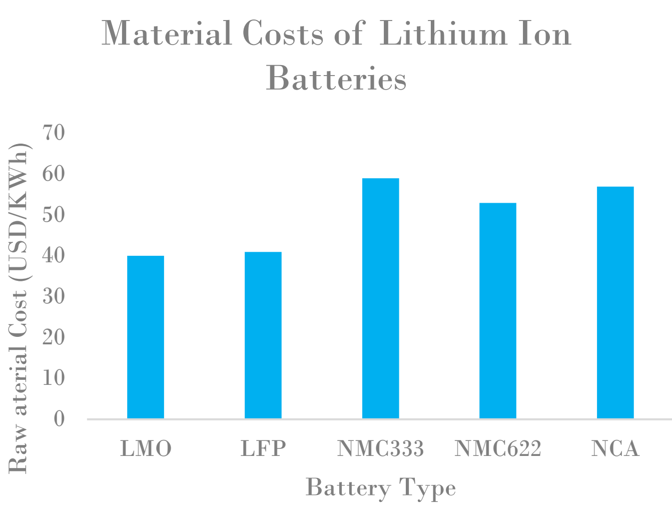
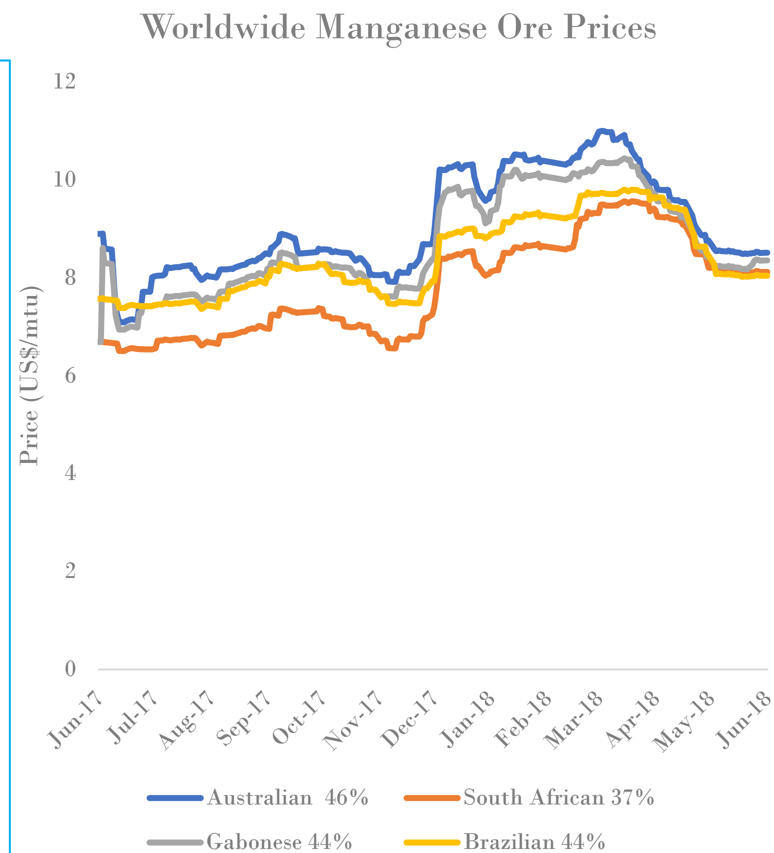
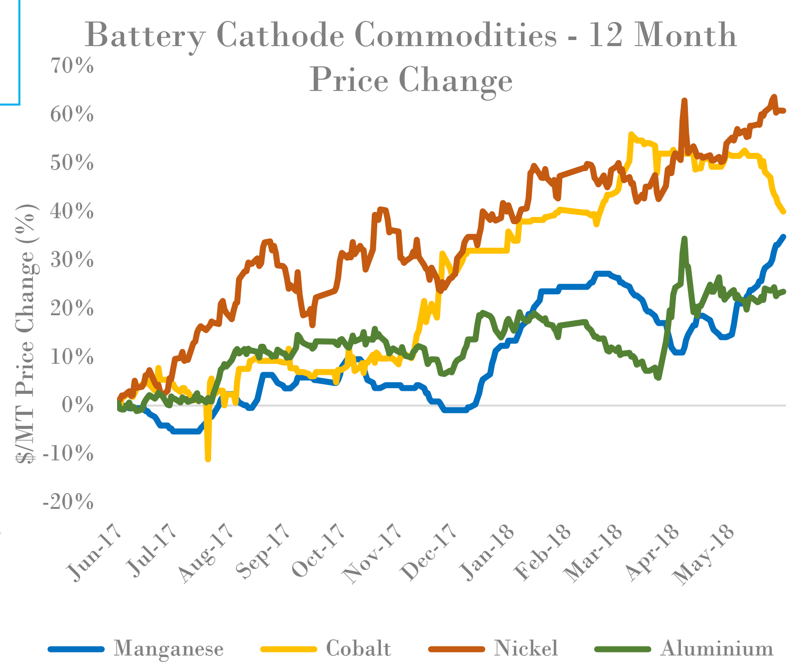
MANGANESE. IS IT THE FORGOTTEN BATTERY MINERAL?

Snapshot

- By 2040 55% of all new car sales (currently ~1.3%) and 33% of global fleet (currently ~0.2%) are expected to be electric, with an on road fleet of 140 million projected by 2035 (currently ~3 miilion).
- Electrolytic Manganese Dioxide forecast CAGR of 5.1% from 2015 to 2022
- Current preferred battery cathode compositions, utlise manganse, cobalt, nickel and aluminium. Of these compositions mangansese is by far the cheapest mineral to mine and produce.
- Cobalt can only be mined as a by-product of nickel and copper. As such, cobalt may face a severe supply shortage once battery demand from electric vehicles hits mainstream production.
- Manganese cannot be replicated in steel manufacturing, which acts as an alternative demand buffer.
- The supply and demand gap between manganese ore production and consumption has widened year on year in China since 2001.







Battery Demand to Disrupt Manganese's Reliance on Steel

Manganese comprises approximately 1,000 ppm or 0.1% of the Earth's crust, making it the 12th most abundant mineral of the crusts elements. Currently, land-based manganese resources are large but irregularly distributed. 78% of the world's identified manganese resource is located in South Africa.

Manganese is a transitional metal which is commonly known for its distinct properties including being ductile, malleable and able to conduct electricity and heat.

Manganese is a vital component in steel making with no apparent substitute. It is defined by the United States Geological Survey (USGS) as a 'critical metal'. Commonly processed to either ferromanganese or silicomanganese for steel production, the addition of manganese in steel making increases both the hardenability and tensile strength of steel.

According to USGS, around 85-90% of manganese ore is used in the production of ferromanganese alloys. However, over the last decade, its consumption in silicomanganese alloys has been increasing as compared to ferromanganese alloys. Around 4–5% is consumed for hot metal production, i.e., production of steel through the blast furnace route. Another 5-10% is used in other industries such as dry cells (batteries) and chemicals. Of the 85-90% of manganese used in ferroalloys roughly 60-65% of the product is silicomanganese with the other 25-30% being ferromanganese.[1]

Between 2013-18 the manganese ore mining industry in Australia experienced strong growth of 4% over the period. Ore producers in Australia are expected to grow revenue by 1.4% over the next 5 years.

Although currently only 10% of the global manganese market by volume (approximately 2.5 Mtpa), high purity manganese makes up about 40% of the global market value. High purity manganese is primarily used in batteries, series 200 stainless steel, speciality alloys, and fertiliser and trace nutrients. The products primarily utilised for high purity manganese are Electrolytic Manganese Metal (EMM), Electrolytic Manganese Dioxide (EMD) and Manganese Sulphate (MS). The utility of these high purity manganese products is highlighted in the table below.

Product	Key Use
Electrolytic Manganese Metal	Speciality Alloys, Batteries
Electrolytic Manganese Dioxide	Batteries
Manganese Sulphate	Batteries

Manganese at present is a bulk commodity with a large tonnage, low margin businesses model. A key question for the future is whether the growing high purity manganese space can create a window of opportunity for suitable ores to become high margin businesses with lower output.

In this report we will take a closer look at high purity manganese, and what the future might hold for this refined commodity.

[1] Asian Metals – 20 June 2018

High Purity Manganese Is Set for Strong Growth

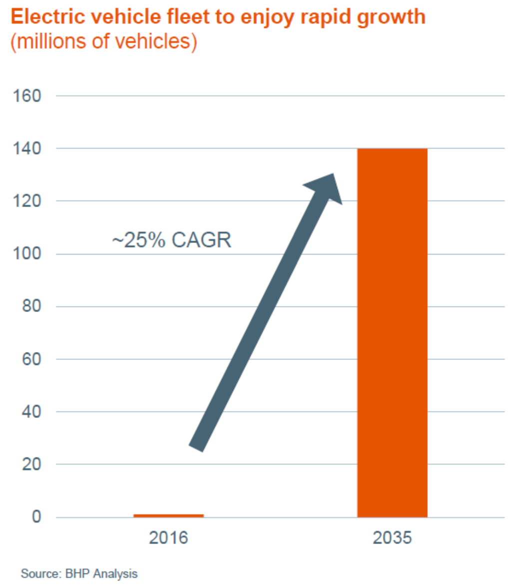
Whilst manganese is commonly associated as being reliant on steel consumption and steel market forces, this paradigm could shift over time as battery technology demand grows. With battery technology still in early stages of development, there is currently no clear winner as to which battery will obtain market dominance. Tesla currently uses two differing batteries depending on the application; Nickel Manganese Cobalt (NMC) for its energy storage product and Nickel Cobalt Aluminium Oxide (NCA) for its electric vehicles. As traditional car manufacturers enter the electric vehicle market, we have seen utilisation of Lithium Ion Manganese Oxide (LMO), which has been used by Nissan and BMW.

Battery consumption of Electrolytic Manganese Dioxide (EMD) has been predicted to be the fastest growing segment of manganese production with a compound annual growth rate (CAGR) of 5.1% from 2015 to 2022.[2] Manganese in agriculture and specialty alloys will also push demand for high purity manganese, with the micronutrient market poised to reach $7.7bn by 2020 and specialty alloys expecting to receive significant CAGR uplift over the next 10 years. The steel industry is also expected to hold long term sustained growth with a projected average growth of approximately 2% p.a. through to 2020.

With steel demand being a sustained driver of baseline manganese pricing and demand, there is no question that manganese has a role to play. This could mean increasing demand for higher grade manganese products, resulting in increased profits for high grade manganese producers. This would see producers in the high purity manganese battery space directly competing with the steel industry on high grade manganese ores suitable for battery production. This increased competition for high grade ores could result in two classes of ore being created on the market. The first being lower grade ores that would still be suitable for ferroalloy and steel production. The second class being the higher-grade deposits which would be utilised within both steel and high purity manganese products. The latter could see high grade deposits suitable for battery cathodes being caught in a price run as steel and battery producers look to create a competitive marketplace for the ores, both deriving utility from the higher grade. The development of cost effective solutions to utilise lower grade manganese deposits for high purity products is subject to research by many players in the high purity manganese space (such as American Manganese, Element 25 and Mineral Resources to name a few). As this research continues, we are interested to see the direction of the manganese market and whether battery technology processing can significant cost reductions and utilisation of lower grade ores.

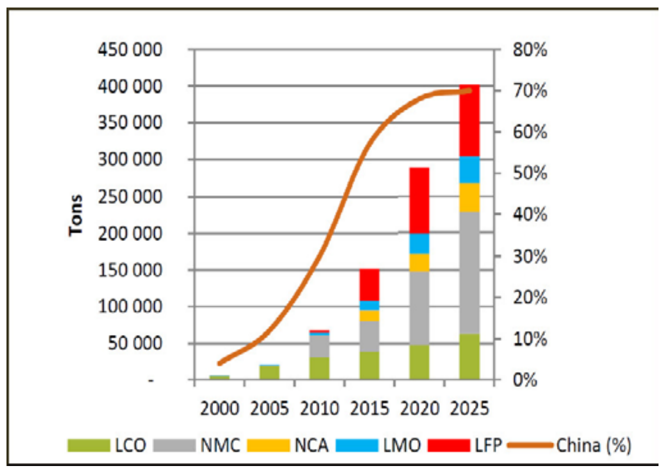
[2] Technavio

Rechargeable Battery Technology Set to Boom



Demand for batteries is growing exponentially as global sales of electric vehicles are forecast to increase from 1.1 million in 2017 to 11 million in 2025. By 2030 the increase of electric vehicles is expected to soar to a fleet of 30 million. In the same period, components of lithium ion batteries will increase from approximately 0.7 million metric tonnes in 2018 to over 10 million metric tonnes3. As of 2035, it is expected that there will be an on-road fleet of 140 million electric vehicles4. 55% of all new car sales and 33% of global fleets are expected to be electric by 20405.

Whilst electric vehicles are commonly considered key for increasing battery consumption, off grid power storage is also a key demand driver. With the increasing push to reduce pollution, countries are increasingly turning to renewable electricity generation. Renewable resources such as wind and solar can be highly volatile in their energy production, which creates issues for continuous grid supply. The solution to this is off grid power storage through the use off battery technology, a solution we have already started to see unfolding in South Australia.



Source: Avicoenne Energy

Cost will be a significant factor as the battery market expands. Of the key minerals utilised within battery cathodes cobalt is by far the most expensive due to its scarcity as a secondary mineral. Cobalt is used within three of the most commonly used lithium ion batteries (Lithium Nickel Cobalt Aluminium Oxide, Lithium Nickel Manganese Cobalt Oxide and Lithium Cobalt Oxide). Cobalt does not exist as a bulk commodity and is generally only mined as a secondary mineral to either nickel or copper. Cobalt's existence as a secondary metal makes it particularly difficult to meet large demand uplifts, generally with the only way to increase supply being to mine further amounts of the primary mineral, with its output being linked to pricing on the primary minerals it is associated with. This creates a situation where, with significant increases in demand, a shortage of cost effective cobalt would be virtually certain. Battery and car manufacturers will need to turn to cost effective cathodic options if they are to obtain a foothold in the mainstream uptake of batteries.

While no one can predict which battery technology will ultimately capture the market, we believe it is highly likely that manganese based batteries will take a leading role in the unfolding story, with cost and supply being the two key drivers of this outcome.

[3] Bloomberg New Energy Finance 2018
[4] Nickel West -EnergisingOur Future
[5] Bloomberg New Energy Finance 2018

Manganese is a Cost Leader of Cathode Composition

Manganese is utilised within two of the most prominent batteries in production, being the Nickel Manganese Cobalt (NMC) and Lithium Manganese Oxide (LMO) batteries. Within LMO batteries, there is approximately 61% manganese in the cathode, being the majority mineral present. Whereas, the manganese in the cathode of an NMC battery constitutes 20-30% of the total cathode material.

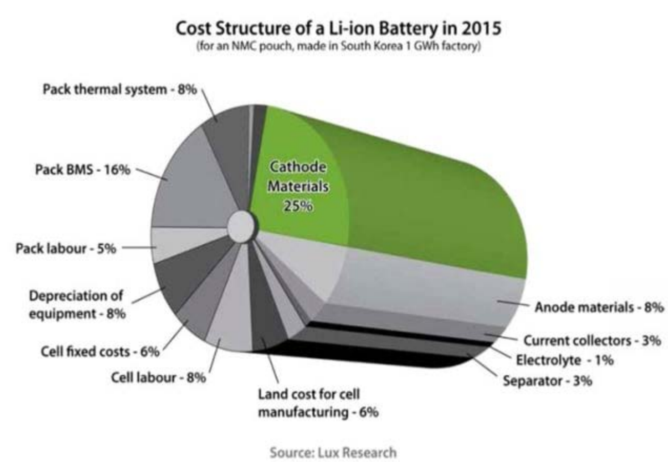
The table below provides a brief outline into the characteristics of the differing battery types for those batteries that are the most commercialised at present, or touted to be heavily commercialised in the future.

Battery* [6]	Energy Density	Power Density	Cycle Life	Safety	Cost
Nickel Manganese Cobalt (NMC)	High	Fair	Low	Fair	High
Lithium Manganese Oxide (LMO)	High	High	Fair	Good	Low
Nickel Cobalt Aluminum Oxide (NCA)	High	High	Fair	Fair	High
Lithium Iron Phosphate (LFP)	Low	High	High	Very Good	Fair
Lithium Cobalt Oxide (LCO)	High	Fair	Fair	Fair	Very High
Lithium-Manganese-Iron (LMF) [7]	Very High	Fair	Very High	Good	Low

Source: TIAX - Phev Battery Cost Assessment

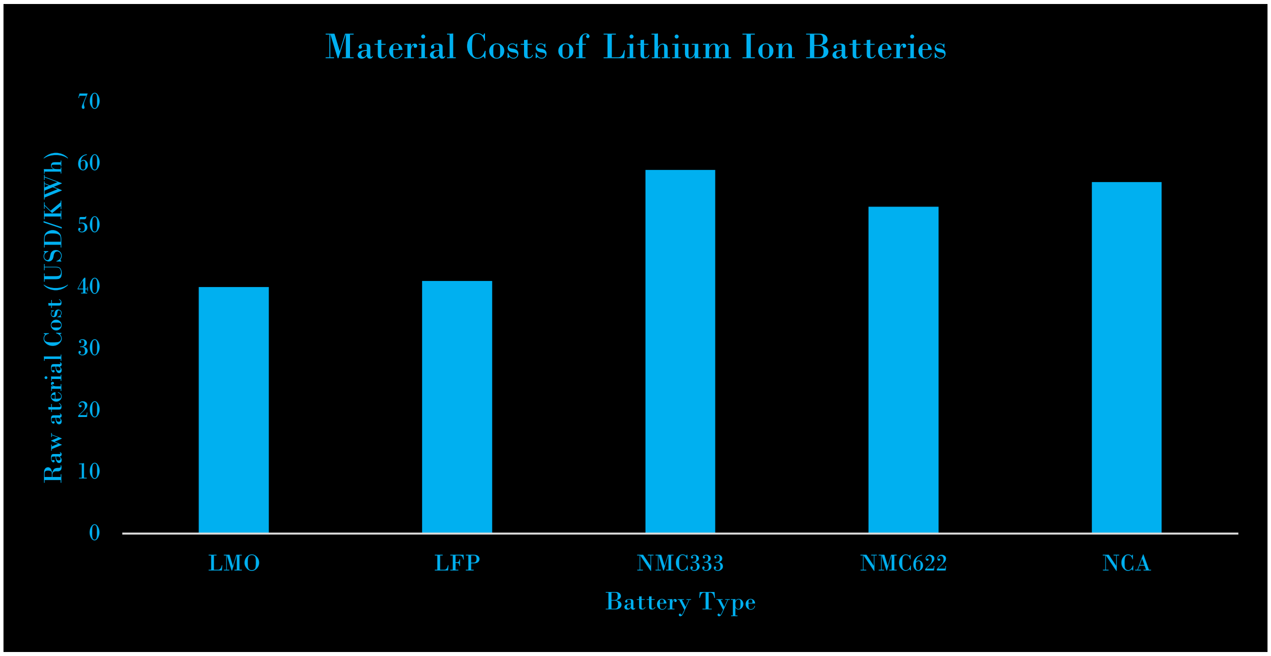
**All battery characteristics are on the assumption that a graphite anode is used within the battery cell. Often a lithium titanate (LTO) is used as the cathode material which creates secondary benefits to the battery.*

As electric vehicles and off grid storage demand increases, there will be significant factors that drive the utilisation of differing battery technologies. Energy, density, power density and cycle life will be significant factors within this decision-making process. The likely drivers behind this evolving industry are cost and safety. Of all the current transition metals used within cathodic material, manganese is the cheapest by a significant margin. This gives LMO batteries a significant cost advantage over other batteries being touted. In 2015, at least 25% of the cost in producing an NMC battery is related to production of the cathodic material. LMO batteries have a significant starting advantage with only 18% of the total cost being associated with cathodic materials.



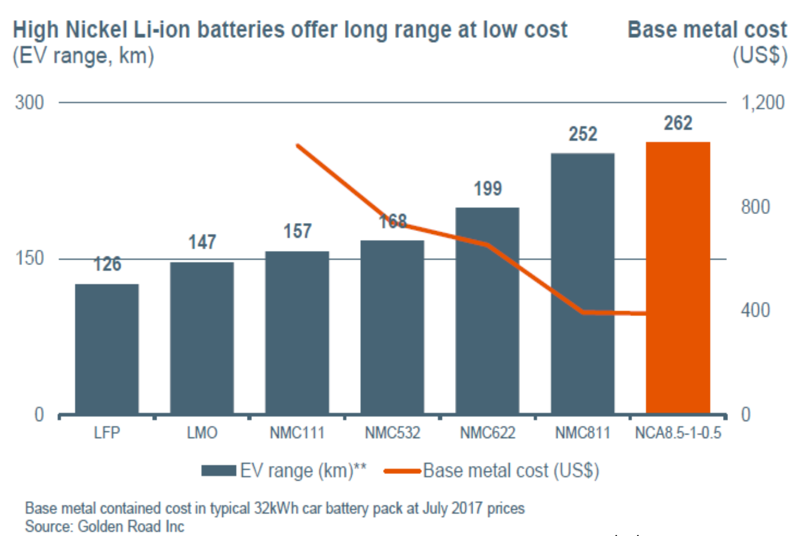
[6] http://batteryuniversity.com/learn/article/types_of_lithium_ion
[7] Magnis Resources – Investor Presentation (Feb 2018)

The table below outlines the raw material cost associated with the production of the cathode for differing battery technologies. As mentioned above, the cost of LMO batteries is currently the lowest of all the major Li-Ion batteries.



Source: Schmidt, O., Hawkes, A., Gambhir, A. & Staffell, I. The future cost of electrical energy storage based on experience curve

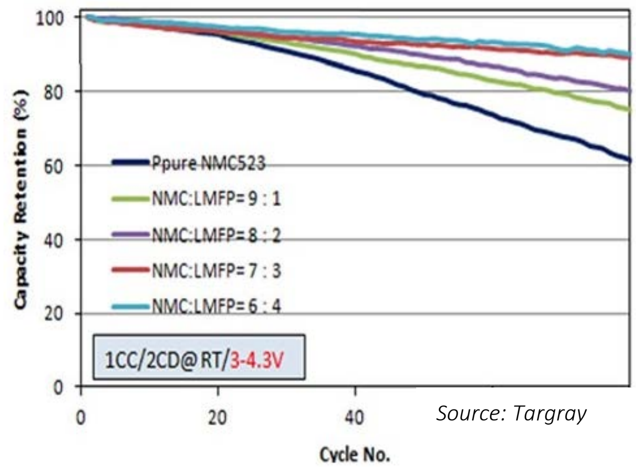
Performance will always be a key driver in the decision behind the direction of battery technology, a hinderance to the current ambitions of LMO battery advocates. Long distance travel has created issues for car manufactures as energy density of LMO battery composition has limited the distances cars are able to travel without significant recharge time. A current example of this is the Nissan Leaf (using LMO batteries) which can attain 80% charge in 40 to 60 minutes and will achieve a range of 156 miles[8]. NMC and NCA batteries have both been selected for use within Tesla vehicles due to their high energy density, which allows for greater run time of the vehicle. As such a composition of battery technology has often been incorporated into vehicles, most prominently the NMC and LMO combination.



Source: Nickel West

[8] https://www.nissan.co.uk/vehicles/new-vehicles/leaf/range-charging.html

An upcoming battery to watch which incorporates cost efficiency and performance will be the Lithium-Manganese-Iron (LMF) battery. LMF batteries are not currently at the same stage of commercialisation as other batteries containing manganese, such as the aforementioned NMC and LMO chemistries. This upcoming battery chemistry, which has been developed by Magnis Resources (ASX:MNS) has shown highly promising results based on current testing. The developed LMF batteries much like LMO batteries, removes the use of both cobalt and nickel, cutting the two highest cost components of current battery minerals. If commercialisation of LMF batteries does eventuate we envision this battery chemistry being utilised with a mixture of other batteries in EV's due to the significant reduction in capacity loss (as shown in the figure to the right).



Source: Targray

Based on batteries currently in commercial production it appears using a mixture of LMO and NMC batteries will be the most effective solution to improving distance and charge times while minimising costs. With NMC batteries having close to double the specific power of LMO batteries, a mixture of the two batteries allows the strength of each technology to be utilised. The future may see a LMF batteries fall into this mix to help improve capacity loss in EV's, as of now commercialisation of these batteries is still to be proven.

Is Manganese the Best Fit for Car Batteries?

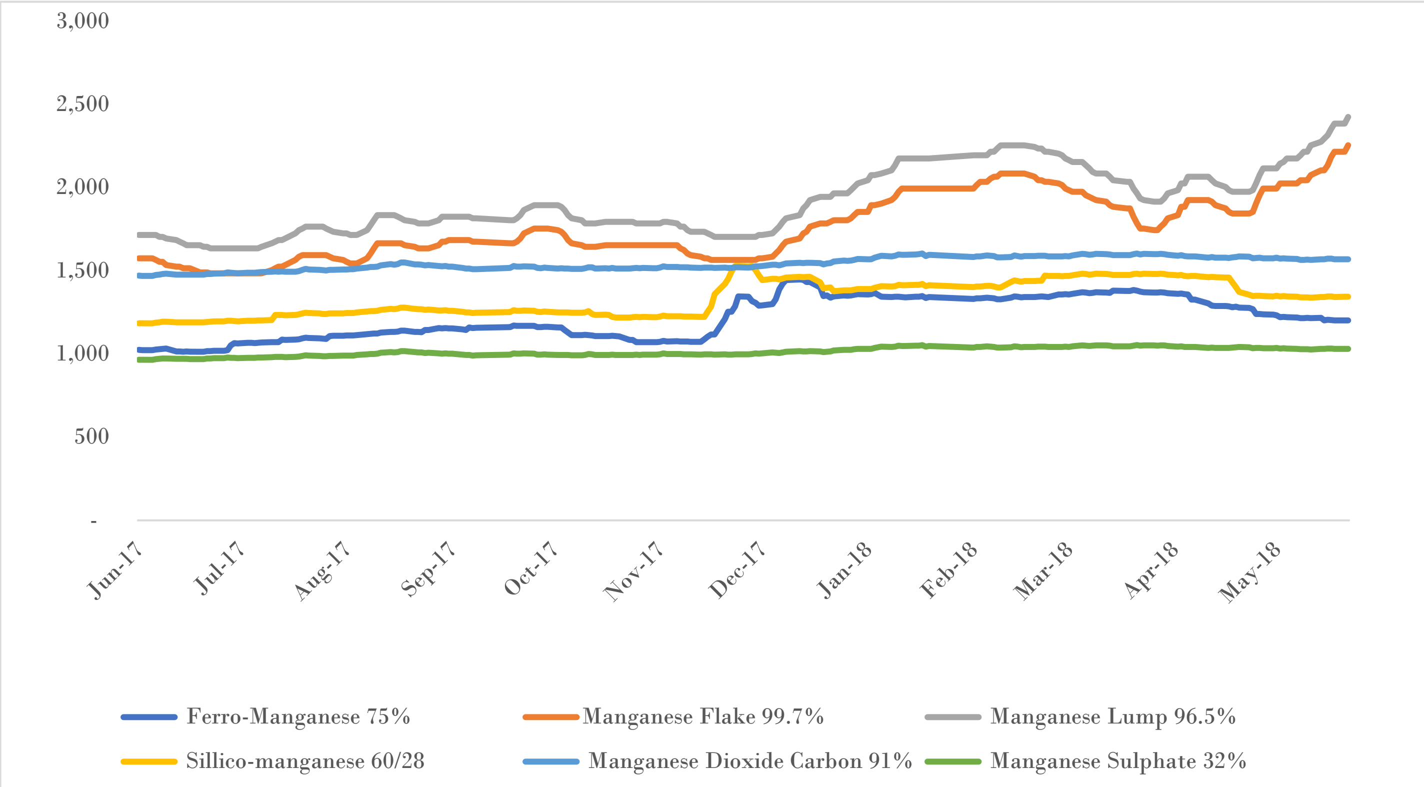
Current battery compositions contain various combinations of cobalt, nickel, manganese and aluminium. These transition metals are suitable due to their various natural ionic states and capacity to hold and discharge electrons. Of these minerals, manganese offers the cheapest solution for producers of battery technology, being more than 43 times cheaper than cobalt. Manganese is the lowest cost mineral to extract it has the second highest reported reserves of all minerals commonly utilised within cathodic materials of batteries. At current production rates world reserves are placed to sustain for another 43 years, by which point it is likely that further resource will be added to world reserves. The table below highlights the metal cost per pound and total global reserves of common minerals utilised within battery cathodes, with manganese being the cheapest mineral.

Mineral[9]	Cost Per lb (US$)	Global Reserves (mt '000)
Manganese	0.80	680,000
Cobalt	34.98	7,100
Nickel	7.08	74,000
Aluminium	1.00	30,000,000

Aluminium is currently the closest cost competitor to manganese. Compared to aluminium, manganese offers a safer solution, with aluminium batteries having a thermal runaway of 195°C. Comparatively, LMO and NMC batteries have a thermal runaway of 240°C and 230°C respectively. Another key differentiator between aluminium and manganese batteries is the number of charges attainable from each battery, otherwise known as cycle durability. Lithium Nickel Cobalt Aluminium Oxide batteries have an average cycle durability of 1000-1,500 charges, while LMO batteries have around 700 charges and NMC batteries have around 5,000 charges. The degradation of battery life in the Nissan Leaf has been acknowledged in the warranty. The warranty covers the battery capacity loss (decrease in car range) for the first 100,000 miles the car travels.

[9] S&P Capital IQ as of 25 June 2018

Supply Squeeze in China Creating Short Term Price Squeeze[10]

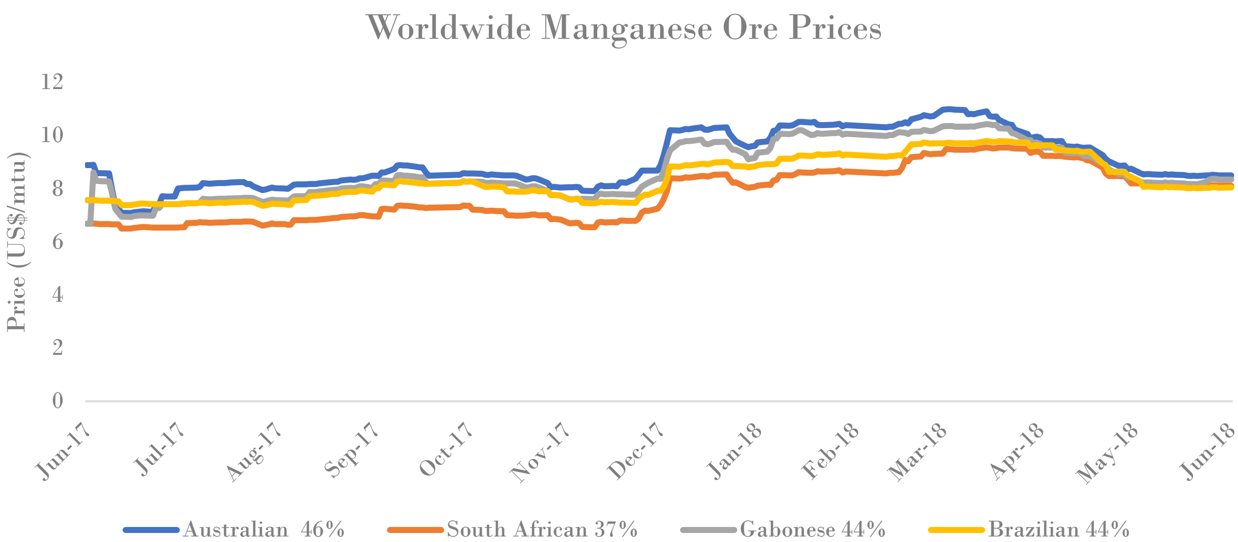


As increasing environmental regulation creeps into Chinese manganese mining and downstream processing, there has been a change in price within the manganese market. Electrolytic manganese flake saw a strong price boost in the first 6 months of 2018 with the suspension of Ningxia Tianyuan (the world's biggest manganese flake producer). In January a suspension was placed on operations due to environmental inspections, decreasing China's monthly output to 76,400t, a year on year change of ~45%. As flake production came back online, the prices over the mid part of the year softened only to be bolstered by news of further production decreases expected at Ningxia Tianyuan, with three facilities shutting down for maintenance. This resulted in a further reduction of ~16,000t of manganese flake supply. A nationwide crackdown on environmental regulation violations has, to date, forced smaller miners, smelters and flotation plants across 30 different Chinese provinces to close. With China controlling ~97% of the world's EMM trade, we are interested to watch this space as environmental regulation further tightens.

European manganese traders are finding it increasingly difficult to source electrolytic flake, with Chinese producers not supplying any flake to the market at present. This supply squeeze is forcing traders to purchase flake from suppliers in Europe, who are demanding much higher prices due to the current supply shortage.

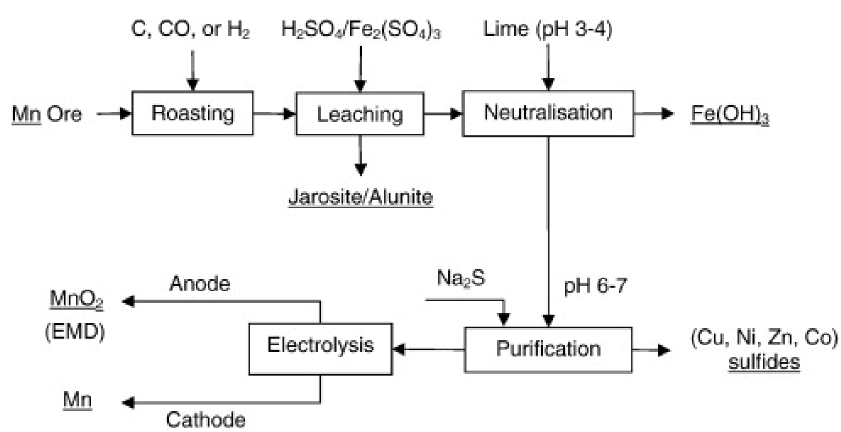
[10] Asian Metals – 20 June 2018

Not All Ore Bodies Are Suitable for High Purity Manganese[11]



Conventionally converting Manganese Oxide Ore (MOO) to Electrolytic Manganese Dioxide (EMD) involves a high-temperature pyrometallurgical roast process. The ore is heated to between 800°C and 900°C as to allow it to dissolve in hot sulfuric acid. This process has several drawbacks such as negative environmental impacts and high input costs.[12]

Since the roasting process decreases the oxide content in the ore, EMD manufacturers face tough competition from chemical and steel industry buyers of high grade manganese oxide fines. High-grade ore improves product quality & production and reduces the problems caused by non-manganese metal ions in sulphate electrolytes.[12]

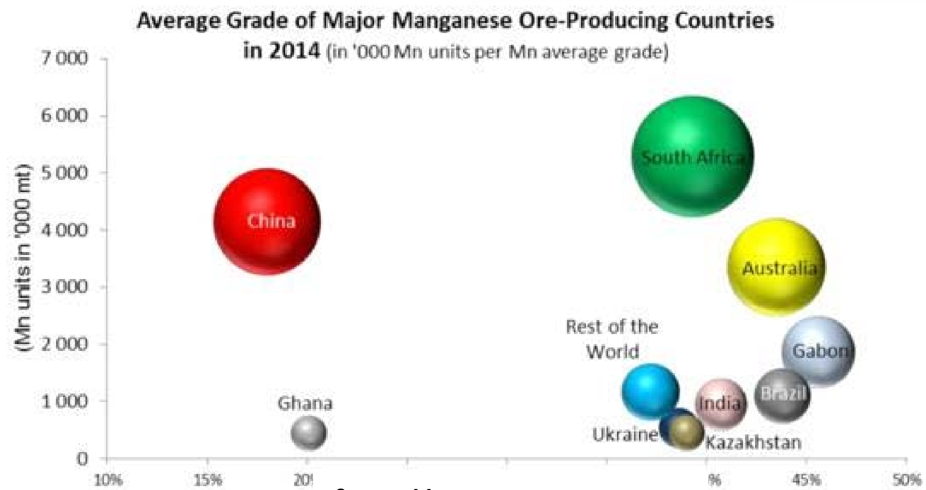


[11] Asian Metals – 20 June 2018

[12] Zhang, W. and Cheng, C. (2007). Manganese metallurgy review. Part I: Leaching of ores/secondary materials and recovery of electrolytic/chemical manganese dioxide. Hydrometallurgy, 89(3-4), pp.137-159.

Specific manganese ores are not always suited to refinement via the electrolytic process of EMD production. Ore with electrochemically similar elements such as chrome, vanadium and titanium will stick to the same electrode as manganese in the refinement process, making it particularly difficult to remove. [13] This all but rules these ores out when producing EMM and EMD. The most common manganese mineral is pyrolusite (MOO) which makes up approximately 60-63% of manganese, this form of ore is the main ore sought after by steel producers.[14] Other commonly occurring ores are rhodocrosite (manganese carbonate), which is detrimental to battery production, and rhodonate (manganese silicate).

High phosphorous content is particularly detrimental to steel production, with phosphorous being difficult to remove and damaging to the mechanical properties of steel. Phosphorus has the greatest effect on impact strength, which decreases 5kgm/cm^3 for each additional 0.02%[15]. Within the scope of production and products created in the high purity manganese space (excluding steel), phosphorous is not an overly detrimental addition to ores.



Source: Manganese.org

Due to the above restrictions certain ore bodies cannot be utlised for electrolytic or high purity manganese products at present. This is primarily due to cost restrictions of processing the materials and impurities that are not feasible to remove. This limitation on ores suitable for manganese battery products has the potential to create a dual stream of ore, with ore suitable for battery minerals attracting a significant premium to other manganese ores. This assumes battery demand increases as expected and manganese is the chosen battery commodity of the future.

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[13] Discussions with high purity manganese producers

[14] Ikeda, K. and Manome, Y. (2017). The Applications, Neurotoxicity, and Related Mechanisms of Manganese-Containing Nanoparticles. Neurotoxicity of Nanomaterials and Nanomedicine.

[15] Sherstyuk, A. and Shul'te, Y. (1963). Effect of phosphorus on the properties of high-manganese steel. Metal Science and Heat Treatment.

A Bullish Outlook for Manganese if the Tech Wins Out

Manganese will be an interesting mineral to watch. With the increasing prominence of battery technology, it can be safely assumed that manganese will play a role.

Is manganese the forgotten battery mineral though? It's definitely not forgotten but appears to be overlooked. We wondered why manganese hasn't had the same uplift as other battery commodities. In our opinion the key reason that manganese has not received the same uplift as other commodities in the battery space is due to the mining technique used to extract the ore. Manganese is a bulk commodity which is mined in high volumes. This creates a situation where small demand uplifts have minimal effect on ore. For manganese to receive the same upside as other battery minerals, it is likely to be gained through large demand for specific ores needed to produce high purity manganese products. This could see the price for high purity manganese prices decouple from industrial steel use manganese.

Key factors that will also contribute to the direction of the manganese market are:

- Whether manganese batteries become widely adopted battery technology in the future;
- The speed at which manganese producers can meet demand increases from the battery sector;
- Whether larger players move into high purity manganese production and away from manganese alloys (which is currently profitable), and the speed this transition could occur;
- China's ability to keep producing high purity manganese and the impact on supply of any further environmental regulation; and
- Whether the production process for high purity manganese can be more environmentally friendly and cost effective (see Element 25 company snapshot below).

While we cannot predict which battery technology will dominate, we are of the opinion that manganese's role will be significant and, as such, will receive significant demand uplift as a result. Not all manganese deposits will reap the benefits of this due to requirements on grade, ore type, mineralisation within deposit and clay type of ore. This separation of ore classes could create a situation where manganese deposits that fit the scope required for battery production have exponential value growth, while deposits that do not fit the scope continue to stay tied to market forces in steel production and ferroalloys. Those that have the required ore to produce high purity manganese products, and are first movers into this growing segment, could see significant upside if EMD, EMM and Manganese Sulphate prices increase at the speeds we have seen from other battery minerals over the last 2 years.

Current Listed Companies Exposed to High Purity Manganese Products:

Ticker	Company Name	Market Cap $m	Enterprise Value (EV) $m	LTM EBITDA $m	TEV/ EBITDA (Trading Multiple)	Return on Equity	Relationship to Manganese
Producers							
ASX:JMS	Jupiter Mines Limited	740	664	6	6.61	20%	South African manganese mine
ASX:S32	South32 Limited	18,492	16,501	2,540	5.45	11%	Australian and South African manganese mines
Developers							
ASX:GMC	Gulf Manganese Corporation Limited	29	27	-3	NM	-51%	Ferromanganese smelting in Timor, Indonesia
ASX:E25	Element 25 Limited	18	8	-2	NM	-1%	Holds Australian manganese deposits and develops technology to produce high grade manganese products
Explorers							
ASX:MIN	Mineral Resources Limited	3,070	2,994	403	7.44	19%	Holds Australian manganese deposits and technology to produce high grade manganese products
Industry Index							
^XMM	S&P/ASX 300 Metals & Mining (Industry)	244,623	265,262	536	7.74	10%	

Focus Company: Element 25 (ASX:E25)

Element 25 currently owns 100% of the Butcherbird deposit, Australia's biggest onshore manganese deposit. The deposit holds an inferred resource of 21.3Mt of contained manganese, a strip ratio of 0.2:1 and ore zone above water table. While not a high grade deposit, the ore can be processed to a higher grade with minimal cost required.

A key point of note for Element 25 is their work with the CSRIO on developing a new processing pathway for high purity manganese products, reducing the need for high cost sulphuric leaching which will allow them to potentially produce EMM, EMD and Manganese Sulphate at significantly lower costs.

Once commercialisation of CSIRO's processing pathway is underway we will be keeping a close eye on Element 25 and the possible disruption it could bring to the space. The figure below highlights the different process Element 25 and CSIRO are currently developing and how it differs from traditional production methods.

Current Production Methods (China & SA)	Element 25 Flowsheet
• Requires high grade imported manganese ore or very low grade domestic ore – both expensive. • Reduction Roasting to 800-1,000°C (for oxide ores) consumes energy. • Sulphuric acid leach. • Potentially more complex purification. • Production of final products using toxic selenium.	• Lower cost ore mined at surface. • Fast leach at ambient temperature and atmospheric pressure. • Exothermic reaction produces energy. • No sulphuric acid plant. • Simple, novel purification pathway. • Purified solution can produce EMM, EMD or manganese sulfate for Li-Ion batteries.
High emission, high energy, high cost, old technology	Lower emissions, lower energy, lower cost disruptive new technology

About Us:

Moore Stephens Perth has done extensive work in the battery minerals space. Working with various companies in an advisory capacity, assisting with commercial analysis, transaction support and tax support for various Lithium, Cobalt, Nickel and Manganese companies. This article does not constitute financial advice and is for informative purposes only. If you would like further information on this article please contact Peter Gray or Josh Snow on (08) 9225 5355.

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