There's more to
Australian Mining

Mineral sands: From ancient oceans to modern technology

WITH THANKS

Emma Vogel B. Eng. (Mining) Hons, B. Com whose extensive operational and corporate experience across the mineral sands sector, and work with rural and regional communities over the past 20 years, has informed this publication.

minerals.org.au

The Minerals Council of Australia is the peak national body representing Australia's exploration, mining and minerals processing industry, nationally and internationally, in its contribution to sustainable economic and social development. This publication is part of the overall program of the MCA, as endorsed by its Board of Directors, but does not necessarily reflect the views of individual members of the board.

March 2020

Contents

There's more to
Australian Mining

In 2020 and beyond, the mineral sands industry offers significant opportunities for the economic growth and diversification of regional communities across Australia.

Introduction

Australia is home to the largest mineral sands deposits in the world. Mineral sands deposits contain titanium, rare earth elements and silica – the building blocks of modern life.

Australia has an abundance of titanium mineral sands with 32 per cent of the world's share of ilmenite resources and 62 per cent of rutile resources.[1] As one of the only producers of rare earth elements such as neodymium and praseodymium, Australia is also an important supplier of minerals critical to driving smaller, faster and more powerful technologies.

80 per cent of the world's titanium is used in the production of TiO_2, a white pigment used in the manufacture of paint, toothpaste and plastics. Titanium is also used in the production of titanium metal, glass, welding rod electrodes and steelmaking.

A major producer of zircon mineral sands, Australia accounts for 68 per cent of world zircon resources.[2] New opportunities are available. Victoria, for example, has 39 per cent of Australia's zircon resources and the potential to be a global supplier of high grade zircon mineral sands.[3] These are typically used for ceramics, digital printing, dentistry and electrical components.

Many of Australia's mineral sands deposits also contain monazite and xenotime, which are sources of the rare earth elements used in smart phones, televisions and computers, as well as medical devices such as x-ray machines and medical lasers and fibre optics.

As the world transitions to a lower carbon economy, demand for rare earth elements is growing because these minerals are also used in the production of hybrid cars, electric vehicles and wind turbines.

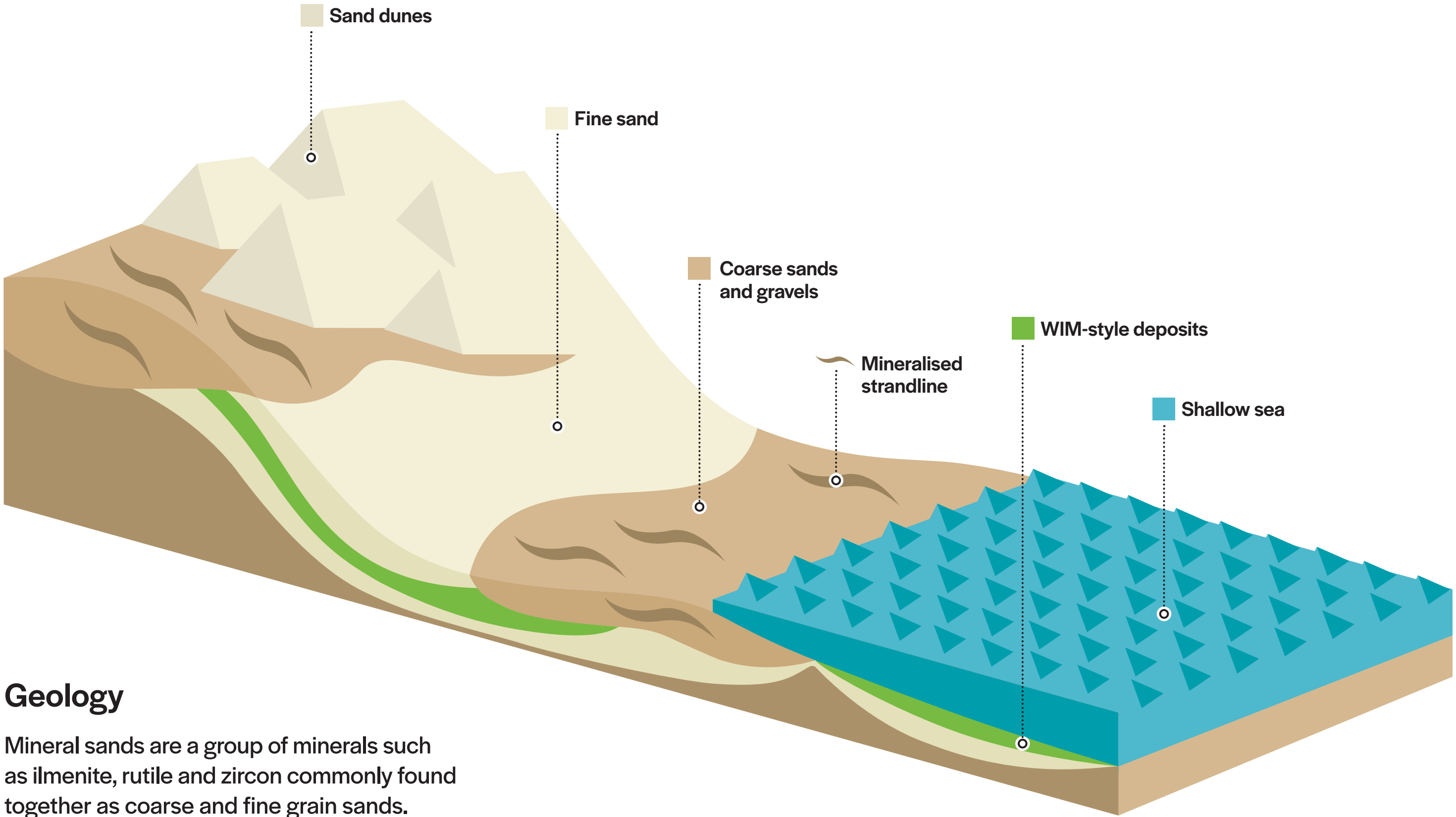
The Australian Industry and Trade Commission's Critical Minerals Strategy 2019 listed zirconium, titanium and rare earths as minerals of key importance to Australia's future economic prosperity.[4] Advances in computing, manufacturing, energy and transport would be impossible without these raw materials.

Australia's mineral sands industry is already a world leader in sustainability and mine site rehabilitation. Approximately 97 per cent of the mined material is progressively returned and the landform restored throughout the life of a mineral sands mine.

In 2020 and beyond, the mineral sands industry offers significant opportunities for the economic growth and diversification of regional communities across Australia.

Tania Constable
Chief Executive Officer
Minerals Council of Australia

Mineral sands
What are mineral sands?



Geology

Mineral sands are a group of minerals such as ilmenite, rutile and zircon commonly found together as coarse and fine grain sands.

Originally formed as crystals in igneous rocks such as granite or basalt and some metamorphic rocks, these minerals were eroded by wind, rain and rivers over millions of years. The resulting grains washed down to the sea to become part of the coastal sands of ancient beaches. Tidal movements washed away the lighter mineral sand grains, such as quartz sands, leaving the heavier mineral sands on beachlines.

As the world's oceans subsided these deposits were left exposed which is why they are now often found more than 100 kilometres from today's beaches.

This natural weathering process formed the two main types of mineral sands deposits that exist today. Coarser sands that remained on shorelines due to their larger size are often referred to as strandline deposits whereas finer mineral sands which typically settled in the basin of the ocean are referred to as 'WIM-style' (originally Wimmera Industrial Minerals) or 'offshore' deposits. WIM-style deposits are generally larger overall than strandline deposits.

The Murray Basin (covering parts of Victoria, New South Wales and South Australia) demonstrates this weathering process. Home to an ancient sea during the Cenozoic Era (up to 66 millions years ago), large deposits of heavy mineral sands formed when heavy minerals entered the marine environment of the Murray Basin through river systems.

Mineral sands deposits are also found in the Eucla Basin (South Australia and Western Australia) and the Perth and Canning basins (Western Australia). Deposits have also been identified in Tasmania, Queensland and the Northern Territory.

Western Australia is already a world leader in the production of ilmenite, rutile and zircon, supplying mineral sands to 35 countries.[5] In 2016-17, Western Australia's mineral sands sector sold almost 1.4 million tonnes of material valued at around $554 million.[6]

One mine. Thousands of products.

Mineral sands Rutile, ilmenite, zircon and monazite are the building blocks of objects we use everyday.

Rutile (TiO_2)

Ilmenite ($FeTiO_3$)

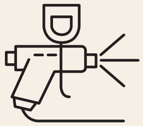
Zircon ($ZrSiO_4$)

Monazite (Ce, La)PO_4

Xenotime (Y)PO_4

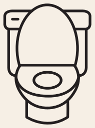
MEDICAL IMPLANTS

Titanium (Ti)



CAR PAINT

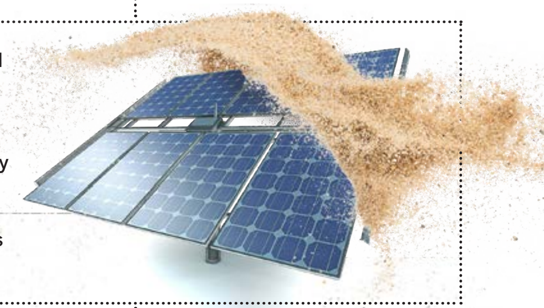
Titanium (Ti)



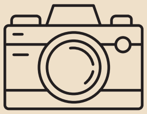
BATHROOMS

Zirconium (Zr)

Advanced tech and low carbon energy generation such as **solar panels**, wind turbines and battery storage are driving global demand for rare earth elements and mineral sands.

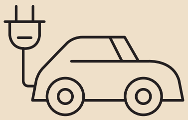


Rare earth elements Most of the 17 rare earth elements can be extracted from mineral sands.



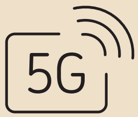
CAMERA LENSES

Cerium (Ce)



ELECTRIC VEHICLES

Dysprosium (Dy)



5G NETWORK

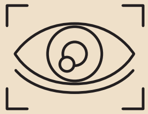
Erbium (Er)

ANTI-FORGERY

Europium (Eu)

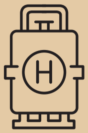
MRI SCANS

Gadolinium (Gd)



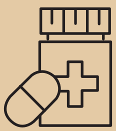
LASER EYE SURGERY

Holmium (Ho)



HYDROGEN FUEL

Lanthanum (La)



CANCER THERAPY

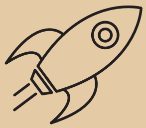
Lutetium (Lu)

WIND TURBINES

Neodymium (Nd)

HARD DRIVES

Praseodymium (Pr)



SPACE TRAVEL

Promethium (Pm)

AUDIO SYSTEMS

Samarium (Sm)

AIRCRAFT

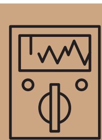
Scandium (Sc)

SUBMARINES

Terbium (Tb)

X-RAY MACHINE

Thulium (Tm)



SEISMIC MONITOR

Ytterbium (Yb)

SATELLITE

Yttrium (Y)

Mineral sands

Rutile, ilmenite (titanium)

Titanium minerals are used in a diverse range of products. 80 per cent of the world titanium market involves the production of TiO_2, a white pigment that is used in the production of paint, toothpaste and plastics, providing non-toxic UV protection. In addition, smaller quantities of titanium are used in the production of titanium chemicals, titanium metal, glass production, welding rod electrodes and steelmaking.

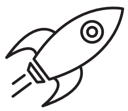
Fast facts

Rutile EDR	35 Mt
Ilmenite EDR	276 Mt
Production (Aust, 2017)	1.6 Mt
Exports (concentrates)	1.3 Mt
Operating mines (Aust)	10

Source: Geoscience Australia

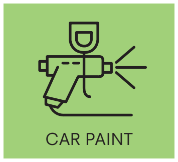
- Titanium is used in medical implants such as knee and hip replacements because it is non-toxic and readily accepted by the body.

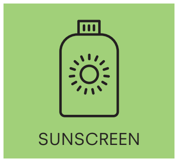
EDR = Economic Demonstrated Resources



DID YOU KNOW?

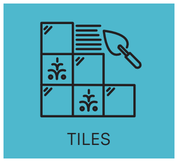
As strong as steel...
but half the weight, titanium is used in the construction of space shuttles and throughout the International Space Station. Titanium also orbits the planet in the form of an etched disc preserving human languages as part of the Rosetta Project.

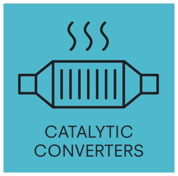




Zircon

Zircon is typically sold into the Chinese and European ceramics markets where it is used in the production of ceramic items including kitchen benches, tiles and bathroom fittings. Zircon is also used in a range of production processes in refractories and foundry casting. Growing markets include zirconium chemicals used in catalytic fuel converters, and air and water purification systems.





Fast facts

Zircon EDR	80 Mt
Production (Aust, 2017)	0.5 Mt
Exports (concentrates)	0.97 Mt
Operating mines (Aust)	9

Source: Geoscience Australia

DID YOU KNOW?

Hadean zircons

Scientists have successfully dated zircons from Jack Hills in Western Australia as the oldest terrestrial material on Earth. Forming 4.374 billion years ago during the Hadean era, the ancient crystals have enabled ground-breaking research on the evolution of the earth.

Source: Nature Geoscience

WIND TURBINE GENERATOR
Neodymium
Dysprosium
Praseodymium

DID YOU KNOW?

Wind turbines…
can use up to 2 tonnes of rare earth permanent magnets. Around 30 per cent of global growth in the use of rare earth magnets from 2015 to 2025 is expected to come from the wind energy industry.

Source: Lynas Corporation

Rare earth elements from mineral sands

Demand for rare earth elements is growing. Monazite and xenotime, which can be found in mineral sands deposits, are sources of rare earth elements used in an ever-expanding range of high tech consumer goods and low carbon technologies.

Medical science, manufacturing, electronics and renewable energy generation are some of the industries that rely on rare earth elements. Smart phones, televisions, computers, x-ray machines, cancer treatments, medical lasers, plastics, catalytic converters, fibre optics, rechargeable batteries, hybrid cars and wind turbines are just some of the products that use them.

As demand grows for technologically advanced 'green' products, the demand for rare earth products also increases. China currently accounts for 70 per cent of world rare earth element production and has approximately 30 per cent of known rare earth resources.[7]

While Western Australia is currently the only state producing rare earth elements, other states have the opportunity to develop mineral sands mines to supply critical rare earth minerals such as neodymium and praseodymium.

Fast facts

Rare earths EDR	4.12 Mt
Production (REE oxide, 2018)	0.02 Mt
Operating mines (Aust)	2

Source: Geoscience Australia

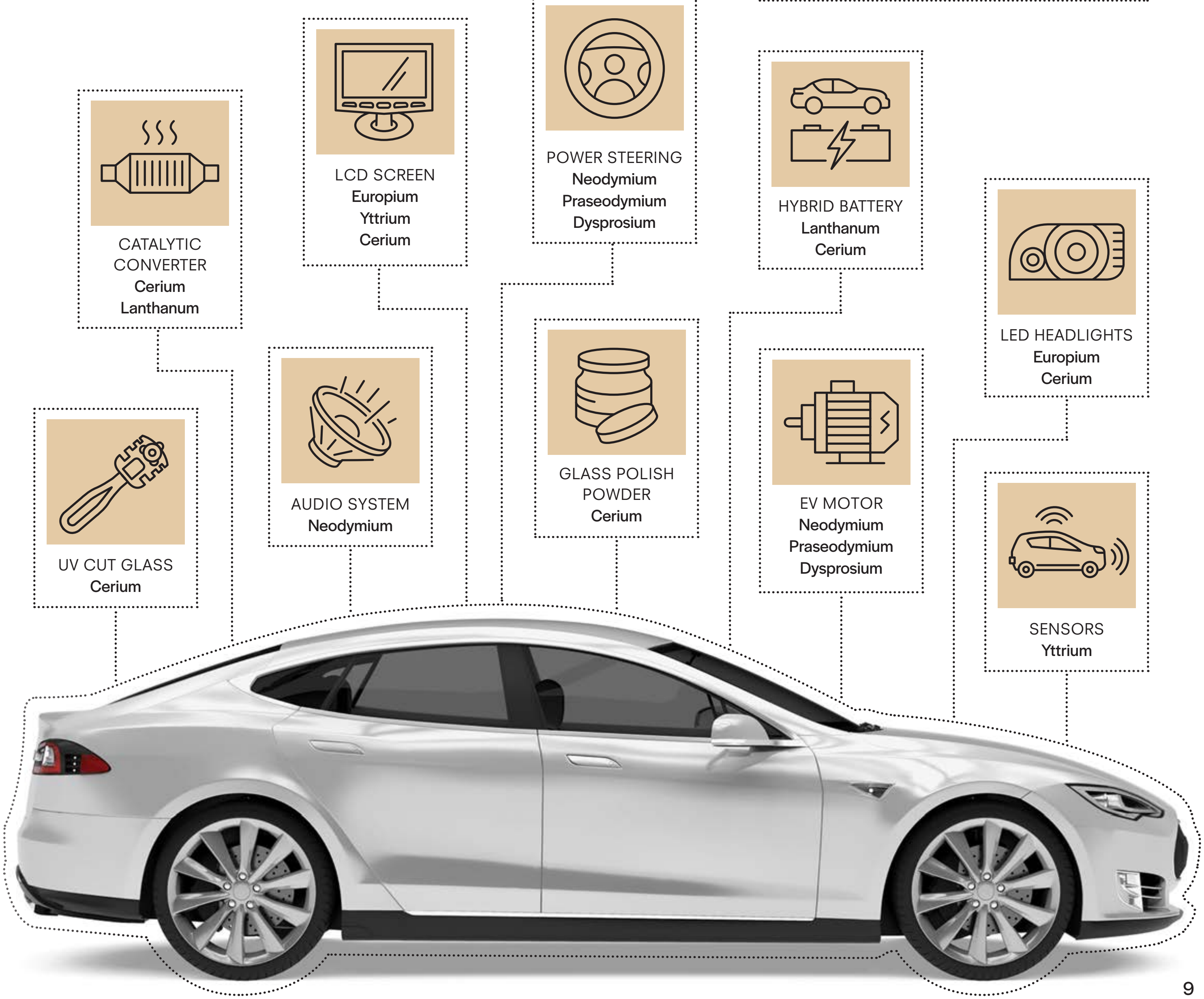
Rare earth elements in EVs

Electric, hybrid and hydrogen vehicles

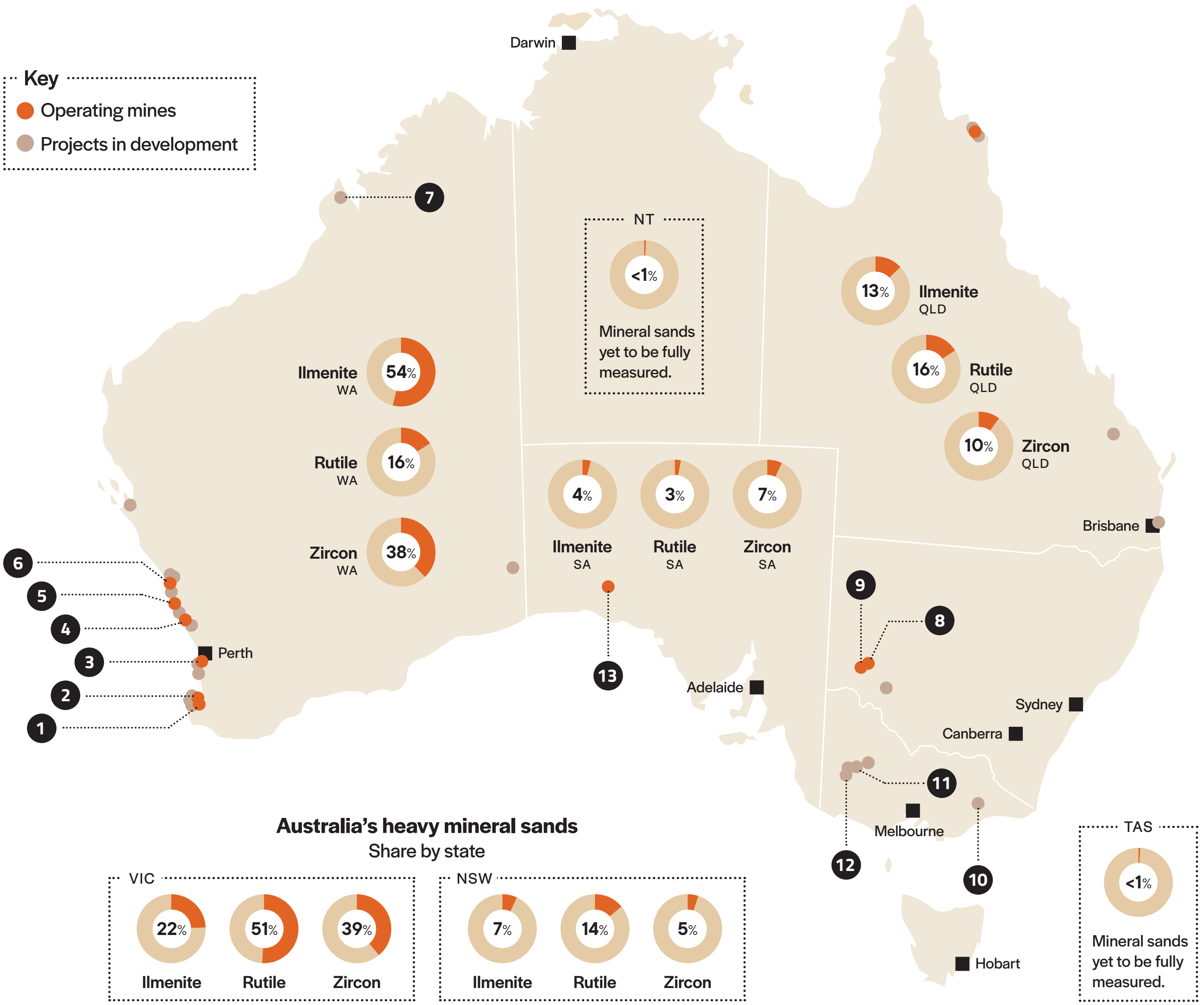
DID YOU KNOW?

Hybrid and electric cars...

will increasingly drive demand for rare earths metals. Bloomberg New Energy Finance estimates EVs will account for 2 per cent of the market by 2020, 8 per cent by 2025 and 20 per cent by 2030.



Mineral sands
Mines and projects



Source: Geoscience Australia, *Australia's Identified Mineral Resources 2018*

Yoongarillup mine 1
WA
Doral Mineral Sands
Operating

Wonnerup mine 2
WA
Tronox
Operating

Keysbrook mine 3
WA
Doral Mineral Sands
Operating

Boonanarring mine 4
WA
Image Resources
Operating

Cataby mine 5
WA
Iluka
Operating

Cooljarloo mine 6
WA
Tronox
Operating

Thunderbird project 7
WA
Sheffield Resources
In development

Gingko mine 8
NSW
Tronox
Operating

Snapper mine 9
NSW
Tronox
Operating

Fingerboards project 10
VIC
Kalbar Resources
In development

Donald project 11
VIC
Donald Mineral Sands
In development

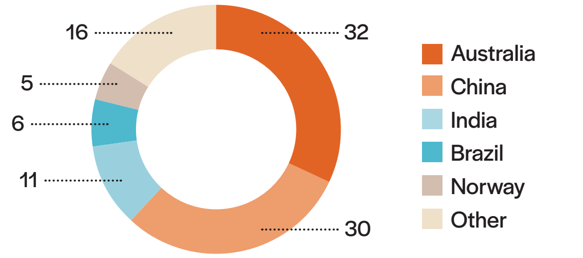
Avonbank project 12
VIC
WIM Resources
In development

Jacinth Ambrosia mine 13
SA
Iluka
Operating

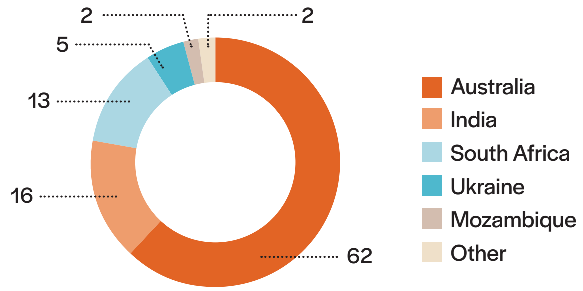
Australia's world share of HMS & REE

Source: USGS, *Mineral Commodity Summaries 2020*

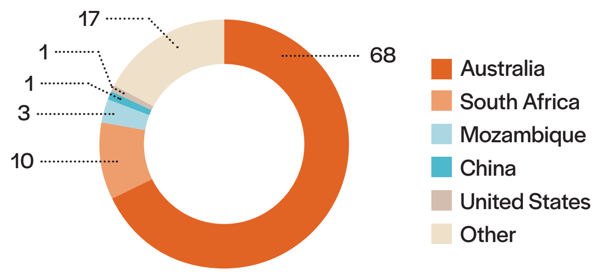
Ilmenite %



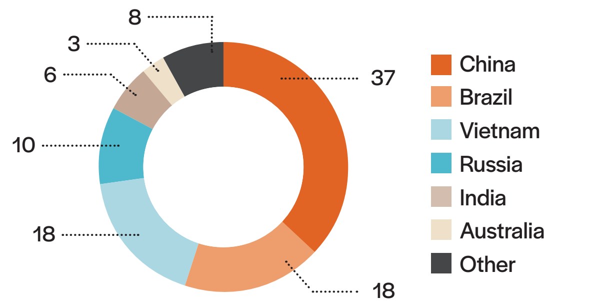
Rutile %



Zircon %

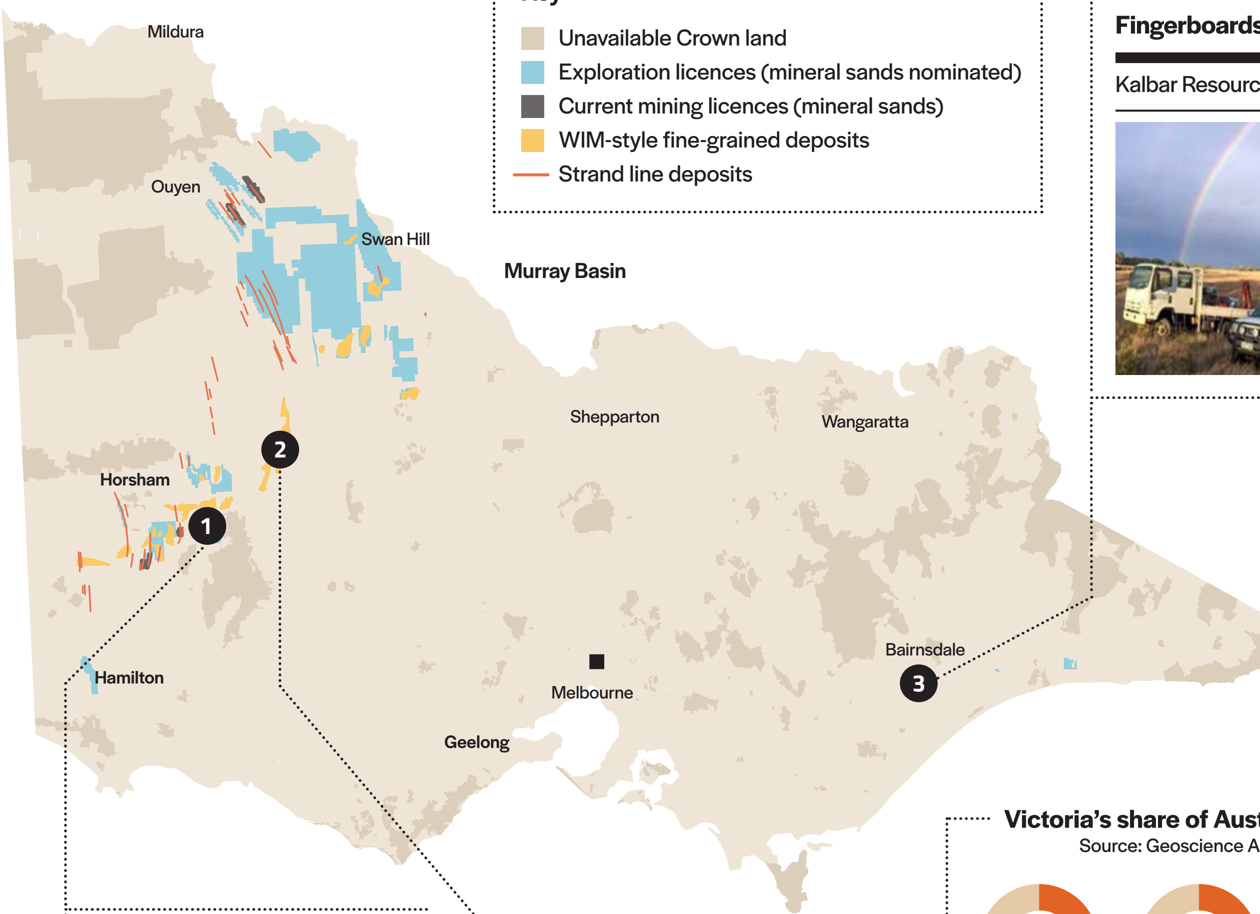


Rare earth elements %



Case study
Advanced projects in Victoria

Key
- Unavailable Crown land
- Exploration licences (mineral sands nominated)
- Current mining licences (mineral sands)
- WIM-style fine-grained deposits
- Strand line deposits



Fingerboards project

Kalbar Resources

Avonbank project

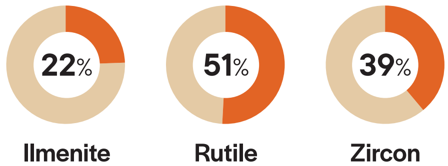
WIM Resource

Donald project

Donald Mineral Sands

Victoria's share of Australia's HMS

Source: Geoscience Australia



"Victoria's mineral sands endowment includes an estimated 350 million tonnes of coarse grained, strandline deposits and a further 3 billion tonnes of fine grained, WIM style deposits."

Source: earthresources.vic.gov.au

WIM Resource

1

Avonbank Heavy Mineral Sands project

Location	15 km north of Horsham, Wimmera
Resource	Zircon and rare earth project
Project	Total ore reserves of 311.8 Mt 4.8% heavy mineral that will underpin a 30-year mine life.
Status	Advanced. Completion of a test pit and demonstration plant and key approvals are underway.

Employment and economic benefits

Long term employment opportunities for Horsham locals and the wider community with several hundred jobs expected during the construction phase and 150 to 200 jobs during the operational stage over 30 years.

Mining and processing method

WIM will use conventional earth moving equipment and will use a direct return mining approach to ensure the landform and land use is restored as rapidly as possible.

Standard wet gravity separation will be employed to produce a high quality heavy mineral concentrate for export overseas.

> Victoria has globally significant resources of mineral sands and in particular zircon and titanium minerals.

Donald Mineral Sands

2

Donald project

Location	50 km north east of Horsham
Resource	One of the largest known zircon and titanium resources in the world. Total resource estimate of 5712 Mt of mineral sand (avg. grade 3.2%).
Project	Two stages with completed project producing 1 million tonne of heavy mineral concentrate per annum.
Status	Completed the environmental effect statement and obtained other approvals including a cultural and heritage management plan. Final stages of project development expected to be completed in 2020.

Employment and economic benefits

The project is expected to create 150 positions onsite during construction, with the number increasing to 350 during full scale operations.

Employees will be sourced from the local community and upskilled or reskilled as required or relocated to the region for employment. The project has a long anticipated mine life offering long-term employment opportunities.

Mining and processing method

Traditional methods including excavators, trucks and conveyors for overburden removal and an ore slurry process for delivering the mined material for primary separation.

Rehabilitation will be undertaken using a cut and fill approach. Depending on the pre-mining land use, rehabilitation will include agriculture re-establishment to either pre-existing conditions or a combination of both pre-existing and diversified agricultural operations.

Kalbar Resources

3

Fingerboards Mineral Sands project

Location	Glenaladale, East Gippsland
Resource	High grade mineral sands deposit
Project	170 Mt ore extraction to produce around 8 Mt of heavy mineral concentrate over 20 years.
Status	Environmental assessment

Employment and economic benefits

Construction phase to create around 200 jobs with up to 200 direct jobs during operation.

Around $20 million in wages will be injected into the economy each year with the project generating another $10 million annually in royalties and taxes to the Victorian Government.

Kalbar is committed to supporting local industry participation via its local content guidelines. The mine will support a further 150-200 indirect jobs in the local community for local businesses and suppliers of services.

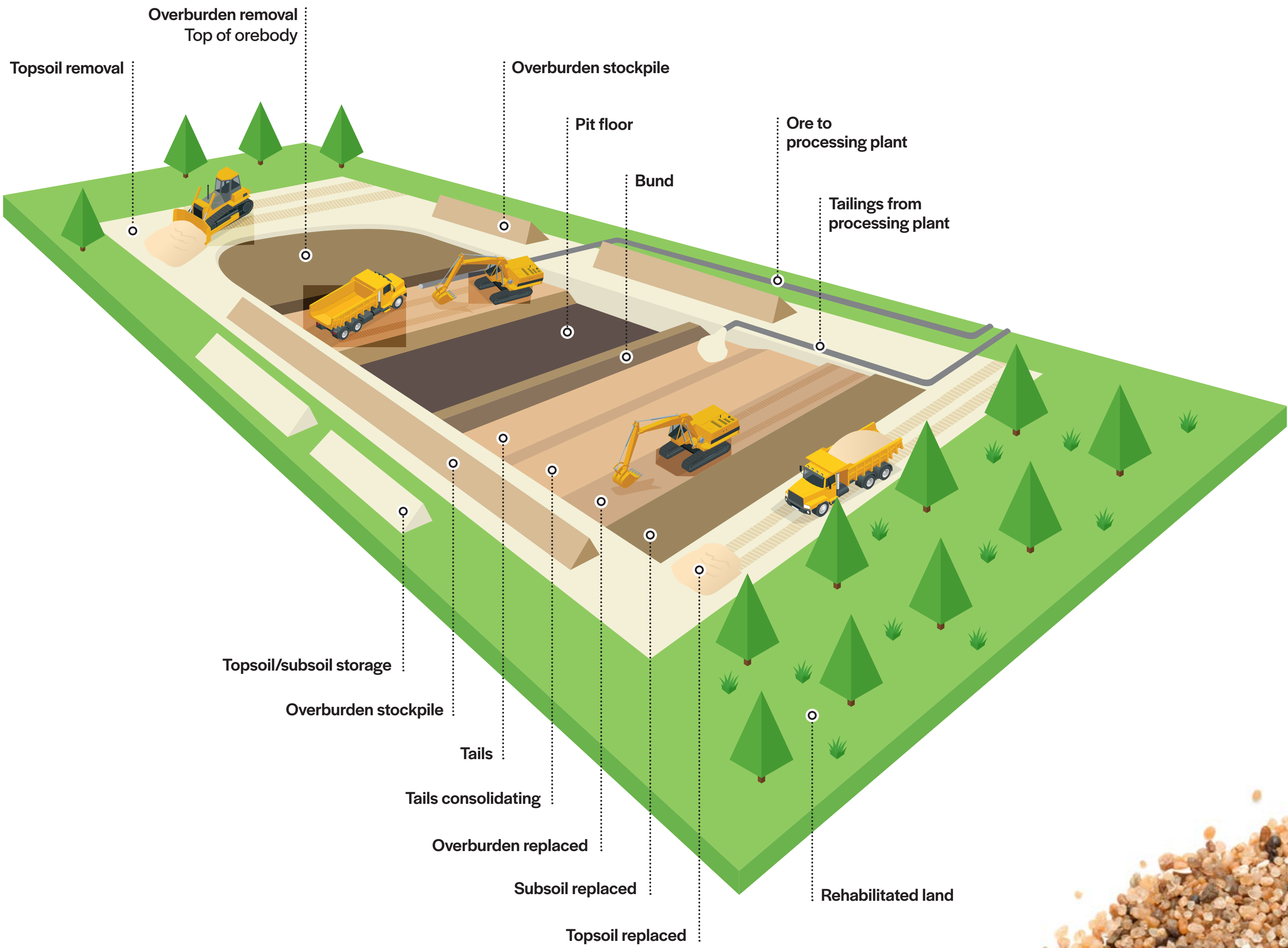
Mining and processing method

Open cut mining method proposed to extract the ore. Ore will be fed to a mining unit plant for slurrying and pumping to the wet concentrator plant. The ore will undergo initial onsite processing to produce mineral concentrate to export for further processing into commercial products such as zircon and rutile.

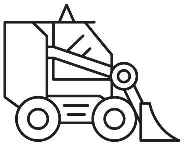
Approximately 96 per cent of the mined ore will be returned to the ground. Overburden and topsoil will be returned and the land surface rehabilitated behind the advancing mine path.

Mineral sands
Operations and processing

Progressive rehabilitation in practice



Surface mining is used to extract mineral sands given the shallow depth of deposits. Under normal operation the mined area is restored within 12 months.



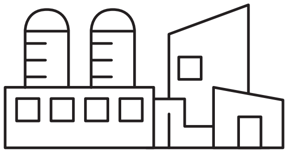
Operations

The shallow depth of mineral sands deposits allows them to be mined using conventional surface mining methods including bulldozers, excavators and trucks.

The topsoil, subsoil and clay (overburden) is removed and stockpiled separately to allow it to be progressively returned in correct order after the mining process. The mineral sand deposit (ore) is then removed from the ground. Water is added to the ore to allow it to be pumped to a processing plant where the valuable heavy minerals are separated from the sand.

The sand is pumped back to the mined area, the water is removed for reuse and the sand is returned to the ground.

The subsoil and topsoil are then replaced and the land rehabilitated back to its original land use. Under normal operation the mined area is refilled within 12 months.



Processing

The process of separating the valuable minerals from the sand to the end product occurs over several stages. Depending on the project, these processes may be undertaken on site or elsewhere including offshore. Generally the processing methods used are less complex than for other commodities, using mainly gravity and magnetic separation.

In the first stage of processing, a slurry of sand and water is pumped to a wet concentrator plant. This machine uses water and gravity and a series of 'spirals' to separate the valuable heavy minerals from the sand to produce heavy mineral concentrate (HMC).

In the second stage of processing, the mineral separation plant separates the zircon, ilmenite, rutile and monazite products from the HMC. There are a variety of separation methods used in the industry depending on the deposit mineralogy. The three most commonly used methods are magnetic separation, using electromagnetics to separate non-magnetic from magnetic minerals; flotation which uses biodegradable flocculant to separate the minerals; and electrostatic separation, which separates the minerals into conductive and non-conductive components.

■ Processing 'spirals' are used to separate valuable heavy minerals from sand.

Other processing methods may also be used to further refine the separation and upgrade products to improve their value.

The zircon, ilmenite, rutile and rare earth concentrates are then transported via road or rail to port for export to customers for further processing into a final product.

In some cases, the second stage of processing may be located off the mine site at a centralised location or offshore close to end use customers. In these cases, the product is exported as HMC.

Mineral sands
Responsible mining

Regional development

Every mining project offers regional communities an opportunity to diversify and grow their economy. Where possible, labour and supplies are sourced locally.

For every job created by the mineral sands industry in Australia, more indirect jobs are created in the local economy as employees consume good and services.

With many operations predicted to span decades, and up to 200 permanent positions created for each project, the industry has the potential to have a profound positive effect on regional economies.

Few industries offer generational employment at the size and scale of mineral sands mining. It offers long term skilled jobs and employment and educational opportunities.

Revenue from mining mineral sands is collected by the federal and relevant state government in the form of taxes and royalties.

The industry offers states and territories an exciting opportunity to be global leaders in mineral sands production, adding not only to the prosperity of states and territories but also the regions in which it operates.

Jobs for the regions
Mineral sands projects generate jobs for engineers, geologists, metallurgists, environmental scientists, plant operators (excavators, dozers, scraper and truck drivers), as well as trades such as mechanics, electricians and fitters.

Indigenous engagement and cultural heritage

Respect for the rights and interests of Aboriginal and Torres Strait Islander peoples in relation to the lands and waters with which they have a special connection is a foundation minerals industry commitment.

Aboriginal and Torres Strait Islander cultural heritage might reflect community values not only in the form of individual sites or groups of sites, but also in terms of the general landscape (that is, the entire landscape within their country is of cultural value, including ancient and recent landforms, flora and fauna, and watercourses).

Native title and state land rights regimes recognise Traditional Owner stewardship and ownership. These frameworks provide processes for consultation and negotiation regarding land use, including minerals development.

Mineral sands companies recognise the importance of sites of cultural significance to Traditional Owners and engage early in project development to minimise the impact of potential operations on sites of significance and to support recognition of culturally significant heritage.

Australia's mining industry has a long history of working collaboratively with Indigenous Australians both in accordance with relevant legislation (state and federal) and more broadly by working to ensure that operations provide opportunities and benefits to Traditional Owners.

> By progressively rehabilitating the mined area, the area of disturbance is minimised and the landscape is reformed more quickly.

Rehabilitation

Rehabilitation is a critical part of the mining process. Mineral sands mining uses a moving hole approach. By progressively rehabilitating the mined area, the area of disturbance is minimised and the landscape is reformed more quickly. The land is returned to previous land use such as agriculture or other agreed use such as revegetation generally within 2-3 years and often sooner.

In Victoria, for example, rehabilitation is regulated under the *Mineral Resources (Sustainable Development) Act 1990*. The Act requires the holder of a mining licence to rehabilitate the land in accordance with the rehabilitation requirements of the approved work plan, licence conditions, or specific code of practice.

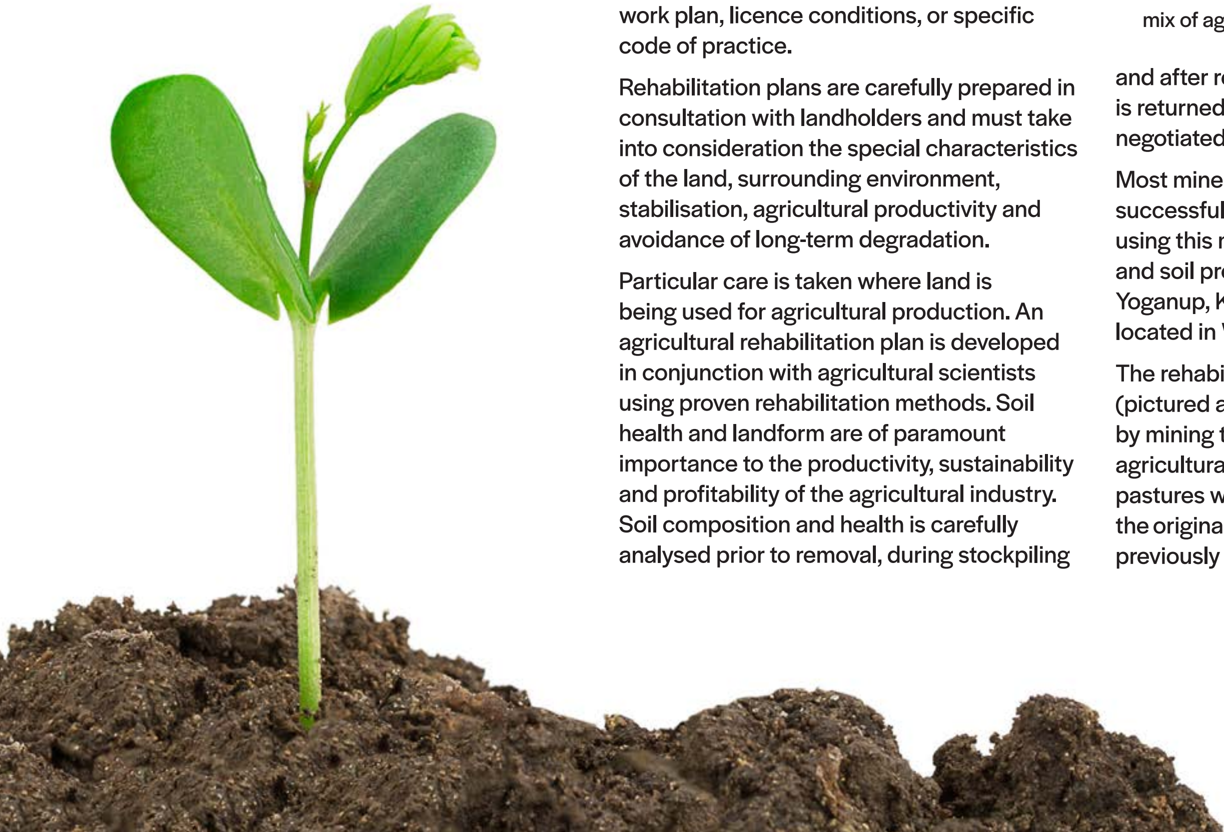
Rehabilitation plans are carefully prepared in consultation with landholders and must take into consideration the special characteristics of the land, surrounding environment, stabilisation, agricultural productivity and avoidance of long-term degradation.

Particular care is taken where land is being used for agricultural production. An agricultural rehabilitation plan is developed in conjunction with agricultural scientists using proven rehabilitation methods. Soil health and landform are of paramount importance to the productivity, sustainability and profitability of the agricultural industry. Soil composition and health is carefully analysed prior to removal, during stockpiling and after replacement. The landform is returned to previous contours or as negotiated with landholders.

■ Gwindinup was successfully rehabilitated to a mix of agricultural use and native vegetation.

Most mineral sands mines have been successfully rehabilitated to agricultural land using this method of returning the geological and soil profile including Wemen (Victoria), Yoganup, Keysbrook and Gwindinup (all located in Western Australia).

The rehabilitation for the Gwindinup project (pictured above) required areas disturbed by mining to be rehabilitated to a mixture of agricultural use and native vegetation. Annual pastures were successfully re-established on the original farmland, including areas that had previously supported blue gum plantations.



Mineral sands
Legislative framework

Legislation

Australia has stringent environmental regulations. Mining operations are subject to legislative provisions at the state and federal level including the *Environment Protection and Biodiversity Conservation Act 1999*. At state level, mining acts such as Victoria's *Mineral Resources (Sustainable Development) Act 1990* are the primary pieces of legislation that regulate companies looking to explore and develop mineral resources.

Depending on the complexity, scale, location and existing land use of a proposed operation, project approval may also require an environmental effects statement (EES) under separate state environmental legislation. Preparation of an EES requires significant consultation with the community where the mine is proposed to be located.

Other major applicable regulation may include completion of a cultural heritage management plan, Indigenous land use agreement, radiation licence, native vegetation management plan, rehabilitation plan, take and use water licence, transporting approvals and exporting licence.

As part of the approval process, companies are required to submit a mining work plan, have complete land access agreements, and lodge a rehabilitation bond prior to commencing operations.

Water

Mineral sands production requires water for processing. Water allocations may be sourced from either groundwater or surface water, and purchase is subject to requirements in state water legislation and local water authority procedures and processes.

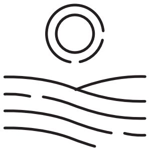
Groundwater and surface water studies are a critical part of the pre-development process to gain an understanding of regional water systems. Ongoing water monitoring and reporting are an important part of mining operations and water reuse is a high priority.

Biodiversity

Flora and fauna removal are often required due to surface disturbance. State and federal legislation apply including the federal *Environment Protection and Biodiversity Conservation Act 1999*.

Extensive studies to establish flora and fauna occurrence on a site and its surrounds are undertaken prior to establishment of a mine and early in the project planning stage to minimise removal of vegetation.

Rehabilitation plans and offsetting of native vegetation habitats are required by companies prior to final approvals for an operation being granted.

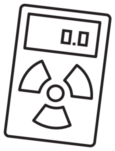


Air quality and noise

Like many industries, mining produces dust and noise. State environmental protection legislation provides the framework for regulation of air quality and noise. Limits are set based on existing local noise levels, and mine operators are required to monitor noise levels throughout the life of the operation.

Air quality baseline levels are established prior to approvals being granted and are monitored continuously during operations to ensure dust levels are kept to a minimum.

There are several methods used to reduce noise and air quality impacts, including design considerations, engineering controls and suppression techniques.



Radiation

Mineral sands naturally contain low levels of the radioactive materials uranium and thorium, mostly contained within the minerals zircon and monazite. As the valuable heavy minerals are concentrated and the sand is removed, small amounts of uranium and thorium are also concentrated in the HMC.

Studies are undertaken during the approvals process to ascertain the existing levels of radioactivity surrounding a potential project.

In Victoria, for example, the framework for regulation is under the *Radiation Act 2005.* The Act sets out limits for the amount of radiation to which a worker can be exposed and companies are required to monitor and report radiation levels throughout the life of the project.

In most cases the radiation levels of a site are reduced by mining as the uranium and thorium contained within the monazite and zircon are removed in the HMC.

Endnotes

1. USGS*, Mineral Commodity Summaries 2019*, Washington DC 2019
2. ibid.
3. Geoscience Australia, *Australia's Identified Mineral Resources 2018*, Australian Government, Canberra 2019
4. Australian Trade and Investment Commission, *Australia's Critical Minerals Strategy*, Australian Government, Canberra 2019
5. Department of Mines, Industry Regulation and Safety, *Mineral sands*, Government of Western Australia, viewed 6 February 2019 (https://www.dmp.wa.gov.au/Investors/Mineral-sands-1473)
6. ibid.
7. USGS*, Mineral Commodity Summaries 2019*, Washington DC 2019

There's more to
Australian
Mining

Minerals Council of Australia
www.minerals.org.au
info@minerals.org.au