability when operating on hydrogen or other net-zero fuels, providing an accelerated pathway to net-zero without the dependence on developing fuel infrastructure.

The opportunity for OZ Minerals is to integrate this technology with renewable energy, hydrogen production and storage capability to provide a fully decarbonised off-grid solution at a lower total cost of ownership compared to the base case renewable solution combined with battery storage. This could potentially be applicable at smaller scale (1MW) for remote borefields such as at Carrapateena or at larger scale (60MW) for whole of site generation such as at West Musgrave, should the project proceed.

Experiment summary

Carnot conducted a study comparing its engine with a standard 1.2MW C13 Caterpillar diesel generator. These generators are currently used to power a number of borefield pumps at Carrapateena. Carnot also investigated the use-case for its engine to be used as a hybrid powertrain for off-highway vehicles.

The results summarised in the table below show that total cost of ownership (TCO) and emissions can be significantly reduced when running the engine on diesel. When running on hydrogen emissions are eliminated, however TCO increases materially due to the cost of supplied hydrogen using conventional generation technology.

	TCO at 50% load over 15 years	Annual Emissions at 50% load
C13 Caterpillar	$7.7m	817 tonnes / year
Carnot with Diesel	$4.4m (down 43%)	409 tonnes / year (down 50%)
Carnot with Hydrogen	$20m (up 201%)	0 tonnes / year (down 100%)

Prototype Carnot Engine

3.5 $FlyH_2$ Aerospace

Mark van Wyk
$FlyH_2$

Company and Innovator Overview

$FlyH_2$ Aerospace is a South African seed round start-up that has been developing hydrogen propulsion systems for large fixed-wing drones capable of performing wide-area environment surveys, presenting an opportunity for long range infrastructure monitoring solutions in the mining industry.

Mark van Wyk – Founder

Mark is passionate about protecting African wildlife and has applied his entrepreneurial spirit to developing innovations that are focused on this cause, including the development of a hydrogen powered drone capable of long distance infrastructure inspection.

The Opportunity

The use of drones is becoming ubiquitous on mine sites for routine collection of survey data both above and underground using an array of sensors capable of sensing beyond what is visible. Battery based drones have a limited range, flight time and payload. Hydrogen offers an alternative that allows ranges of up to 600km and larger payloads. The opportunity for OZ Minerals is to develop remote inspection capability for haul roads, tailings dams, powerlines and borefields. While this will not directly impact OZ Minerals' emissions, Prominent Hill agreed to sponsor the drone development as building this capability will be important as our assets transition to remote operations.

Experiment summary

$FlyH_2$ Aerospace proposed to build, optimise and test a hydrogen powered drone in an environment representative of an OZ Minerals mine site. Due to COVID-19 constraints and in an attempt to minimise the cost of the experiment, the demonstration will be conducted in South Africa and will be completed by mid-2022.

The aim of the experiment is to demonstrate that a hydrogen powered drone has the capacity, endurance, reliability and low vibration characteristics required to perform long-range infrastructure surveying operations in an arid environment.

The key components of the experiment are:

- **Drone development:** The Dragonfly V aircraft will be constructed including the drone and fuel cell propulsion pod. The heat exchanger within the fuel cell will also be optimised and upgraded to suit the operating environment.
- **Testing**: The drone will be tested on several 30 minute flights at the Karoo desert in South Africa, which has a similar arid landscape to that of the Prominent Hill mine.

> Through the program we're now closer to delivering a commercial solution than we've ever been before - **Mark van Wyk**

3.6 Avid Group

Aaron Teo
AVID Group

Company and Innovator Overview

Avid Group is an electrical and renewables business based in Western Australia who are commercialising a hydrogen powered lighting tower. This technology aims to replace the diesel-powered alternatives that are ubiquitous on mining and construction sites.

Aaron Teo – Managing Director

Aaron is an internationally experienced electrical engineer specialising in electrical power and decarbonisation. He was recognised as a BusinessNews '40Under40' Winner in 2021 from which celebrates Western Australia's leading innovators and future business leaders under 40.

Experiment summary

Avid Group conducted testing of their ECO hydrogen LED lighting tower, to understand the potential stability and runtime of the system in a mining environment. The lighting tower was successfully operated and runtime data collected for a range of operating conditions. Market research conducted by Avid Group and OZ Minerals during the experiment identified a number of competitors to the Avid Group product, including one that is more advanced in producing a commercial product. Further work is required to optimise the design of the system including benchmarking against diesel equivalents as well as these commercially available hydrogen systems from other suppliers.

The Opportunity

In mining, there are many small-scale applications which require electricity such as lighting towers, small pumps, weather stations, temporary wi-fi towers and traffic signage. Due to low power consumption and mobility of equipment, small diesel generators or solar pv-battery solutions are traditionally used.

While not a material decarbonisation opportunity, Avid Group were included in the acceleration cohort to promote curiosity and a conversation within the workforce around a fairly progressed hydrogen use case that could be adopted into the business within a relatively short timeframe.

3.7 YaKum Queens

Yeonuk Choi
Queens Uni

Ahamd Ghahreman
Queens Uni

Peter Kondos
YaKum Consulting

Company and Innovator Overview

YaKum Queens is a Canadian collaboration between YaKum consulting, a small business, and academics from Queen's University. They are developing a novel copper extraction method using hydrogen as a reducing agent. The team was inspired by the vision of a fully integrated hydrogen operation with the use of hydrogen in multiple application could lead to significant cost reductions because of the systems approach with hydrogen as an integral part of the entire mining operation..

Yeonuk Choi, Peter Kondos, Ahmad Ghahremana

Yeonuk Choi, Peter Kondos and Ahmad Ghahreman are respected professionals within the global mining industry and have hard won experience in the implementation of innovation and new technology. Yeonuk and Peter were formerly senior technology executives with Barrick Gold. Ahmad is a professor at Queen's University.

The Opportunity

Traditionally copper extraction from leach solutions involves solvent extraction followed by electrowinning. Electrowinning is capital intensive and power hungry, with increasing emissions, opex and capex to produce copper cathode. YaKum Queens' proposal is to utilise green hydrogen to reduce copper from leach solutions producing a copper metal powder directly rather than by electrowinning.

The opportunity for OZ Minerals is to integrate this approach and realise its benefits with either Ingenious Extraction or the Biox project being pursued by Carrapateena for the production of copper metal from concentrates.

Experiment summary

YaKum Queens' work has been delayed due to COVID-19 induced equipment shortages and is forecast to finish in early 2022. A series of small proof of concept tests will be conducted to demonstrate the feasibility of the process.

Should the process prove to be feasible, opportunities to integrate this approach into copper metal production on OZ Minerals assets will be considered.

> Think & Act Differently is inspirational, as it provides an innovation platform, where innovators from diverse backgrounds can test their ideas and collaborate with each other.
>
> - Peter Kondos (Principal)

Appendix

A.1 | Technology readiness level (TRL)

A.2 | References

A.3 | Disclaimer

A.1 | Technology readiness level (TRL)

TRL	Description
1	Basic principles observed. Principles are assumed but experimental evidence is lacking.
2	Technology concept formulated. Both concepts and applications are defined.
3	Experimental proof of concept. Applied research. The first laboratory tests have been done.
4	Technology validated in lab. Small scale prototype build in laboratory environment ("ugly" prototype).
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies). Large scale prototype tested in intended environment.
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies). Prototype system tested in intended environment close to expected performance.
7	System prototype demonstration in operational environment.
8	System complete and qualified. Technology solution that is the first of its kind. Manufacturing problem solved.
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space). Full commercial application, technology available for consumers

A.2 | References

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4. CSIRO (2018) CSIRO National Hydrogen Roadmap.

5. International Mining (2021) *HYBRIT partners start building underground fossil-free hydrogen storage facility in Lulea. https://im-mining.com/2021/04/07/hybrit-partners-start-building-underground-fossil-free-hydrogen-storage-facility-in-lulea/*

A.3 | Disclaimer

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