Sources and uses of high-tech metals

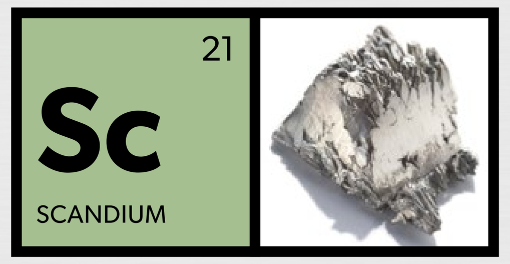
What makes some metals more special than others?

A metal is a solid material which is typically hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity (e.g. iron, gold, silver, aluminium and alloys such as steel).

Almost 80% of the elements listed in the periodic table are metals, but only some are considered high-tech.

The technological innovation behind the rapidly growing high-tech industry would not be possible without the unique chemical (conductivity, high melting point) and physical (strength, density and hardness) properties of particular metals – the high-tech metals. Without them, some of the high-tech products we take for granted, such as mobile phones, lithium-ion batteries, satellites, and hybrid vehicles, could not have been developed.

Some of these high-tech metals are rare, in short supply or hard to refine. For these reasons, significant effort is focused on reducing the amount of these metals required for end-use applications, to lower costs and sustain the supply of raw materials into the future. New ways of using high-tech metals are constantly being developed for emerging technologies.



Properties and sources

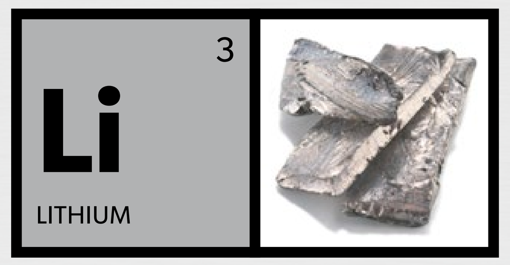
Scandium is a silver-coloured metal that tarnishes in air, burns easily and dissolves in water. It also has a low density and a high melting point.

Scandium is a valuable commodity because economic deposits are extremely rare. Current global supply is mainly from secondary sources, such as mineral waste stockpiles, or as a by-product from other mineral processing operations.

Recently a number of large, high-grade scandium oxide deposits have been discovered in central New South Wales and northeast Queensland. NSW already has scandium projects (see side 1) that include areas which have undergone very little exploration.

Uses

Scandium is mostly used in alloys with aluminium for the aerospace industry, as it has excellent strength and is lightweight.



Properties and sources

Lithium is a soft, silver-coloured metal that reacts vigorously with water. Nearly all types of igneous rocks contain a small amount of lithium-bearing minerals. Mineral-rich springs and brines can also contain lithium.

Mining operations in Australia (43%), Chile (33%), and Argentina (13%) accounted for the majority of world lithium production in 2017 (United States Geological Survey (USGS) 2018a).

Uses

Rechargeable (Li-ion) batteries are the main use for lithium. Li-ion batteries, such as in your smartphone, typically contain a lithium manganese oxide liquid gel. Lithium is also used in aluminium alloys for the aerospace and transport industries, and alloyed with magnesium and aluminium in military armour plating on tanks and ships.

Properties and sources

Cobalt is a distinctive blue and lustrous metal. Like iron, it is magnetic, and used to make powerful magnets in aluminium–nickel alloys. It has a high melting point and is resistant to corrosion.

Cobalt is reasonably abundant in Earth's crust and is often found in copper and nickel deposits, and in manganese nodules on deep-sea ocean floors (Atlantic, Indian and Pacific oceans).

In 2017, the Democratic Republic of Congo (DRC) produced about 58% of the world's cobalt. Australia was the world's 4th largest cobalt producer (4.5%), with about 17% of the global cobalt reserves (USGS 2018b). NSW has several advanced cobalt projects near Nyngan, Fifield, Port Macquarie, Goulburn, Thuddungra and Broken Hill.

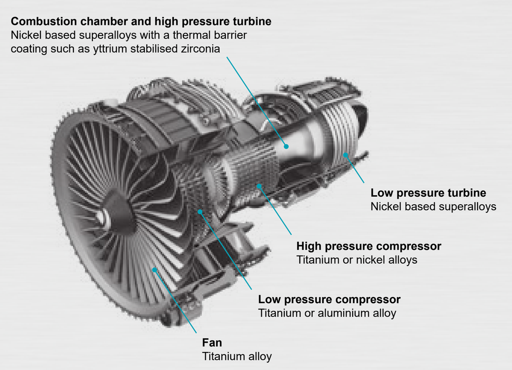
Uses

The main uses for cobalt are in magnets and metal-ion batteries. Cobalt was the first cathode material used for commercial lithium-ion batteries. Due to high cobalt prices, manufacturers often mix cobalt with nickel, manganese and aluminium to create powerful cathodes that are cheaper and can have better performance than pure cobalt. Despite this substitution, cobalt typically comprises between 5–60% of the cathode by weight, with approximately 50% of the cobalt produced globally used in rechargeable batteries.

A typical smartphone battery contains 16 grams (g) of cobalt and an electric vehicle battery uses up to 15 kilograms (kg) of cobalt (https://s1.q4cdn.com/337451660/files/doc_downloads/factsheet/2017/170712-Cobalt-Fact-Sheet.pdf).

Cobalt-bearing metal alloys are also used in gas turbine generators and jet turbines due to their strength and high temperature resilience properties. Paints, enamels and pottery glazes also use cobalt, due to its vivid blue colour. It is also used in a range of medical and scientific applications.

Jet engine



Rare earth elements (REEs) are a diverse group of 17 metals, which include the lanthanide series of elements, scandium (Sc) and yttrium (Y). The lanthanides include lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu).

Properties and sources

REEs are a group of metals which have unique chemical, nuclear, electrical, magnetic and luminescent properties.

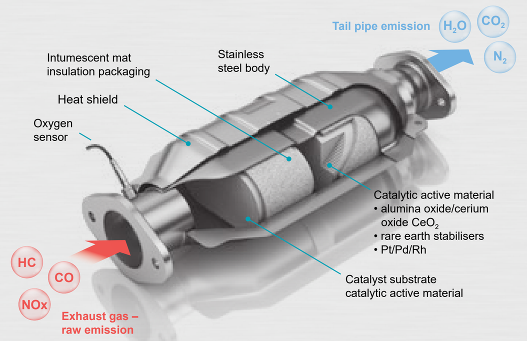
REEs are not as rare as their name implies. However, they do not generally accumulate in rich ores so they are often difficult to mine and process. In 2017, China produced approximately 81% of the global REE supply, with Australia producing 15% – making it the second largest supplier (USGS 2018d).

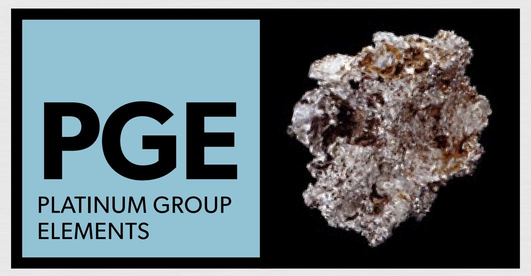
REEs occur across a range of geological settings and provinces in NSW, including granites, volcanic rocks and the extensive heavy mineral sand deposits in the Murray Basin.

Uses

REEs are essential for high performance optics (lenses, fibre optics) and lasers. They are also used in powerful magnets, which are critical in many electric motors and generators including servo motors in power tools, electricity generators in wind turbines, and drive motors in electric vehicles. REEs are also very important in batteries and catalytic converters to reduce motor vehicle emissions.

Catalytic converter





The platinum group elements (PGE) are a group of six precious metals grouped together in the periodic table. The PGEs include platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), rhodium (Rh) and ruthenium (Ru).

Properties and sources

Of the six PGEs, the most commercially significant are platinum, palladium and, to a lesser degree, rhodium. The properties which make these elements commercially important include their resistance to corrosion and oxidation, high-melting points, electrical conductivity and catalytic activity. They are used in the chemical, electrical, electronic, glass and motor vehicle industries (Geoscience Australia 2013).

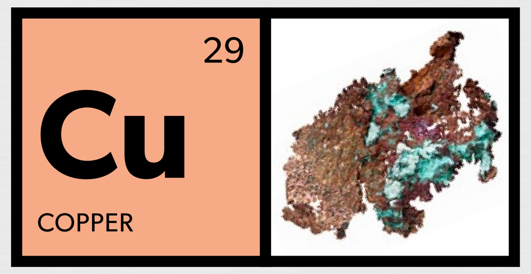
PGEs are very rare, with the upper crust of Earth containing only about 0.0005 parts per million of platinum, making these metals highly sought after and valuable. In 2017, approximately 200 000 t of both platinum and palladium were produced worldwide, mainly from Russia and South Africa (USGS 2018c).

Uses

Since 1979, the car industry has been the main consumer of PGEs, with over 40% of the world's platinum used in catalytic converters, resulting from efforts to control emissions and to improve fuel efficiency.

PGEs are also used in high-tech alloys for specialist industrial and electronic applications such as computer hard drives, ceramic capacitors, integrated circuits, glass manufacturing, jewellery and laboratory equipment.

Computer hard disk.



Refined copper and gold metal are the 'unsung heroes' that underpin electronic components and circuitry in a wide range of everyday and cutting-edge technological applications. Copper, in particular, remains a relatively cheap but essential raw material for electronic applications at microscale (microcircuits) to megascale (energy infrastructure and power grids).

Properties and sources

Copper was first used in coins and ornaments around 8000 B.C. About 5500 B.C., copper tools helped civilisation emerge from the Stone Age. The discovery of bronze (copper–tin alloy) in 3000 B.C. marked the start of the Bronze Age. Copper is still an important metal in high-tech applications as it is easily stretched, molded and shaped, is resistant to corrosion, and is an efficient conductor of heat and electricity.

Gold was first smelted in Ancient Egypt 5600 years ago to decorate tombs and temples. Since then, it has become the most widely used mineral due to its diverse properties. Apart from its wonderful colour and lustre, gold can be melted, recast and beaten into atom-thin sheets through to wire thread, is a highly reliable and durable electrical conductor, and is resistant to rust and corrosion.

In 2017, approximately 20 Mt of copper (USGS 2018e) and 3150 t of gold (USGS 2018f) were produced globally.

Uses

Copper and copper alloys are widely used in building construction, electrical and electronic products, transportation equipment, consumer and general products, and industrial machinery and equipment. A petrol car uses about 20 kg of copper (mostly in the 1.5 km of wiring). In contrast, a hybrid car uses about 40 kg of copper and a fully electric car uses about 80 kg of copper. A single battery electric bus uses about 370 kg of copper (Copper Development Association Inc. 2018a).

A 1.5 megawatts (MW) wind turbine requires approximately 1800 kg of copper (Copper Development Association Inc. 2018b). The recently approved Liverpool Range Wind Farm in NSW will be Australia's largest wind farm. Potentially, it will have up to 267 turbines, generate over 1000 MW of electricity, and contain over 1000 t of copper. Clearly, copper will be just as important in the high-tech, environmentally sustainable future as it has been for the last 10 000 years.

Most of the gold produced is used for jewellery (52%) and as currency (25%), but it is also essential for making electronic components and connections which are extremely reliable and efficient. Gold is commonly used as a very thin coating over copper circuitry components to prevent corrosion or oxidation and maximise performance. In 2017, technological applications used 332.8 t of gold, accounting for approximately 10.6% of the amount of gold produced (https://www.gold.org/research/gold-demand-trends/gold-demand-trends-full-year-2017).

A mobile phone contains on average 50 milligrams of gold. With an estimated 7 billion mobile phones worldwide, that adds up to 350 t of gold contained in these devices (Straterra 2018).

Emerging uses for gold nano-particles include catalysts in industrial processes; pollution reduction in air and water; fuel cells and lithium-air batteries; and solar cells. Gold is also vital in medical applications such as new diagnostic tools and treatments.

Recycling high-tech and associated metals – challenges and opportunities

Some high-tech metals, in particular copper and gold, are relatively straightforward to recycle and retain their properties during recycling. Roughly 25% of all copper and gold used today is from recycling. For both these metals, recycling can be a cost-effective alternative to mining.

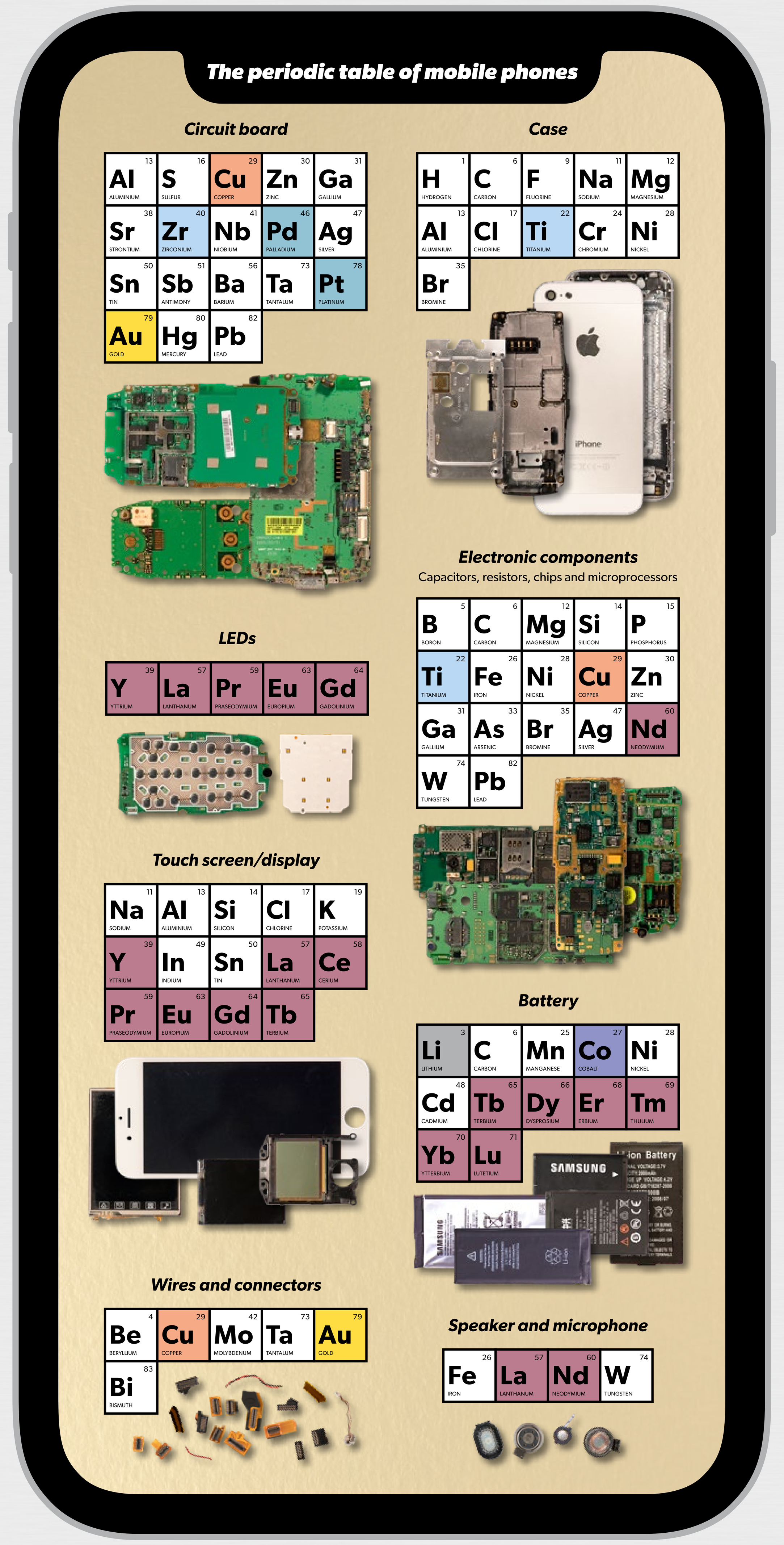
Although platinum and palladium can be difficult to recycle due to their scarcity (among the rarest metals on Earth), very high value and necessity in many modern technologies, recycling provides a significant proportion of the world's total supply, helping to close the gap between world mine production and consumption.

Apple's disassembly robot Daisy can dismantle up to 200 iPhones per hour. Image courtesy of Apple.

For metals such as lithium, scandium and REEs, less than 1% of the metal used is recycled. This is a major challenge for recycling lithium-ion batteries, as currently less than 5% of batteries are recycled. Of the batteries which are recycled, it is profitable to recover the copper, nickel and cobalt but not the lithium. New technologies need to be developed to make lithium recovery viable. This is particularly important given the expected growth in demand for batteries for electric cars.

While there are environmental, economic and social benefits to recycling, current recycling rates are also low for most other high-tech metals. Some of the technical barriers to recycling (Dominish et al. 2017) include –

- products are not designed for disassembly, remanufacturing, repair or recycling
- products are not designed to be durable, which limits the ability to reuse
- products are more complex, with increasing numbers and mixes of materials, making them harder to recycle
- rapid technological development has led to demand for new materials, limiting the potential to remanufacture new products using recycled materials.



In 2006, Tesla publicly unveiled the all-electric 'Roadster', with the first cars sold in 2008 at a starting price of $US98 950. Nissan released the all-electric 'Leaf' in 2010, which quickly became the bestselling electric highway-capable vehicle in the world, in part due to its starting price of around $US30 000.

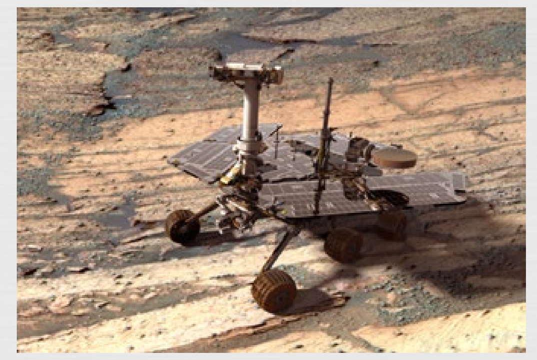
Over the next few years, in response to the demand for EVs, we can expect to see a number of new electric cars come to the market from some of the traditional car makers.

Super magnets

Neodymium magnets were first developed in 1982 by General Motors and Sumitomo Special Metals as an economical, high performance replacement to the very expensive samarium-cobalt magnets. They are also called rare-earth magnets, because neodymium is part of the rare-earth family of elements.

They are extremely versatile and have become part of our everyday lives. What makes them so versatile is their strength – they are the strongest magnets in the world, able to support thousands of times their own weight. Their super strength allows them to be miniaturised and made in many shapes and sizes, even as small as 1 mm in diameter. They have made possible many of the technologies we take for granted today, including medical imaging machines, electric motors, wind turbines, computer hard drives, speakers, microphones, jewellery and mobile phones.

Did you know that they are also used to hold together dentures where several teeth are missing, in magnetic levitation trains, and to collect dust from the surface of Mars?



Mars Exploration Rover 'Opportunity' has been using magnets to explore the Red Planet since 2004. Image courtesy of NASA.

Wind turbines

Wind turbine generators are the latest evolution of the simple windmills that have been used since the 11th century. Instead of grinding grain or pumping water, they are now used to generate electricity.

The 1973 oil crisis spurred much research into renewable energy sources, with government policies in countries belonging to the Organisation of Economic Cooperation and Development, providing targeted tax incentives for renewable energy projects.

The first modern electrical wind turbine was developed in 1985 with an average rating of 100 kilowatts (kW), supplying electricity for up to 60 average households. Since then, wind turbines have become larger, cheaper and more efficient.

Most new wind turbines installed in Australia have the capacity to generate approximately 3 MW each; enough power for up to 2000 average households, and a life span of 20–25 years (Clean Energy Council 2018).

In 2017, more than 33% of renewable electricity generated in Australia was from wind power; almost the same as that produced by hydro energy. By the end of 2017, 15 large scale wind projects were either under construction or financially committed. Wind power is the lowest cost form of large scale renewable energy (Clean Energy Council 2018).

New South Wales has 8 major wind farms operating, with a total capacity of 827 MW. Another 4 farms are under construction, adding 674 MW of capacity, and 13 more wind farms (3268 MW) have planning approval.

Wind farms in NSW

	Name	No. turbines	Capacity (MW)
Operational	Boco Rock	67	113
	Capital	67	141
	Cullerin Range	15	30
	Gullen Range	73	166
	Gunning	31	47
	Taralga	51	107
	White Rock	70	175
	Woodlawn	23	48
	Total	**397**	**827**
Under construction	Bodangora	33	113
	Crookwell 2	28	91
	Sapphire	75	270
	Silverton 1	58	200
	Total	**194**	**674**

The White Rock and Sapphire Wind Farms in NSW have some of the largest turbines in Australia, with 121 metres and 126 metres rotor diameters respectively. (Clean Energy Council of Australia 2016).

Glossary

alloy
a physical mixture of a metal with one or more other elements (usually including other metals). This mixing is generally done at very high temperatures where the elements and metals are melted, mixed, and left to cool.

catalytic activity
the increase in the rate of a chemical reaction caused by the presence of a catalyst.

catalytic converter
a device that converts pollutants in exhaust emissions into less-toxic pollutants.

ceramic capacitor
a device used to store an electric charge, consisting of one or more pairs of conductors separated by a ceramic/porcelain insulator.

conductivity
the property of conducting heat, electricity or sound.

ductile
able to be drawn out into wire or threads e.g. gold.

emissions
a discharge, especially of pollutants such as greenhouse gases, into the environment.

fusible
able to be fused or melted.

igneous rocks
formed from molten material which has cooled and solidified either at Earth's surface (volcanic rock) or deep within Earth's crust (plutonic rock). Common examples include basalt, granite, dolerite and pumice.

ilmenite
a black iron-titanium oxide mineral ($FeTiO_3$) commonly found in igneous rocks, sediments, and sedimentary rocks. Apollo astronauts found abundant ilmenite in lunar rocks.

kilowatt (kW)
one kW = one thousand (1000) watts.

laterite
a red iron- and aluminium-rich soil or rock formed in tropical regions by the decomposition of the underlying rock.

malleable
able to be shaped by hammering or applying pressure.

megawatt (MW)
one MW = one million (1 000 000) watts.

metamorphic rocks
sedimentary, igneous, or earlier metamorphic rocks that have been modified by heat, pressure, and chemical processes, usually while buried deep below Earth's surface. Common examples include gneiss, schist, slate and marble.

monazite
a phosphate mineral (Ce, La, Nd, Th)(PO_4) that usually occurs in very small amounts in igneous and metamorphic rocks. It is resistant to weathering and becomes concentrated in soils and sediments, which may be mined for rare earth elements.

periodic table
a diagram in which the chemical elements are arranged in rows and columns so that elements with similar chemical properties lie in the same column.

rutile
a red-brown titanium oxide mineral (TiO_2) most commonly found in igneous and metamorphic rocks. It is also found in sand, made from weathered rocks, that are dredged for magnetite and ilmenite.

sedimentary rocks
rocks formed at or near Earth's surface by the accumulation of sediments or pieces of once-living organisms. Common examples include mudstone, sandstone, conglomerate, limestone and shale.

sediments
loose pieces of minerals and rock (silt, sand and gravel) that are moved by water, ice or wind.

ultramafic rocks
dense, dark coloured igneous rocks, rich in iron and magnesium, that also contain minor concentrations of nickel, copper, cobalt and scandium.

zircon
a zirconium silicate mineral ($ZrSiO_4$) that is found in igneous, metamorphic and sedimentary rocks. Crystals of zircon are often used to determine the age of the rocks.

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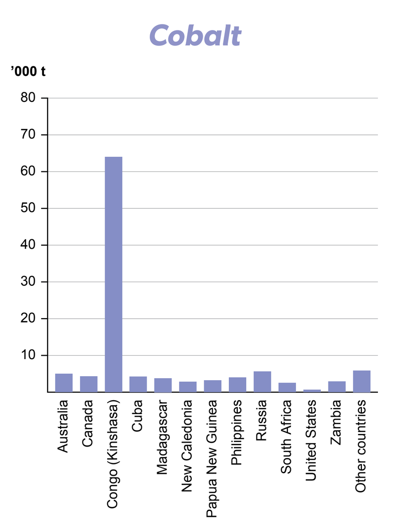
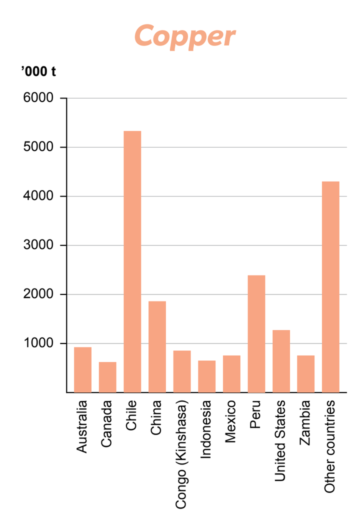
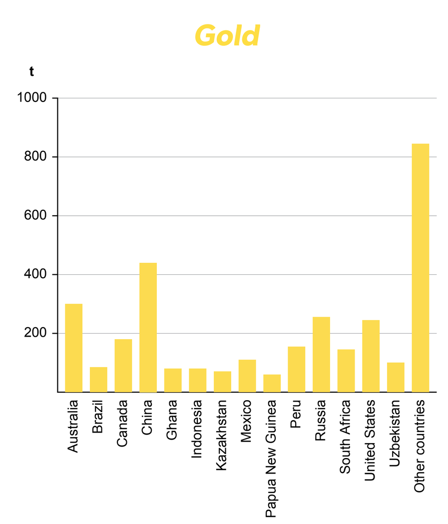
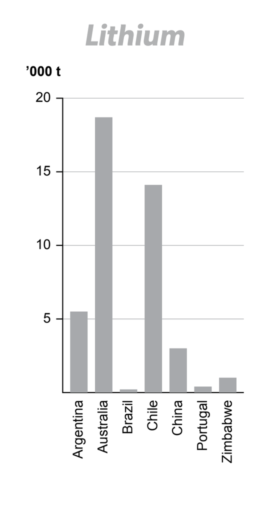
World production

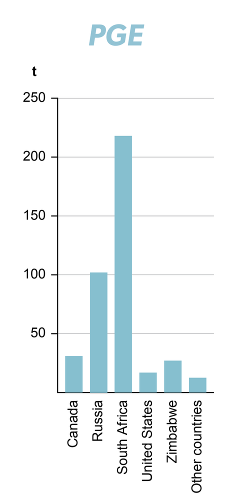
	Production (t)	%
Cobalt	110 000	0.550
Copper	19 700 000	98.566
Gold	3150	0.016
Lithium	43 000	0.215
PGE	410	0.002
REE	130 000	0.650
Total	**19 986 560**	











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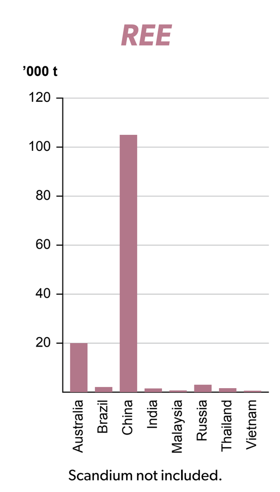
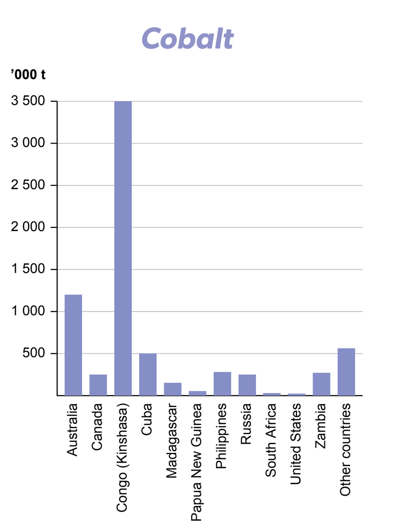
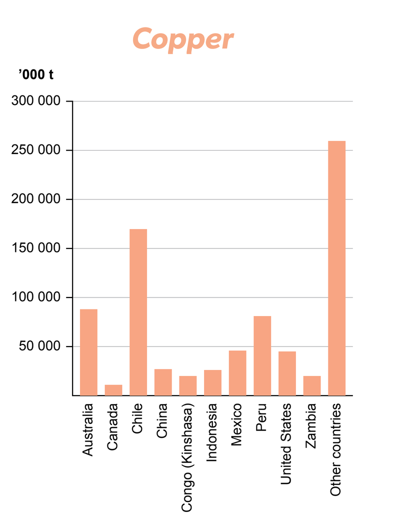


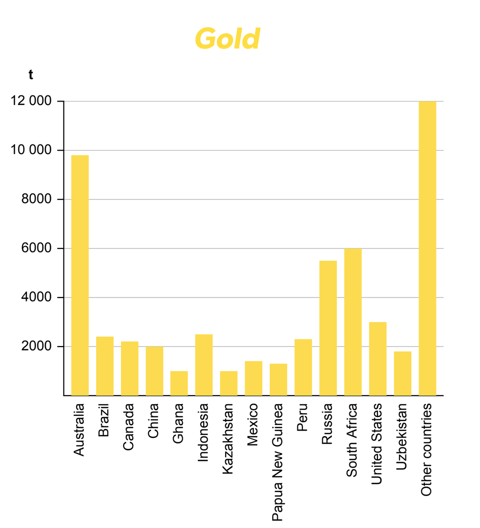
Scandium not included.

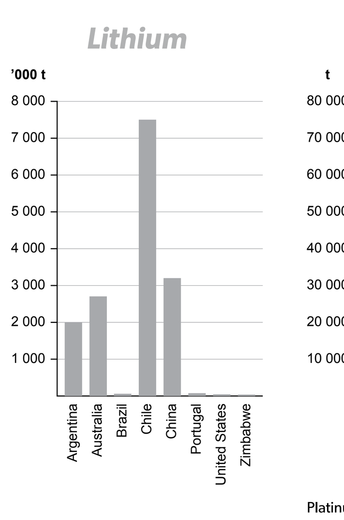
World reserves

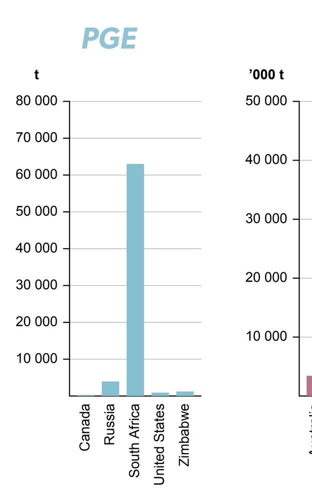
	Reserves (t)	%
Cobalt	7 100 000	0.761
Copper	790 000 000	84.653
Gold	54 000	0.006
Lithium	16 000 000	1.714
PGE	69 000	0.007
REE	120 000 000	12.859
Total	**933 223 000**	











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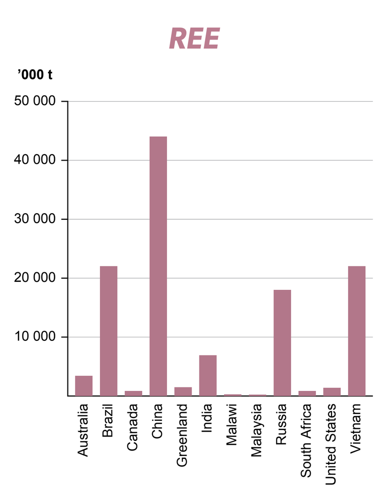


Scandium not included.

t = tonnes. '000 t = thousand tonnes.
All figures from 2017 reported Jan. 2018. All totals rounded. Reserves based on reported company data and/or information supplied by respective governments.

Mobile phones

The first call on a mobile phone was made on 3 April 1973 by Motorola employee Martin Cooper. In 2019, the total number of mobile phone users is expected to exceed 5 billion (this equals over 7 billion mobile phones), attributed mostly to the increasing popularity of 'smartphones' (Statista 2018). This phenomenal increase in the number of mobile phone users over the past 45 years is one of the key driving forces behind the increased demand for high-tech metals, such as gold, copper, cobalt and nickel.

Sea of smartphones in concert crowd.

Batteries

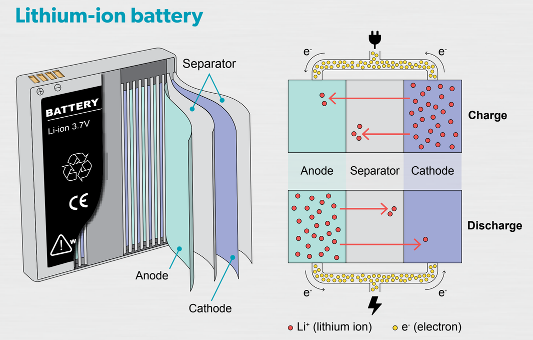
The first battery (voltaic pile) was invented in 1800 by Alessandro Volta. In 1859, French physicist Gaston Planté invented the rechargeable lead-acid storage battery. The first commercial zinc-carbon dry cell batteries were developed in the 1880s and are still used in 'low drain' or intermittent-use devices such as remote controls, torches, clocks and transistor radios. The first common alkaline battery was invented in the 1950s, the rechargeable nickel-metal hydride battery in the 1970s, and the more-rapidly recharged lithium-ion battery in the 1980s, which made it possible to develop mobile consumer electronic devices, such as mobile phones, cameras and laptops.

Lithium-ion batteries also play a vital role in renewable energy (grid storage batteries), and clean fuel efficient transport (electric vehicles).

Grid storage batteries may play an essential role in clean energy generation and distribution, by storing excess generated energy for later use. This may be at a national level or at a household level, with the development of new household battery systems, such as the Tesla power wall.

Lithium is not the only metal in a lithium-ion battery. In fact, lithium makes up only a small portion of the battery, driving the demand for several other high-tech metals (graphite, nickel, copper and cobalt).

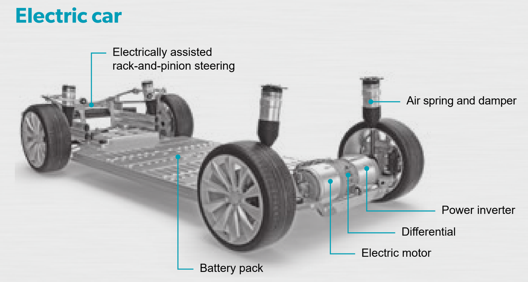
Lithium-ion battery



Electric vehicles

Electric vehicles have been around a lot longer than you may think. Several different inventors have been given credit for inventing the first electric vehicle: Anyos Jedlik of Hungary (1828), Robert Anderson of Scotland (1832), Professor Stratingh of Holland (1835) and Thomas Davenport of Vermont (1835). In 1891, William Morrison of Des Moines, Iowa, built the first successful electric automobile in the United States. The first commercial EV application was a fleet of New York City taxis in 1897. In 1900, 28% of the cars produced in the United States were powered by electricity (Public Broadcasting Service 2009).

Electric car



During the 1920s, electric vehicles ceased to be popular, as consumers wanted longer travelling distances and more horsepower, gasoline became readily available, and the cost of an EV was US$1750 compared to US$650 for a gasoline-powered car (Bellis 2017).

Concerns over pollution and the soaring price of oil saw interest in EVs start to grow again in the 1960s and 1970s, but again limitations in range and speed prevented them from being adopted on a mass scale, and their popularity declined in the 1980s.

In 1997, Toyota unveiled the 'Prius' – the world's first commercially mass-produced and marketed hybrid car. The 'Prius' helped create interest in fuel efficient cars with Toyota selling more than 10 million hybrid vehicles between 1997 and 2017.

Medical applications

Metals have been used in medicine for hundreds of years. The first written account was in the Ebers Papyrus from 1500 BC which described the use of copper to reduce inflammation and iron to treat anaemia. Today, various metals are used for medical applications, including:

- gold in diagnostic testing (e.g. pregnancy testing, Salmonella detection, HIV testing) and treatments for cancer, microbial infections and rheumatoid arthritis
- platinum in chemotherapy drugs to treat testicular, bladder, ovarian, lung and several other types of cancers
- lithium to treat bipolar disorder.

Without high-tech metals, many of the treatments we take for granted (joint replacements, pacemakers, heart valves and stents) would not be possible. Their resistance to corrosion, strength, durability, and biocompatibility (not toxic) with human tissue, makes them critical to modern medicine.

The number of joint replacements, particularly hips, is growing rapidly due to the aging population, and the prevalence of osteoarthritis, rheumatoid arthritis and musculoskeletal disorders. In Australia there were 63 300 knee and 47 254 hip replacements in 2017 (Australian Orthopaedic Association 2017). Globally, more than 1 million joint replacements are performed each year. Prosthetic parts are made from or contain metal because it is durable and non-corrosive. Chromium, nickel, cobalt, titanium and molybdenum are among the metals most commonly used in implants (Watson 2017).

Manual insertion of copper windings into the generator stator of a wind turbine. Around 9 t of copper strands are formed into bundles during this step.