BATTERY MINERALS

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INTELLIGENT MINING

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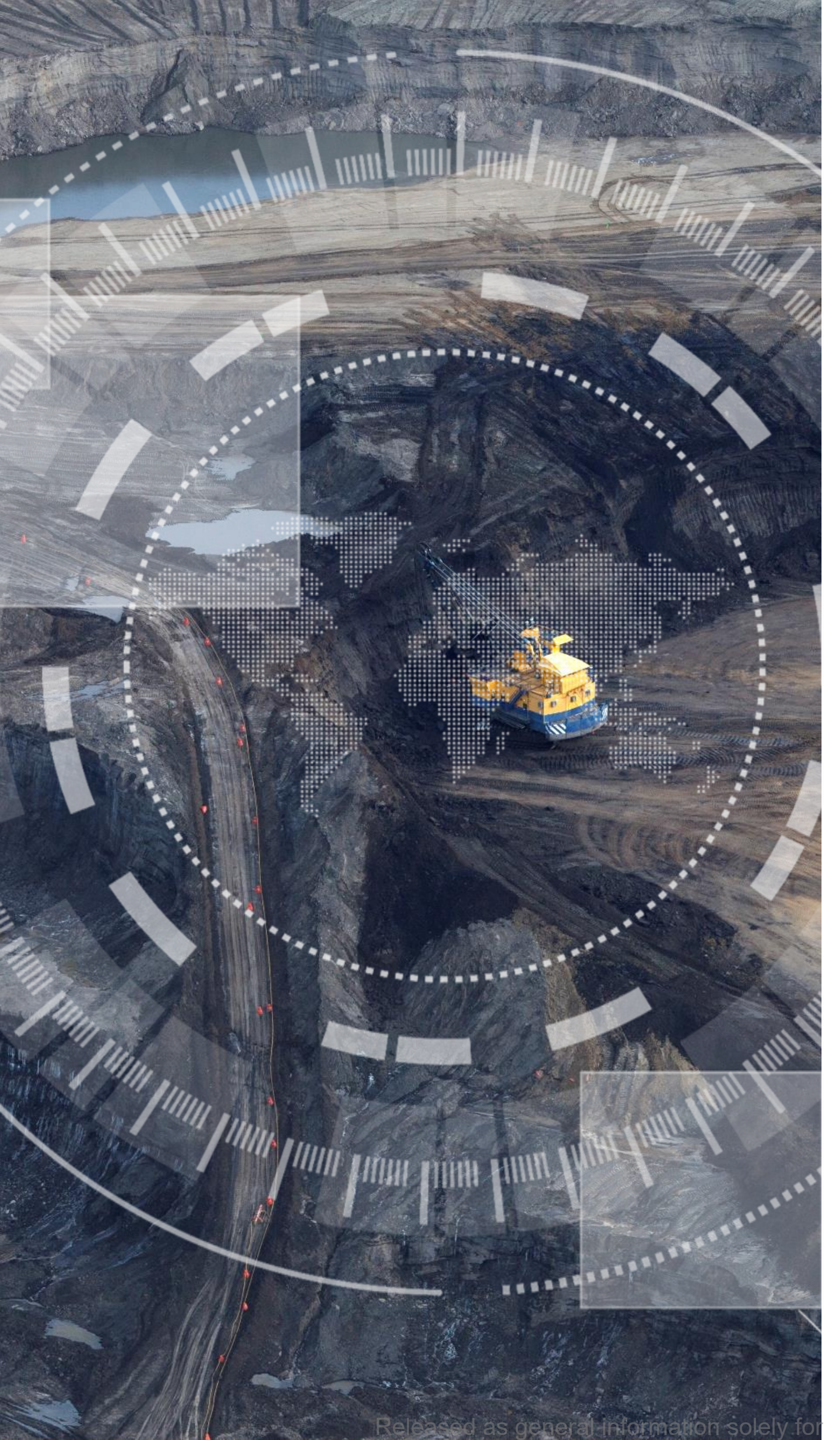


AGENDA

SEPTEMBER 2019

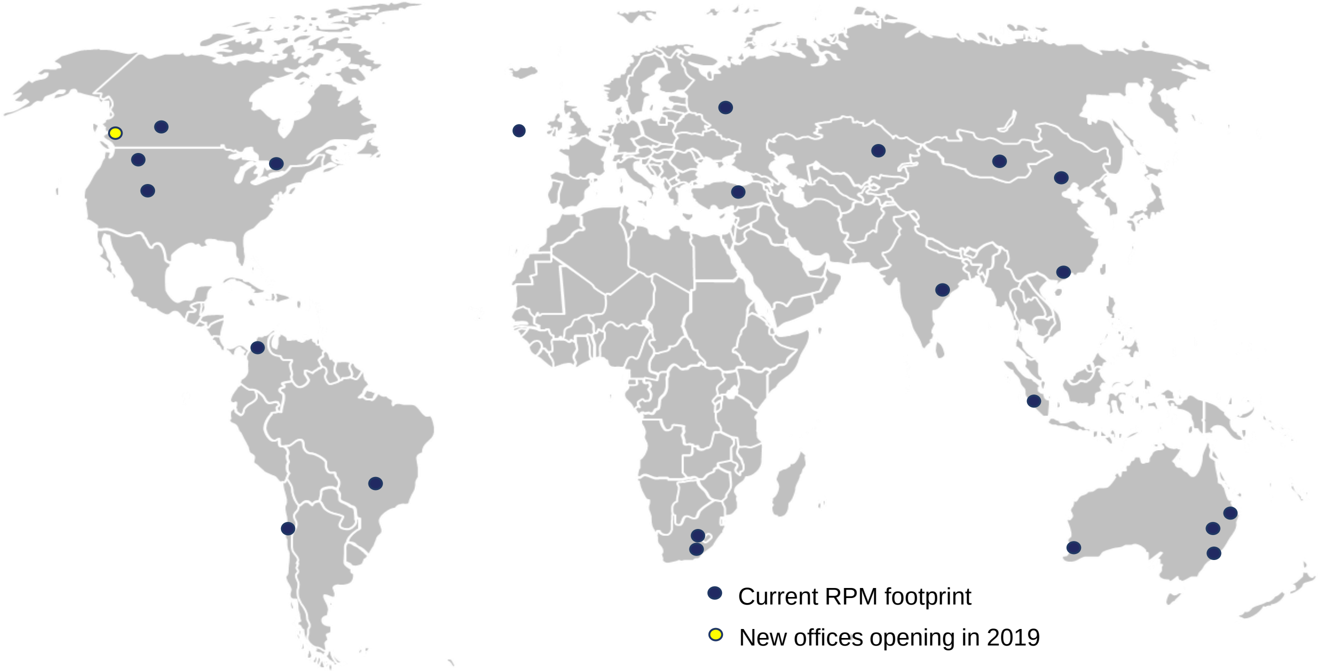
- Brief Corporation Introduction
- Battery minerals have had an exciting mining investment run in recent years
- Interest has been driven by plans to transition to electric transportation and the proliferation of battery powered devices
- Many elements are involved in this transition;
    - Lithium (Li)
    - Cobalt (Co)
    - Graphite (Cg)
    - Nickel (Ni)
    - Manganese
    - Copper (Cu)
    - Rare Earth Elements (REE)
- RPM will focus on the first three in this presentation

CORPORATE INTRODUCTION

RPMGLOBAL OVERVIEW

We are a global industry leader in the provision of mining technology and consulting & advisory services globally.

- ASX Code: RUL
- 23 Offices Globally
- 400+ Technical Consultants
- 2,000+ Global Associates
- 50 Years Experience
- 125 Countries
- 15,000+ Studies
- Resource and Reserve Estimates.
- Feasibility Studies
- Independent Expert / due diligence



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RPMGLOBAL OVERVIEW

- Due Diligence, Lenders Engineering and Peer Reviews for all of the worlds major banks and their advisors
- Capital raisings worth **60 billion USD**
- 75% of mining IPOs on the Hong Kong Stock Exchange* and Broader International Financial Markets

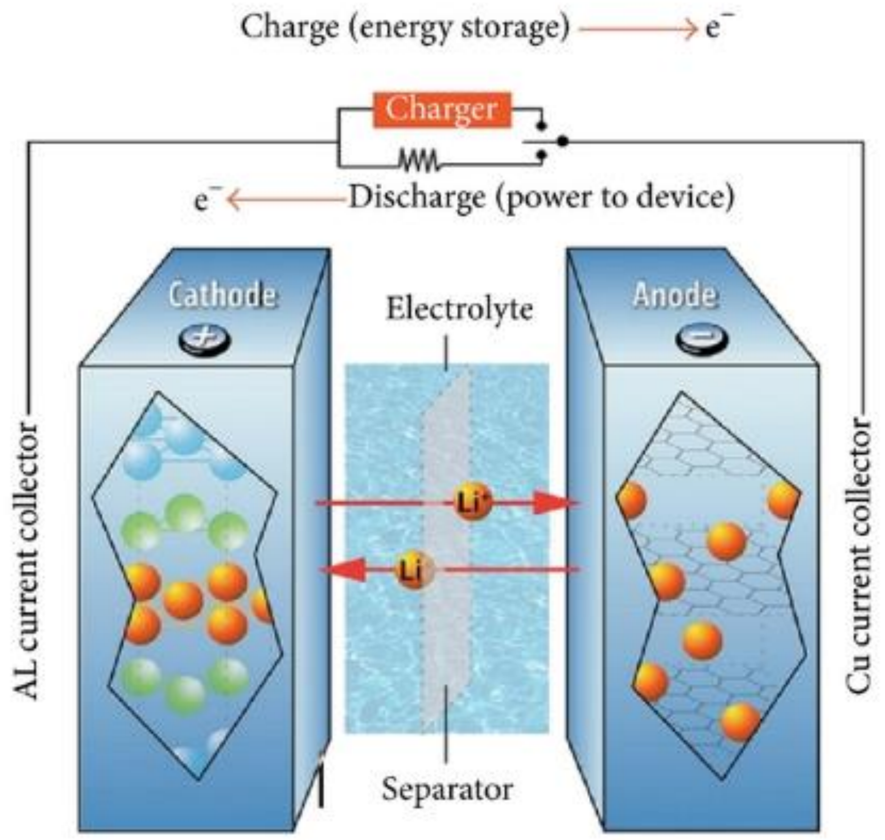
**Since the introduction of JORC reporting standards.*

LITHIUM ION BATTERY (LIB) FUNDAMENTALS

LITHIUM ION BATTERIES

- Important Minerals / Elements Needed

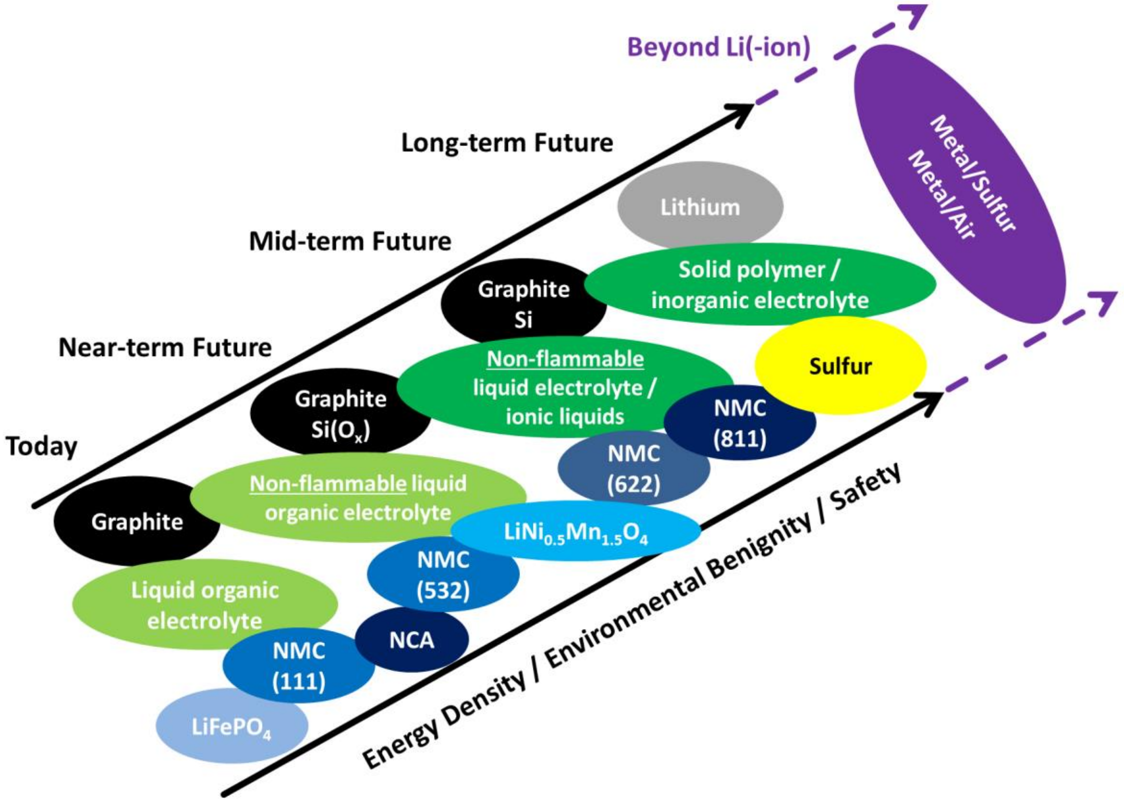
- Anodes
  - Graphite – Li on interlayers and Solid Electrolyte Interface SEI
- Cathodes (Interlayer compounds – up to 60% Li is mobile to / from structure but the structure must be preserved or the cell will fail). Elements used include:
  - Cobalt
  - Lithium
  - Nickel
  - Manganese
  - Iron
  - Aluminium
- Electrolytes
  - Lithium



LITHIUM ION BATTERIES TYPES

			Capacity	Energy
Cathode Material	Structure	Voltage	mAh/g	Energy, Wh/kg
$LiCoO2$ (**LCO**)	Layered	3.9	140	546
LiNi0.8Co0.15Al0.05O2 (**NCA** - Tesla)	Layered	3.8	180–200	680–760
LiNi1/3Co1/3Mn1/3O2 (**NMC**)	Layered	3.8	160–170	610–650
LiMn2O4 and variants (**LMO**)	Spinel	4.1	100–120	410–492
LiFePO4 (**LFP**)	Olivine	3.45	150–170	518–587

Source : Marca M. Doeff



Source : Helmholtz Institute Dec 2018

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MARKET OVERVIEW

Battery Mineral Offtake is Dominated by EV Growth

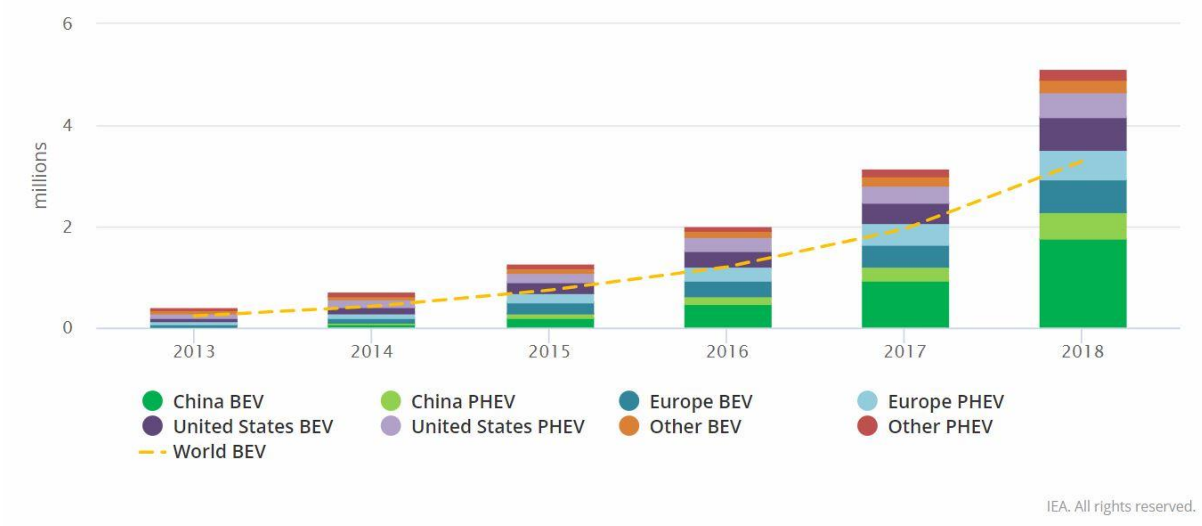
Tidal wave of megafactories drives demand for graphite development

Mr Moore told the US Senate, in February 2019, that the scale and speed of this growth was unprecedented and it would have a profound impact on the raw materials that fuel battery plants.

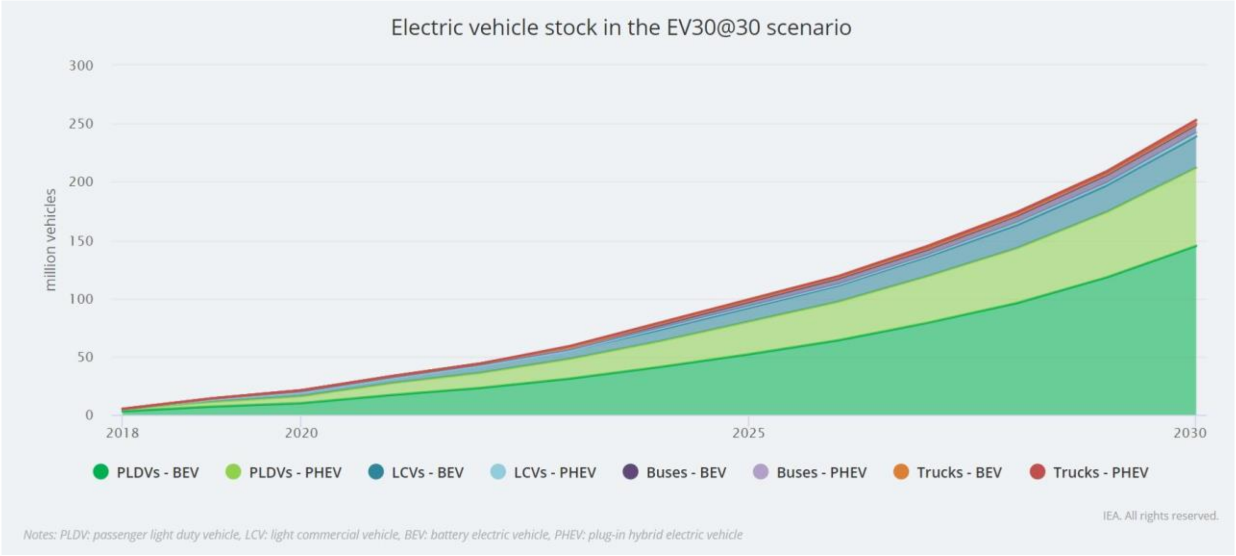
“Since my last testimony only 14 months ago we have gone from 17 lithium ion battery megafactories to 70,” Mr Moore said. “In gigawatt hour-terms, we have gone from 289 GWh to 1,549 GWh – that’s the equivalent of 22 million pure electric vehicles worth of battery capacity in the pipeline.

“This adds extra impetus to this mega-trend of battery megafactories and the impact on the demand for critical battery raw materials of lithium, cobalt, nickel and graphite…in the next decade the demand for lithium [used in the battery industry] is set to go up 9-times, cobalt is set to go up 6-times, nickel is set to go up 5 times, and graphite anode is set to go up 9 times.”

Source: Mining News



Source : IEA June 2019



Source : IEA June 2019

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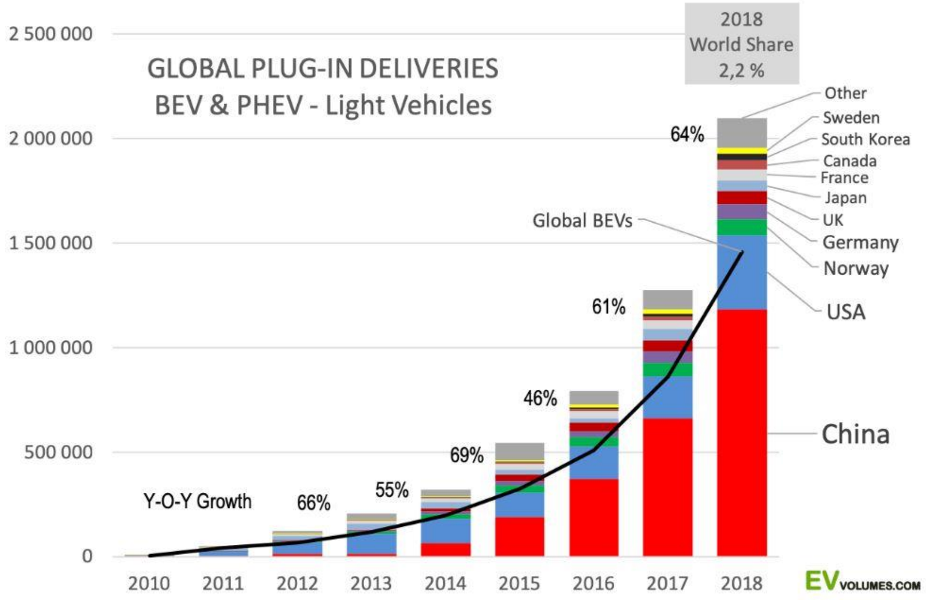
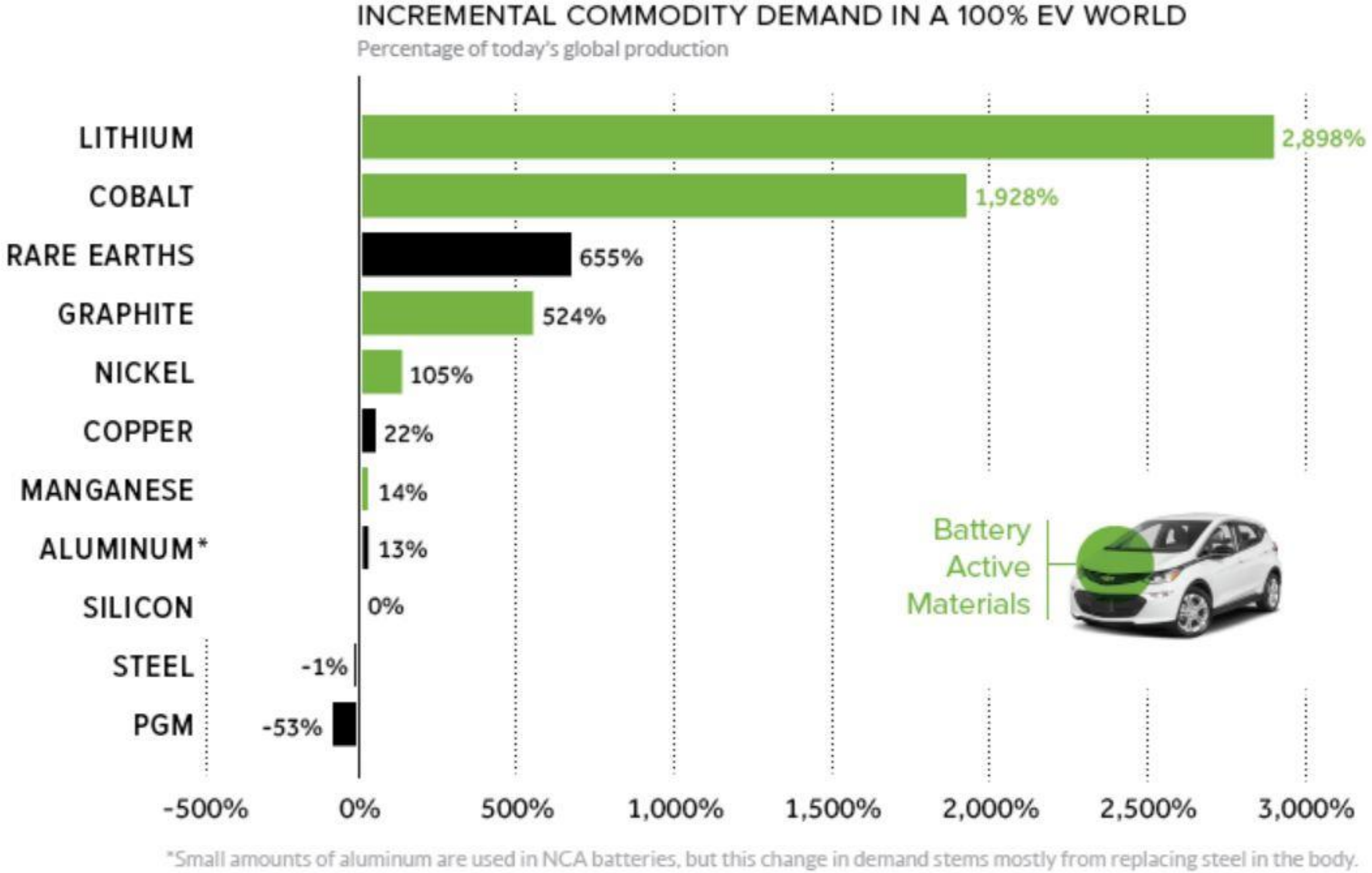
MARKET OVERVIEW

Changed metals demand in a 100% EV world

- Significant changes in commodities demand for a 100% EV world,
- But as yet only minimal EV penetration (2.2% for 2018 – 3.8% in December 2018), therefore current over supply and depressed prices,
- Volatility is to be expected!



Source :EVvolumes 2019



Source : UBS September 2018

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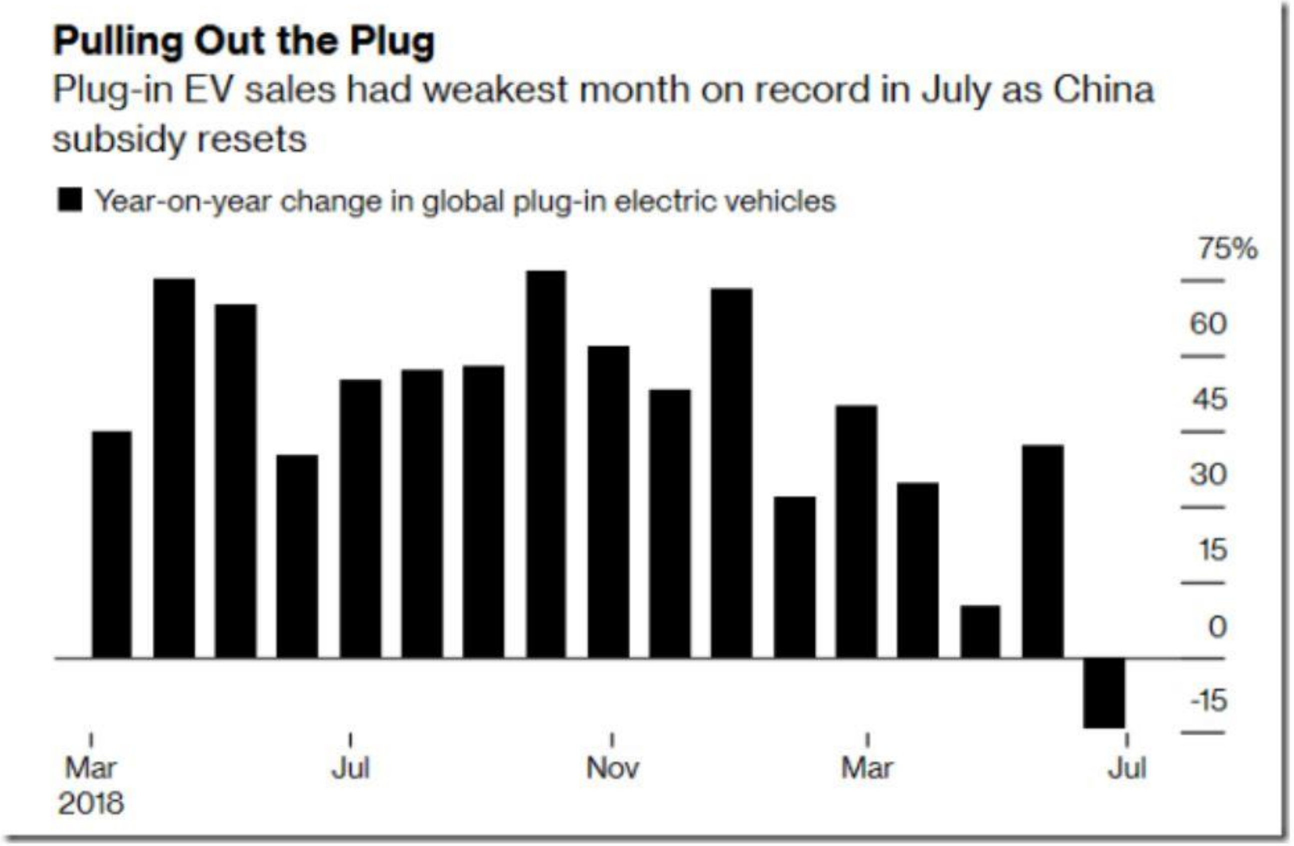
MARKET OVERVIEW

However we are not in a 100% EV world and subsidies; therefore government whims are the main driving force!

- China has progressively decreased subsidies with slight effect initially, but in June 2019 the market reacted savagely, because:
  - New energy vehicle" (NEV) subsidies were cut off completely for vehicles with less than 250 km of electric range; and
  - Those with higher range saw their subsidies halved.
- This made some EV models sales peak in June, but with a crash thereafter.
- Volatility, because of government subsidy changes, was confirmed!



Source: Sanford C. Bernstein

LITHIUM ION BATTERY (LIB) RECYCLING

RECOVERING THE COBALT, NICKEL, LITHIUM AND GRAPHITE

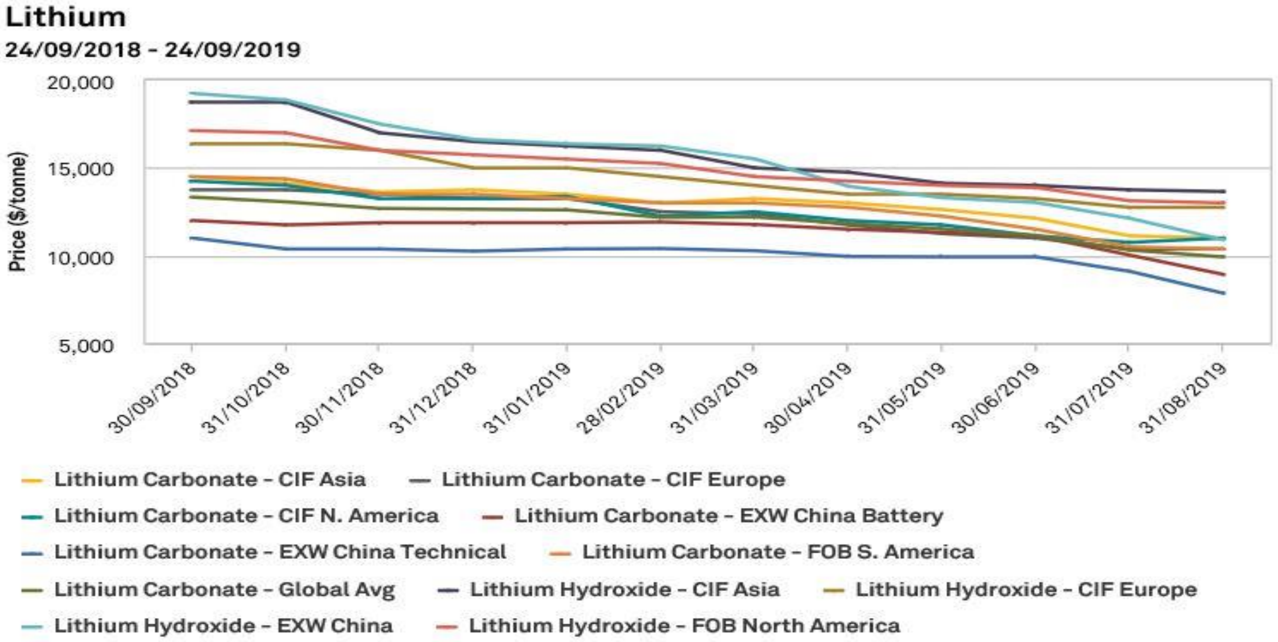
- Patent Activity
  - A third of patents in the lithium technology area (>300) have been taken out for the recycling of lithium since 2007
- Not widely practiced - limited current impact
  - Base metals easily recovered
  - Lithium and graphite more difficult
- Conventional Battery Recycling
  - The Envirostream battery recycling operation in Victoria recovers the metals as MMD (Mixed Metal Dust)
  - Lithium Australia reports that they can extract the lithium from MMD and produce lithium phosphate for batteries
- Research - Active
  - CSIRO has been commissioned to conduct research and explore the basis for developing a sustainable LIB recycling industry

LITHIUM GEOLOGY

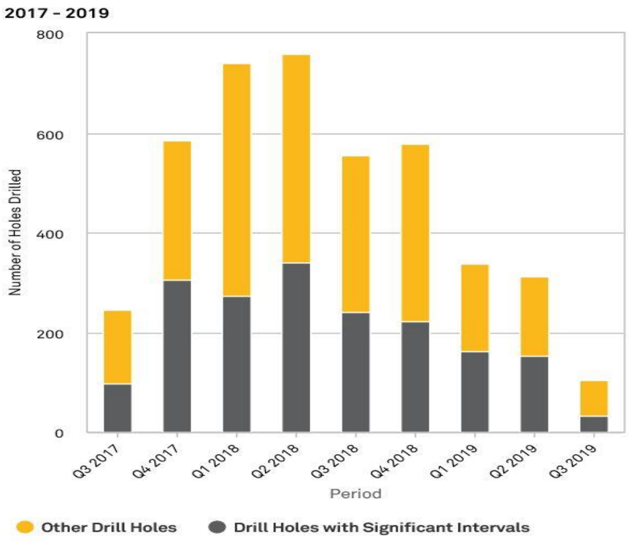
LITHIUM

WHAT'S IMPORTANT?

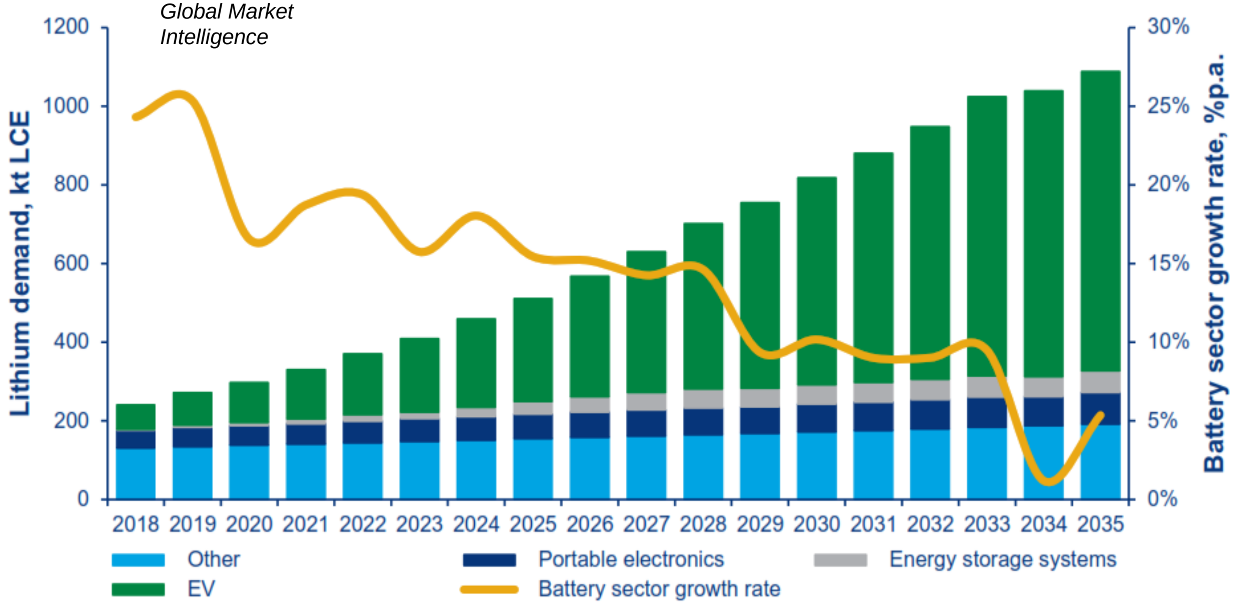
- Current high performance battery chemistries involve Li
- Substitution is possible but unlikely
- Resources and Reserves are large ~62 Mt of contained Li (USGS 2018)
- Exploration Targets larger!
- Projected Li demand growth until 2030's then slowing
- A race to production, competitive pressures in time, drilling activity fall-off suggests – **arrived already**?
- As have Pegmatite Project Failures - **second peak?**



Source : S&P Global Market Intelligence



Source : S&P Global Market Intelligence



Source :Wood Mackenzie

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DEPOSIT TYPES

PEGMATITES

Typically small but numerous and widely distributed. Higher operating costs, multiple commodities.

- Coarse grained rocks
- Mostly in spodumene and lepidolite
- World wide distribution
- Mostly small deposits (except Greenbushes)
- Valuable byproducts: Cesium, Tin and Tantalum
- Careful about mineralogy e.g. Fluorine in fluorophosphates

SALARS

Huge, low operating costs, long time to build to full capacity.

- Brines ‘rich’ in Li
- Salt evaporitic deposits
- Found in:
  - Arid belts of the Equator.
  - Western S. America and USA,
  - Tibet and Dead Sea
- Li source is surrounding rocks, air-fall tuffs, dust and hydrothermal fluids
- Reliance on evaporative concentration

“FOSSIL” SALARS:

Huge but not currently in production. Economics more attractive when associated with boron.

- Fine grain sedimentary rocks
- Large deposits
- Ioneer’s Rhyolite Ridge, NV - USA
- Khukh Del Project, Mongolia
- Jadar Deposit, Serbia

LITHIUM

Summary

- Resources / Reserves and Exploration possibilities are large
- Projects could be beached by over production and lower prices (Galaxy write down, $150million, Alita administration)
- Low cost projects are attractive
- Pegmatites: easily explored, low exploration costs, small size, quick to production with and simple mining and primary processing. Performances of some operating plants is troubling, while downstream processing costs are significant. Salars: very large resources, however not fully extractable. Slow to bring into full production but lower operational cost. Relatively few Salar locations, other producers may be extracting from the same brine pools
- Fossil Salars: Wild cards, tip of a mostly unrecognised behemoth. Operating costs will likely be relatively high compared to brine deposits, contribution from borax important – e.g. Rhyolite Ridge , Jadar
- Surety of supply will be a driver e.g. Rhyolite Ridge (USA) and Jadar (Europe)

It’s a most interesting space – take your pick ☺

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LITHIUM PROCESSING

LITHIUM PROCESSING

SPODUMENE

- **Background**
  - Mineralogy : spodumene ($LiAlSi_2O_6$ - 8.03% Li_2O [3.72% Li]), mica, feldspar, quartz and iron bearing minerals
  - Lower start-up costs, rapid ramp-up (mineral processing)
  - High overall operating costs >~USD4,500/t LCE (mineral processing : ~USD2,000-2,500/t LCE)
  - High extraction rates (>70%)
  - Primary aim is to make a 'C6' concentrate ≥6% Li_2O [2.79% Li]; high transport costs (markets in China)
- **Primary Spodumene**
  - Typically very coarse and simple mineral processing techniques employed
  - Crushing, classification and gravity separation (Dense Media Separation, DMS)
  - By-products e.g. tantalite recovered with spirals
  - Fines can be ground and floated (see Secondary Spodumene)
- **Secondary Spodumene**
  - Typically fine and flotation employed for recovery – fatty acids
  - Typical flowsheet : milling, de-sliming, collector conditioning, flotation with mechanical scrapers with typically two stages of cleaning
  - Magnetic separation applied to final concentrate (mica)
- **Mineral Processing Issues**
  - Presence of petalite ($LiAlSi_4O_{10}$) - lower lithium content (4.9% Li_2O)
  - Presence of mica and iron bearing minerals (hardest to deal with)
  - Presence of slimes
  - Water quality
  - Activation of quartz and feldspars by soluble iron salts

Source : geology.com

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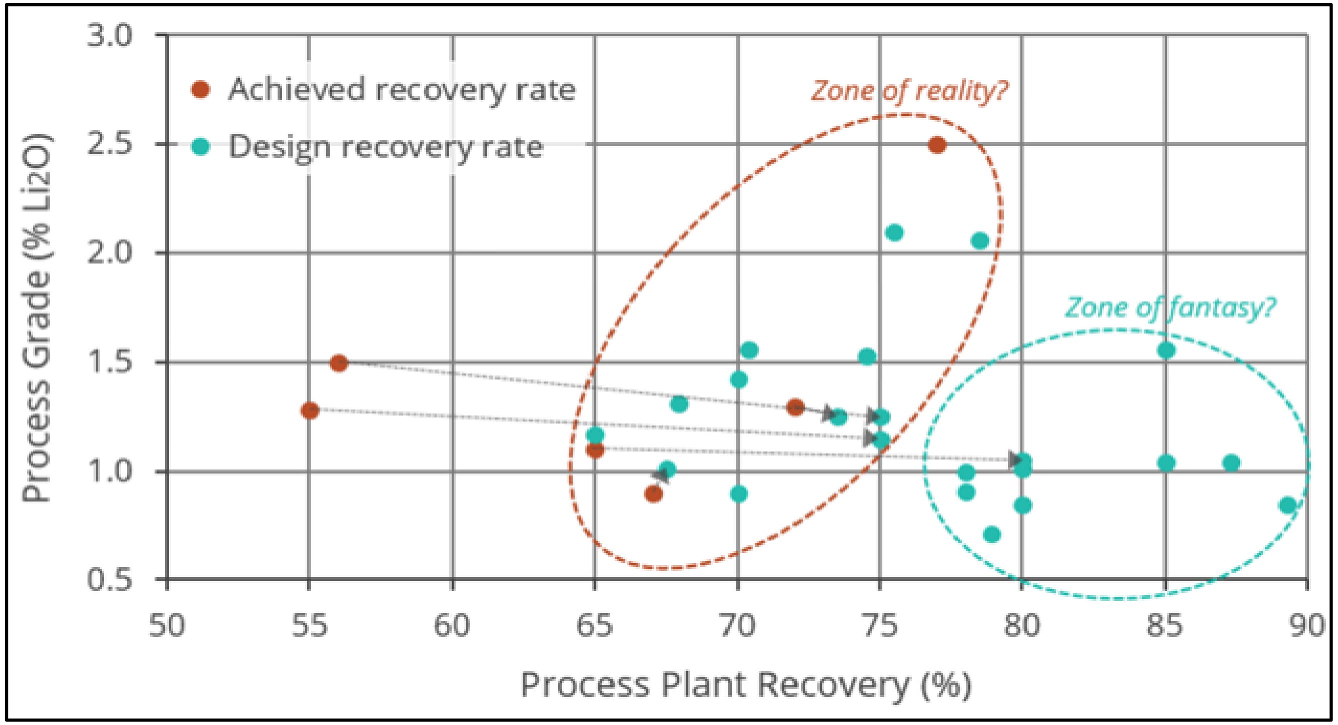
SPODUMENE PROCESSING

SCALE-UP PROBLEMS OR SOMETHING ELSE?

- Over the last two years, there has been a stampede to bring mainly primary spodumene plants into operation
- Design recoveries are not being achieved in some of these newer operations
- Roskill believes the problem is due to insufficient experience in scaling-up spodumene processing plants
- Any analysis needs to appreciate distinction between
    - Primary and Secondary spodumene
    - Gravity and flotation processing



Source : Roskill "Lithium: Are spodumene plant design recovery rates realistic?", 09/09/2019

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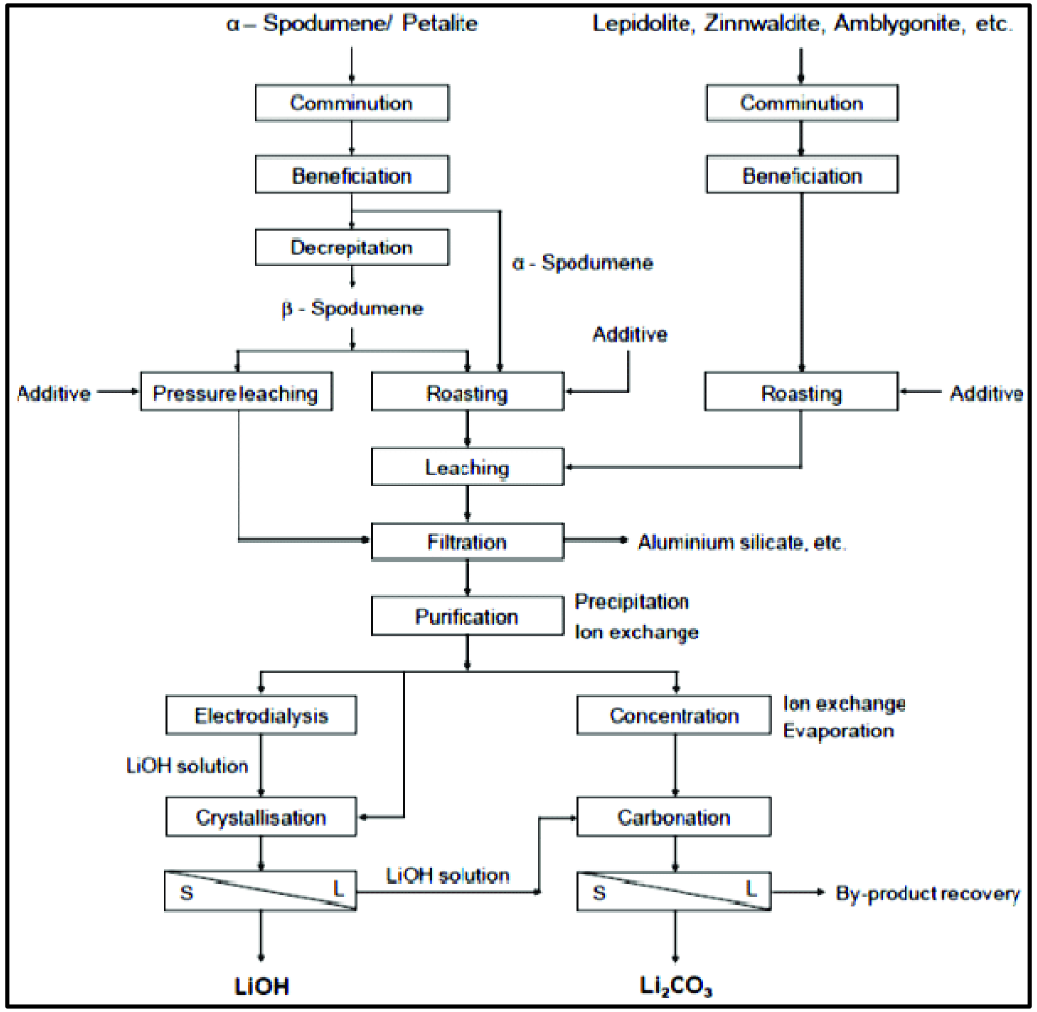
LITHIUM PROCESSING

SPODUMENE – LITHIUM EXTRACTION

- **Background**
  - Product is typically lithium carbonate (hydroxide and phosphate becoming more common), relatively pure >99.5% Li_2O
  - Purification process common to lithium processes
- **Flowsheet**
  - Calcination at 1,050-1,100°C (decrepitation) : conversion to beta spodumene – lower density, numerous surface and internal cracks, amenable to leaching
  - Often ground finely before mixing with sulphuric acid and roasted (250°C)
    - Solubilises lithium and many other cations (Na, K, Mg, Fe,…)
  - Product mixed with water, then a solid/liquid separation followed by precipitation to remove calcium and magnesium
  - Concentration stage – electrodialysis (membrane separation), ion exchange, evaporation
  - Precipitation of lithium with sodium carbonate (or hydroxide) followed by dewatering
- **Processing Issues**
  - Ratio of other alkali metals e.g. sodium
  - Multiple dewatering stages
  - Loss of Li with calcium and magnesium removal (~1.5%)



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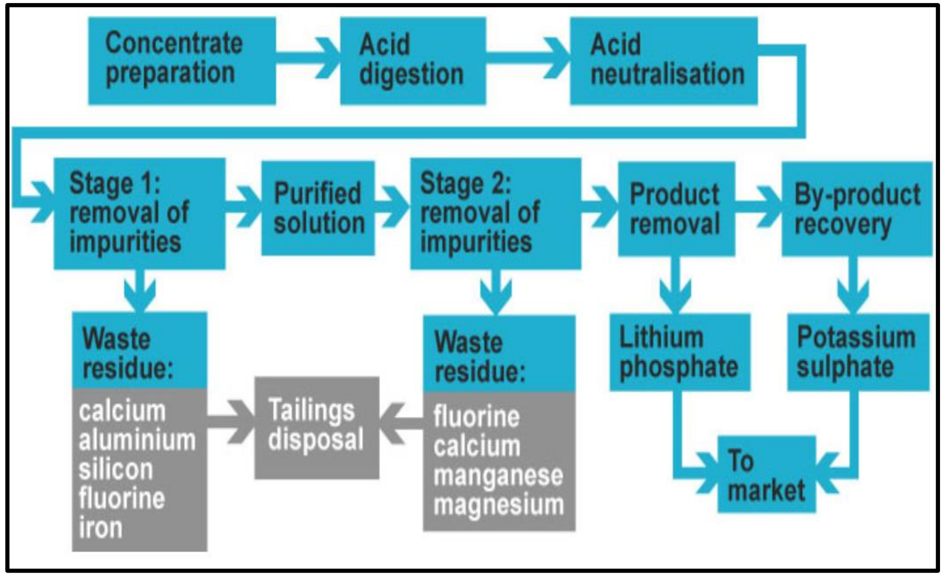
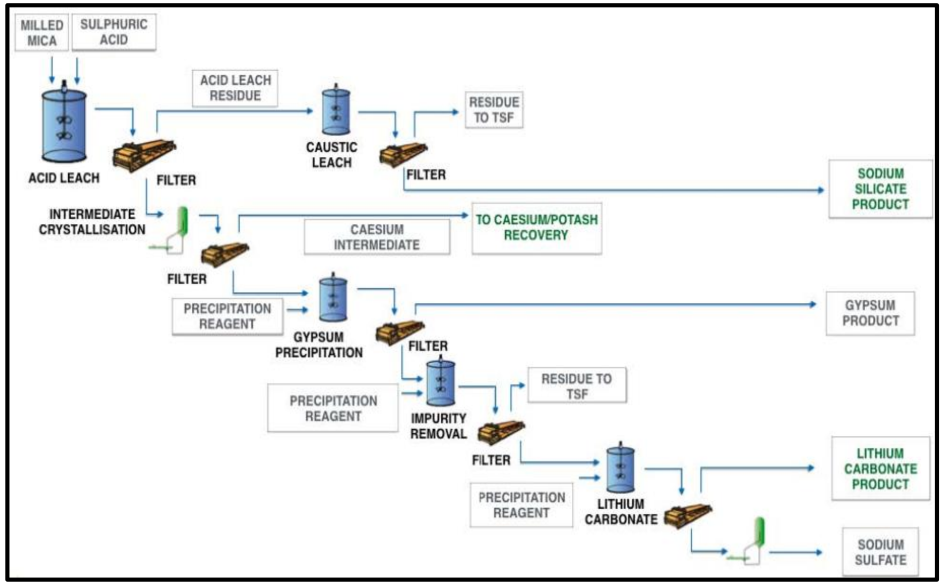
LITHIUM PROCESSING

SPODUMENE – DEVELOPMENTS

- A number of proprietary processes reported
  - **Spodumene**
    - Flotation
      - Selective collectors [reagent suppliers]
    - Roasting additives
      - (Lower calcination temperature (800-900°C) [Murdoch University]
    - Alternative lixivants/processes
      - Direct leaching after fine grinding – avoid calcination
      - Nitric leach process (ICS Process) – based on recycling nitric acid [CSIRO]
      - SiLeach^{TM} : 'halogen' based leach – hydrofluoric acid? [Lithium Australia]
      - LieNA^{TM} : high pressure and temperature and caustic soda leach to produce sodalite ($Na_8(Al_6Si_6O_{24})Cl_2$), which is then converted into lithium phosphate (Li_3PO_4) [ANSTO-Lithium Australia]
  - **Lepidolite and petalite**
    - Back to the future : original source of lithium
      - Fine grinding and sulphuric acid leaching of flotation concentrate
      - L-Max technology to produce Li_2CO_3 (Lepidoco)
    - Economics?
      - Main issue is lower Li_2O head grade and feed costs
      - Chinese lithium producer reported extraction uneconomic and turned to spodumene



Source : Lithium Australia, website



Source : Lepdico, website

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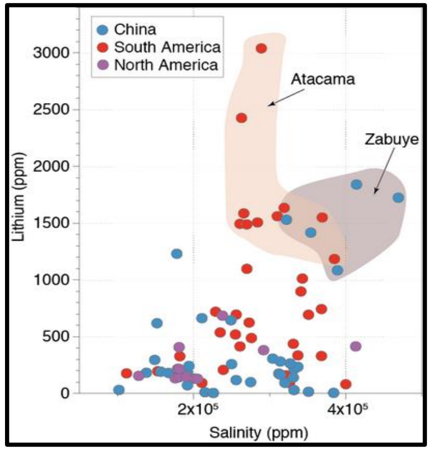
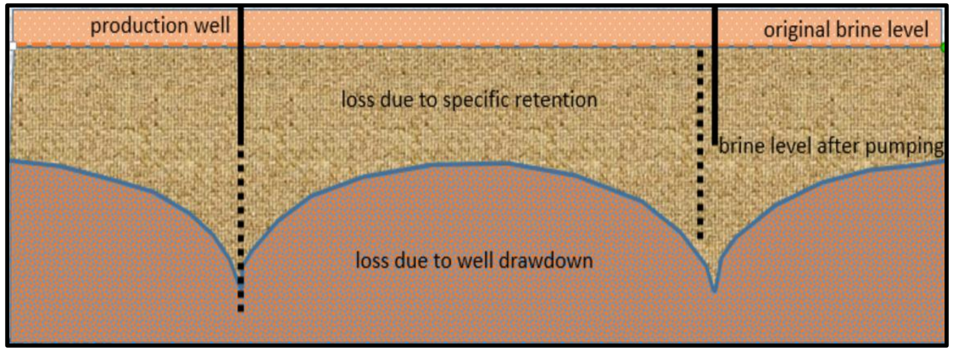
LITHIUM PROCESSING

SALARS

- **Background**
  - Feed source is saturated brines – sodium and potassium chlorides; lithium is present as soluble species (LiCl)
    - Lower tenors : 300-1,500ppm (400ppm cut-off); variable chemistry that changes with time
  - Need to do a considerable amount of developmental testing
    - Confirm extraction rates (stable flows – takes up to a year)
    - Confirm replenishment
    - Borehole/trench/pattern designs
  - High start-up costs, low operating costs (~USD2,500-2,750/t LCE)
  - Slow ramp-up (18-24 months)
  - Long processing times (up to 24 months)
  - Low extraction rates mainly due to permeability
    - 3-10%; Canadian NI reporting 33% maximum
  - Reliability – weather related issues (evaporation rates)



Source : Warren, Saltworkconsultants website



Source : Welham, 2018

Soil Type	Efective Solution Recovery (%)
Sand dominant	41.0
Silt & sand/clay mix	16.0
Halite dominant	14.0
Clay dominant	4.5

Source : SRK, 2016

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LITHIUM PROCESSING

SALARS – FLOWSHEET

- Series of evaporation ponds, where sodium, magnesium and potassium salts crystallise and precipitate out as the solubility limit reached
  - Evaporation achieved by sun, wind and altitude
  - Very large footprint
- When the lithium concentration reaches around 5,000-7,000ppm (g/L), the solution is ready for harvesting i.e. lithium recovery

Salt	Formula	% Li	Solubility Limit (g/L, 20 ℃)	Li^+ (g/L)
Sodium Chloride	**NaCl**	-	**359**	
Sodium Sulphate	Na_2SO_4	-	195	-
Magnesium Chloride	**$MgCl_2$**	-	**546**	-
Magnesium Sulphate	MgSO4	-	629	-
Potassium Chloride	**KCl**	-	**342**	-
Potassium Sulphate	K_2SO_4	-	111	-
Lithium Chloride	**$LiCl_2$**	**16.37**	**835**	**136.7**

Source : SQM, Chile

Pond Number	Area (ha)	Volume (m^3)	Lithium Concentration (g/L, ppm)	Precipitates
1	308	757.1	680	-
2	210	454.2	780	sodium chloride
3	36	94.6	930	sodium chloride
4	35	83.3	1,200	sodium chloride
5	19	56.8	1,400	sodium chloride, calcium sulphate, magnesium hydroxide
6	17	20.8	1,900	sodium chloride, calcium carbonate
7	7	5.7	2,400	sodium chloride, sodium/potassium sulphate
8	5	3.8	3,100	sodium chloride, sodium/potassium sulphate, potassium chloride
9	6	11.4	5,000	sodium chloride, sodium/potassium sulphate, potassium chloride

Source : Barrett and O'Neill, 1969

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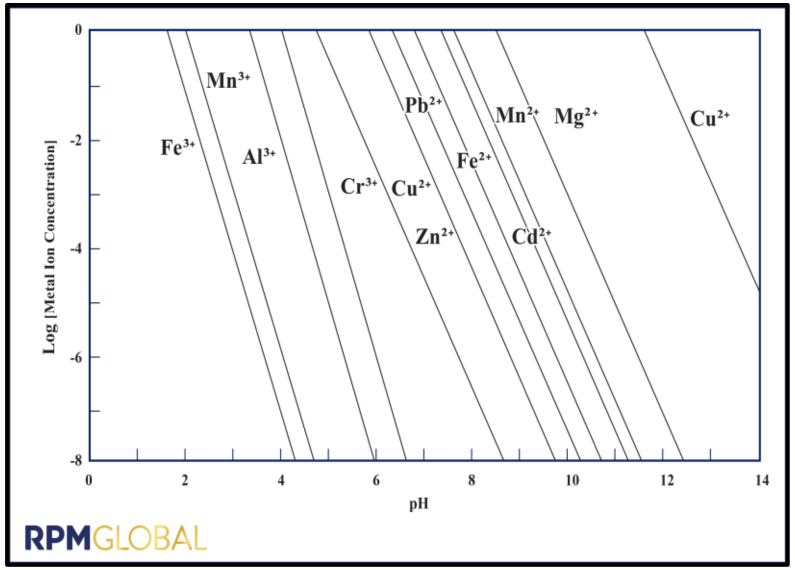
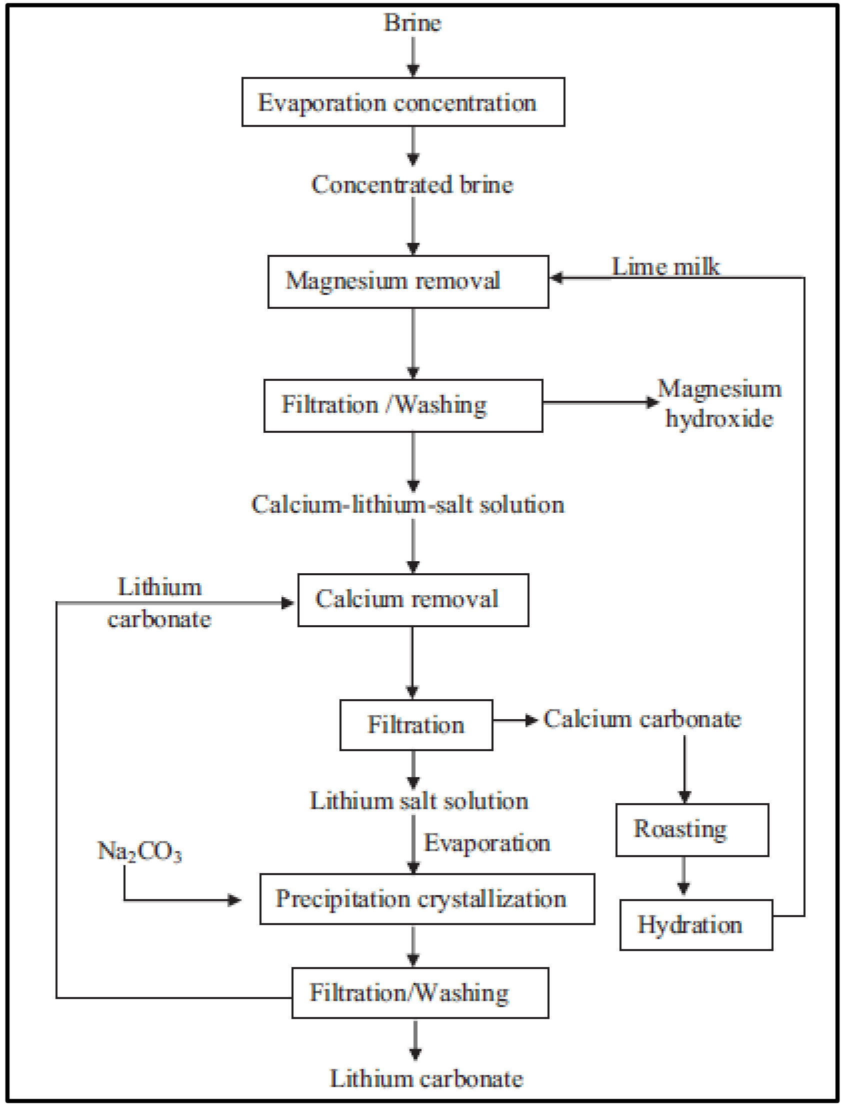
LITHIUM PROCESSING

SALARS – LITHIUM SALT RECOVERY

- Impurity removal by precipitation and ion exchange – depends upon cations present (i.e. lime, sodium carbonate,…)
- Calcium and magnesium (not full extraction)
- Precipitation of lithium with sodium carbonate or carbon dioxide followed by dewatering (effective if Li^+ >20-25g/L)

Salt	Formula	% Li	Solubility Limit (g/L, 20 ℃)	Li^+ (g/L)
Lithium Sulphate	Li_2SO_4	12.63	348	43.9
Lithium Bicarbonate	$LiHCO_3$	10.21	57	5.8
Lithium Carbonate	**Li_2CO_3**	**18.79**	**13**	**2.5**
Lithium Hydroxide	LiOH	28.98	128	37.1



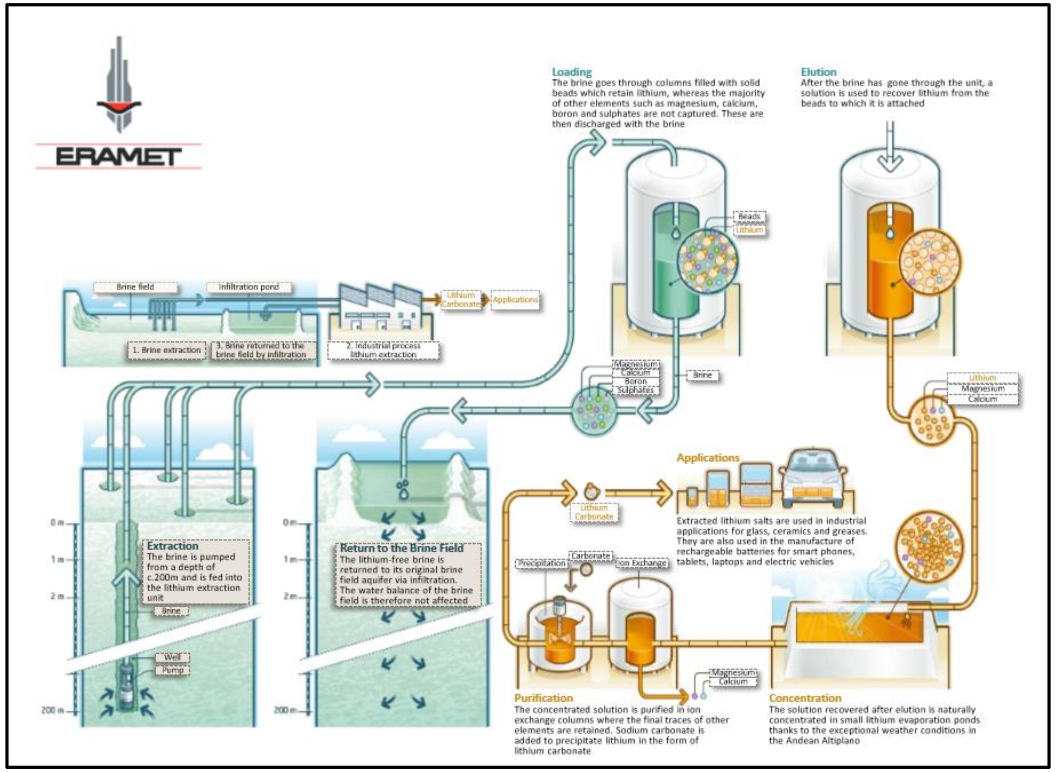


Source : Meshram et al., 2014, Hydrometallurgy

LITHIUM PROCESSING

SALARS – DEVELOPMENTS

- Primary aim : speed up processing times and indirectly smaller footprint
- Trade-off : increased capital costs and operating costs as well as power requirements
- The developments being explored to replace evaporation stages and the separation selectivity include :
    - Reverse Osmosis/membrane separation techniques
    - Solvent extraction (SX) and ion exchange (IX) processes
        - Li not very amenable to SX and IX
    - ERAMET has developed a process employing IX (resin) and membrane separation
        - Perceived benefits
            - Higher overall lithium recovery : 85% cf. 40-60%
            - Elimination of evaporative ponds – faster as well as smaller footprint
            - Operating or capital costs not revealed



Source : ERAMET, website

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LITHIUM 2018 PRODUCTION COSTS

Spodumene	
Lepidolite	
Petalite	
Salar	

Property	Country	Product	Production (kt)	Grade (Li_2O %)	2018 Cost (USD/product tonne)															
					Mine	Mill					Conversion Plant					Transport and Offsite	Cash Operating	Seaborne Shipment	Total Cash Cost	Total Production Cost
						Labour	Reagents	Power	Other	Total	Labour	Reagents	Power	Other	Total					
Wodgina	Australia	Direct Shipping Ore	2,402.0	1.2	22.79	3.76	0.00	0.55	1.92	**6.23**	0.00	0.00	0.00	0.00	0.00	24.64	53.67	9.14	**68.20**	**72.44**
Pilgangoora	Australia	Direct Shipping Ore	410.6	2.1	18.38	8.18	2.63	5.61	8.12	**24.54**	0.00	0.00	0.00	0.00	0.00	26.51	69.43	3.98	**83.96**	**93.77**
Greenbushes	Australia	Concentrate	730.0	6.0	38.74	22.81	4.45	8.53	22.22	**58.00**	0.00	0.00	0.00	0.00	0.00	51.35	148.09	30.00	**222.31**	**255.30**
Mount Marion	Australia	Concentrate	440.2	5.1	199.45	40.85	14.87	5.05	35.48	**96.25**	0.00	0.00	0.00	0.00	0.00	82.89	378.58	30.62	**443.68**	**477.10**
Yichun	China	Concentrate	114.2	4.0	**286.97**	49.06	18.28	52.05	48.32	**167.70**	0.00	0.00	0.00	0.00	0.00	36.89	491.57	0.00	**551.04**	**683.82**
Mt Cattlin	Australia	Concentrate	156.7	5.8	**207.56**	76.16	0.00	31.02	104.40	**211.59**	0.00	0.00	0.00	0.00	0.00	38.79	457.94	30.74	**548.06**	**792.23**
Bald Hill	Australia	Concentrate	51.1	6.0	**562.35**	65.19	0.00	14.33	33.70	**113.22**	0.00	0.00	0.00	0.00	0.00	57.53	733.09	27.00	**805.44**	**913.63**
Cachoeira	Brazil	Concentrate / Carbonate / Hydroxide	1.8	71.4	**1,190.97**	501.24	0.00	60.95	266.81	**829.00**	573.24	172.10	172.20	796.02	**1,713.56**	30.06	3,763.59	0.00	**3,868.67**	**5,116.36**
Alvarroes	Portugal	Concentrate	20.0	2.5	**84.45**	36.38	0.00	3.51	19.10	**58.99**	0.00	0.00	0.00	0.00	0.00	30.15	173.59	0.00	**173.59**	**187.93**
Bikita	Zimbabwe	Concentrate	60.0	4.2	**70.67**	64.14	0.00	4.13	6.99	**75.25**	0.00	0.00	0.00	0.00	0.00	47.43	193.35	0.00	**215.50**	**231.89**
Salar de Atacama	Chile	Carbonate	38.2	99.5	0.00	0.00	0.00	0.00	0.00	0.00	272.78	1,480.41	281.63	1,599.26	**3,634.07**	59.65	3,693.72	29.88	**4,470.93**	**5,122.66**
Salar de Atacama	Chile	Hydroxide / Chloride	51.1	94.7	0.00	0.00	0.00	0.00	0.00	0.00	244.41	1,471.34	267.20	1,756.66	**3,739.61**	59.65	3,799.27	36.93	**7,040.67**	**8,736.87**
Salar de Olaroz	Argentina	Carbonate	12.5	99.5	0.00	0.00	0.00	0.00	0.00	0.00	535.24	1,898.93	240.89	1,036.24	**3,711.29**	105.47	3,816.76	41.20	**4,583.53**	**5,286.81**
Salar del Hombre Muerto	Argentina	Carbonate / Chloride	22.2	99.5	0.00	0.00	0.00	0.00	0.00	0.00	512.42	1,759.08	431.19	570.22	**3,272.91**	105.47	3,378.37	41.20	**3,870.37**	**4,048.00**
Silver Peak	USA	Carbonate	5.9	99.5	0.00	0.00	0.00	0.00	0.00	0.00	1,720.09	2,538.16	1,491.49	706.40	**6,456.14**	14.96	6,471.11	0.00	**6,785.50**	**7,410.79**
West Taijinair	China	Carbonate	1.0	99.0	0.00	0.00	0.00	0.00	0.00	0.00	2,072.25	4,956.07	2,990.16	3,205.79	**13,224.27**	116.61	13,340.88	0.00	**14,850.89**	**17,243.08**
Zhabuye	China	Carbonate	8.0	99.0	0.00	0.00	0.00	0.00	0.00	0.00	346.48	3,131.97	570.61	615.38	**4,664.44**	191.41	4,855.85	0.00	**6,359.12**	**8,044.03**
Chaerhan Lake	China	Carbonate	10.0	99.0	0.00	0.00	0.00	0.00	0.00	0.00	669.12	4,842.30	2,255.47	978.84	**8,745.73**	116.61	8,862.33	0.00	**10,375.25**	**11,179.56**
East Taijinair	China	Carbonate	2.0	99.0	0.00	0.00	0.00	0.00	0.00	0.00	840.02	4,714.89	1,193.52	1,457.54	**8,205.98**	116.61	8,322.58	0.00	**9,832.59**	**10,796.62**

Source : S&P Global Market Intelligence

LITHIUM CONCLUSIONS

- Demand is driven largely by the EV market;
  - Likely to remain the battery type of choice but substitution is possible,
  - Demand predicted to peak by early 2030's, and
  - Removal of subsidies by China will have depressive effects – **already apparent**!
- Already a large Resource base and good possibilities of additional exploration finds
- Diverse space with slow to develop but low operating cost Salar deposits, versus "agile" but higher cost pegmatite Projects
- Agility wins as long as demand outstrips supply but Salar's lower costs will allowing project survival if oversupply happens and lithium prices drop, consider Alita and Pilbara Minerals difficulties.
- Security of supply factors may allow developments that would otherwise be impossible

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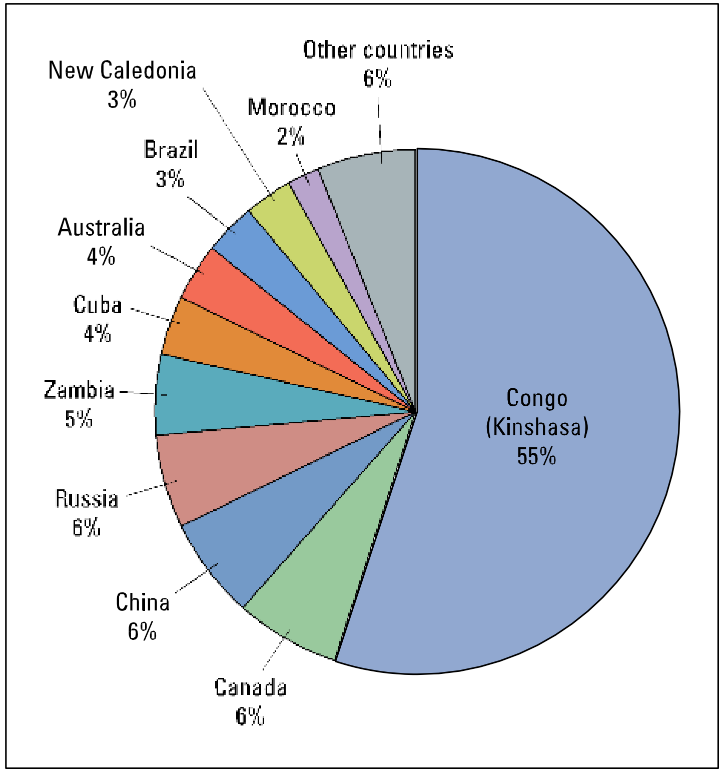
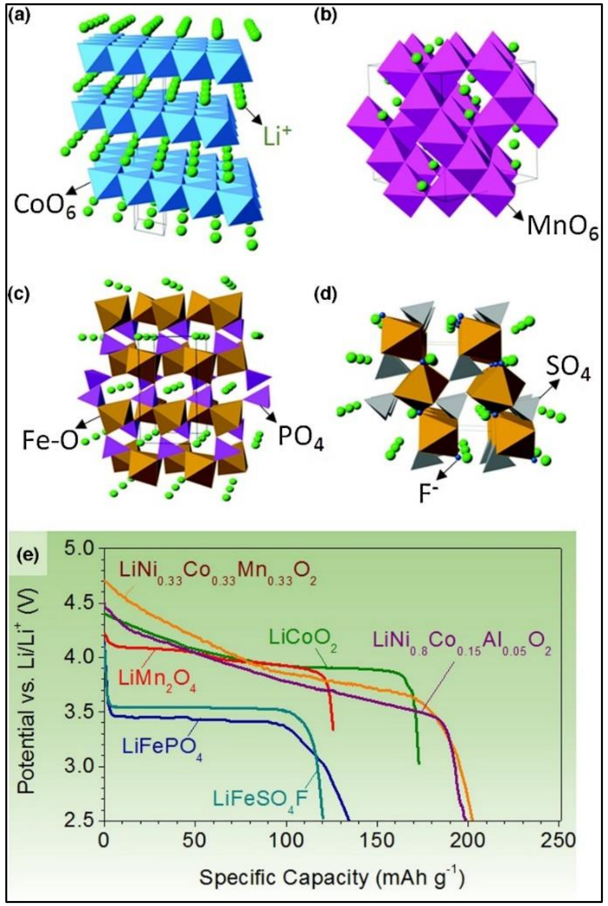
COBALT GEOLOGY

COBALT

WHAT'S IMPORTANT

- Cobalt - cathode stability in high performance batteries
  - Lithium battery cathodes are intercalation compounds,
  - Lithium atoms in and out - structure does not change,
  - Co changes oxidation state if Li leaves or enters keeping the electrochemical potential cathode neutral,
  - Cheaper elements e.g. Ni can substitute for Co but fires/explosions possible - O_2 generation from cathode O layer,
  - Al and Mn used to fix the O_2 - small loss of voltage. Tesla/Panasonic uses NCA chemistry, NCM is common.
- Cobalt has a "bad wrap"
  - Expensive
  - DRC (55% of Production in 2017)
  - Social and Political unrest
- Much Cobalt production is by-product - DRC producers quickly transitioned to higher Co outputs





Source : Li-ion battery materials present and future, Materials Today June 2015

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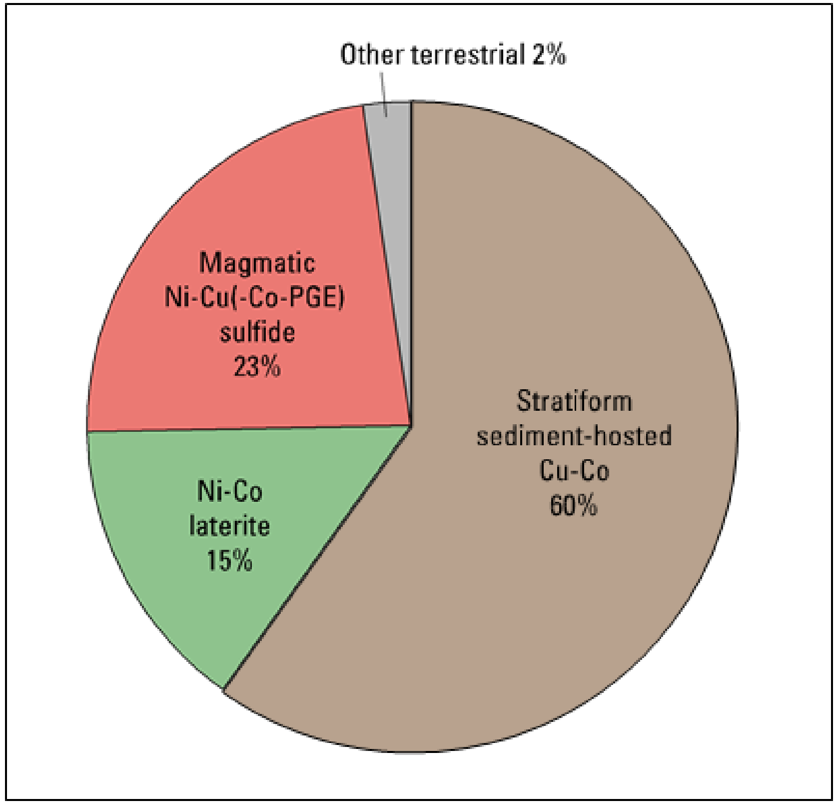
COBALT

DEPOSIT TYPES

- Three main deposit types;
  - DRC style copper/cobalt belt deposits,
  - Laterites, and
  - By-product of Ni-Cu-(PGEs) sulphide mining.
- Stratiform sediment-hosted Copper/Cobalt belt deposits;
  - 55% of cobalt production,
  - Meta-sediment hosted veins and disseminations,
  - Variable deposit sizes and grades,
  - Much of the current production from oxidised deposits; less capital (still substantial) to process,
  - Artisanal production part of feed, majority of ore buying by Chinese, a “wild west” situation,
  - Political risk and unreliable infrastructure.
- Ni-Cu-(PGEs) sulphides
  - Production tightly tied to the main output elements
- Laterites
  - Huge potential resource for Cobalt, but
  - Mostly extracted for Fe/Ni for the steel industry.
  - Cobalt from HPAL but Projects, - complex materials handling and clarification issues.
- Many other occurrence types
  - Submarine nodules and crusts (the largest accumulation of Co on the planet)
  - Syn-sedimentary and (or) diagenetic (a spectrum of types)
  - Co-Cu-Au deposits in metasedimentary rocks
  - Iron oxide-copper-gold (IOCG) deposits
  - Five-element vein deposits (Ag-Ni-Co-As-Bi) (Kissin, 1992)
  - Hydrothermal deposits associated with ultramafic rocks



Source : USGS, Report 2017–1155

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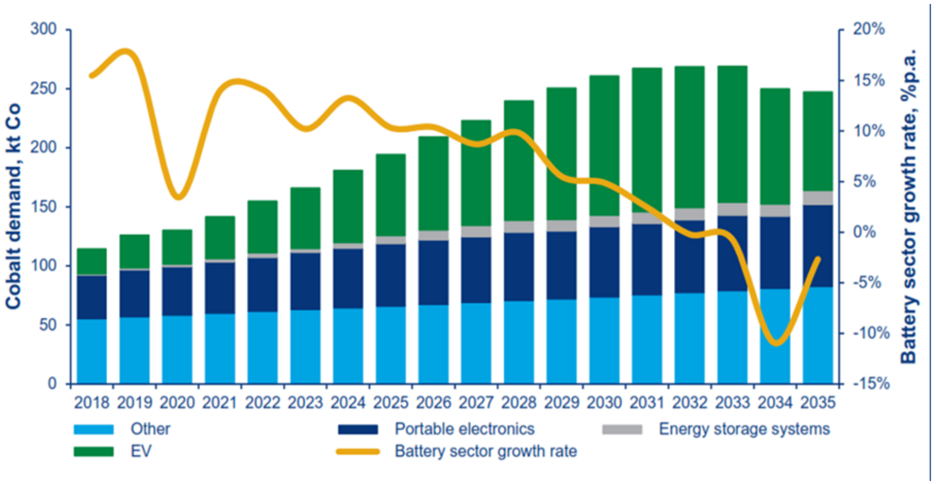
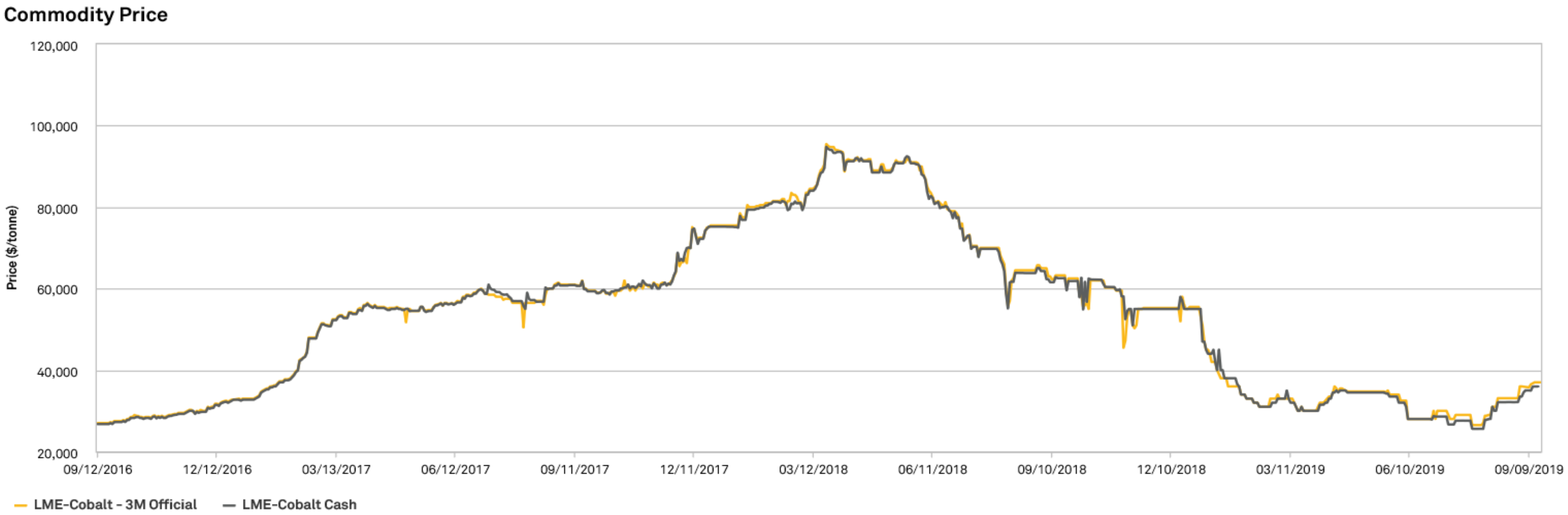
COBALT

WHAT TO MARKET / WHAT TO BUY

- Quick projects. Predicted cobalt offtake peak early 2030’s – risks - decreased contents, substitution, alternatives and bad press.
- Will Co get another run?
- Depends on where the EV “revolution” goes??
- China is removing subsidies on EVs;
  - Reduced by 60% in 2018; midsize and large > 400 km range - 10% boost.
  - Another 67% compared with 2018 in 2019
  - Plans to remove subsidies completely after 2020.



Source : Wood Mackenzie



Source : S&P Global Market Intelligence

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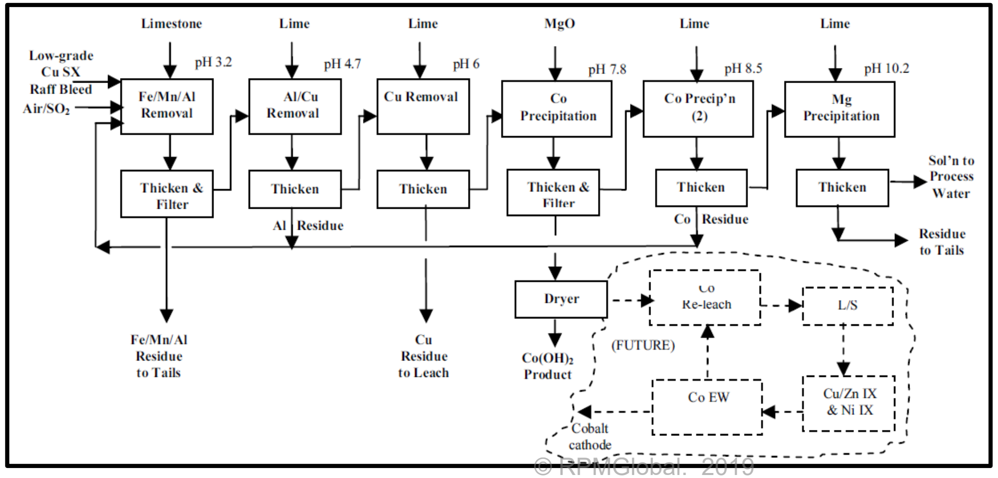
COBALT PROCESSING

COBALT PROCESSING

OXIDE ORES : NICKEL AND COPPER

- **Background**
  - Cobalt typically a by-product of either nickel or copper
  - Either as a *nickel-cobalt laterite (*e.g. Murrin Murrin WA and Greenvale QLD) or as a *weathered 'oxide' zone of a copper-cobalt deposit* (DRC)
  - Sulphuric acid leaching is employed which is relatively non-selective…dissolves much of the ore including the aluminium and iron minerals
  - Moderate to very high acid consumptions : 20kg-400kg/t
- **Flowsheet**
  - **Nickel-cobalt laterite**
    - Acid leaching, often needs to be under pressure, viz. HPAL, followed by a refinery where impurities are removed by precipitation (Fe, Al, Si, Mg)
    - Cobalt and nickel are either precipitated as a bulk product (hydroxides or sulphides) for further processing or processed to yield separate products e.g. nickel and cobalt sulphate or nickel metal
  - **Copper-cobalt 'oxide' ores**
    - Acid leaching, conventional solvent extraction / electrowinning [SX/EW – product is LME Grade A copper cathode]
    - Cobalt - precipitation of the impurities (Fe, Al, Mn, Al) and recovery of the cobalt as an hydroxide or sulphate (occasionally electrowon as the metal)



Source : Fisher, 2011, SAIMM

COBALT PROCESSING

OXIDES ORES : NICKEL AND COPPER

- **Processing Issues**
  - Abundance of acid consuming minerals…limestone, dolomite, siderite, apatite,…
    - Copper-cobalt ores employ sulphidisation-flotation flowsheet
  - Significant amounts of manganese: usually cobalt mineralogy (e.g. heterogenite) or pyrolusite (MnO_2)
  - Unreactive copper mineralogy e.g. some forms of chrysocolla (copper silicate)
  - Fine materials (e.g. clays) - viscosity and dewatering

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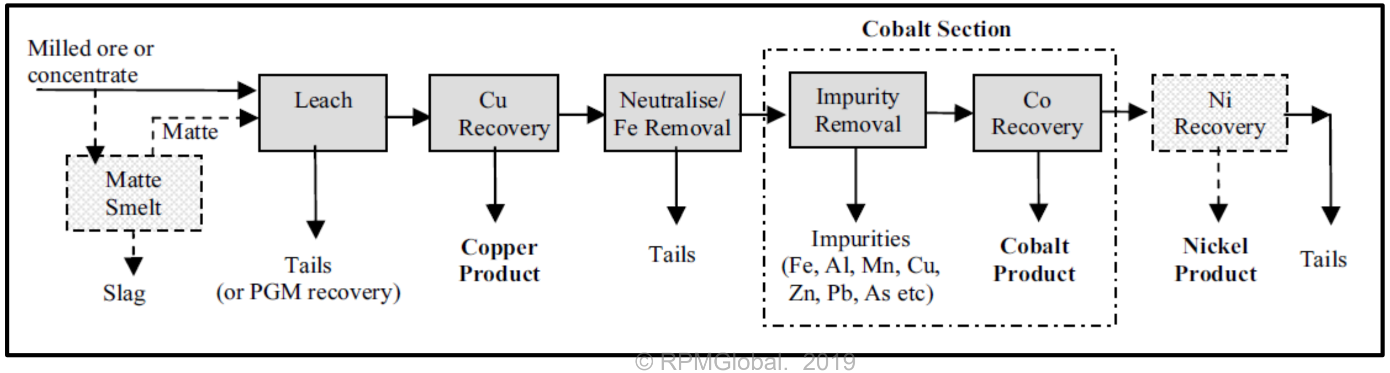
COBALT PROCESSING

SULPHIDE/ARSENIDE ORES : COBALT, NICKEL AND COPPER

- **Background**
  - Cobalt arsenide ores tend to be specific to North America
  - Nickel-copper-cobalt sulphide ores - Canada, Russia, Australia and China
  - Copper-cobalt sulphide ores - DRC (underlie copper-cobalt oxide ores)
  - Pyrite (solid solution)
- **Flowsheet**
  - **Cobalt arsenides**
    - Concentrated by flotation
    - Ferric leaching with sulphuric acid of the concentrate (precipitates scorodite – benign form of arsenic), followed by purification and recovery of the cobalt as a sulphate/hydroxide
  - **Nickel-copper-cobalt sulphides**
    - Concentrated by flotation
    - Smelted to produce a nickel-copper-cobalt matte
    - Typically leached with ammonia (Sherritt Gordon process) followed by precipitation to remove impurities and recovery of the cobalt as a sulphate/hydroxide



Source : Fisher, 2011, SAIMM

COBALT PROCESSING

SULPHIDE/ARSENIDE ORES : COBALT, NICKEL AND COPPER

- ***Flowsheet cont'd***
  - **Copper-cobalt sulphide ores**
    - Concentrated by flotation
    - Partial roasting to form sulphates
    - Application of a conventional copper-cobalt oxide flowsheet i.e. SX/EW, etcetera
  - **Pyrite (iron sulphide) ores**
    - Concentrated by gravity and flotation
    - Need to oxidise (e.g. roasting, ferric leaching e.g. bacterial leaching) to solubilise and release the cobalt
    - Remove impurities – precipitation and solvent extraction
    - Recover cobalt through either crystallisation (cobalt sulphate) or precipitation (cobalt sulphate)
- **Developments**
  - Presence of manganese is main problem
    - Resin in Pulp : promising – selective over Mn, Mg
    - Selectivity improvements in Solvent Extraction (pH control issues)
    - Ion Exchange (Molecular Recognition Technology – MRT) : promising (specific element removal) however requires more development

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COBALT 2018 PRODUCTION COSTS

Laterite	
Oxide	
Sulphide	

- Not overly informative data – no standard methodology for reporting by-product costs. Main take-away message is that it generally appears to be much cheaper to produce cobalt from ‘oxide’ ores (yellow), followed by ‘sulphide’ ores (green) and then ‘laterite’ ores (purple).

Property	Country	Equity Owner(s) (Ownership %)	Paid Cobalt (kt)	Cost (USD Cents/lb)						
				Labour	Power	Reagents	Other On-site	TC/RC + Shipment	Royalty	Total Cash Cost
Ruashi	Dem. Rep. Congo	Jinchuan Group International Resources Co. Ltd. (75.00) Gécamines SA (25.00)	4.20	260.20	141.99	190.83	80.16	0.00	134.09	807.27
Norilsk	Russia	PJSC Norilsk Nickel Co. (100.00)	3.20	207.06	17.62	10.83	76.56	708.91	49.45	1,070.43
Deerni	China	Zijin Mining Group Co. Ltd. (100.00)	1.00	213.66	173.63	15.82	201.44	618.70	140.81	1,364.07
Sudbury Operations	Canada	Glencore PLC (100.00)	0.40	448.52	95.00	13.54	505.50	491.30	0.00	1,553.86
Eagle	USA	Lundin Mining Corp. (100.00)	0.50	468.20	48.07	25.88	243.88	550.04	218.12	1,554.19
Mutanda SX-EW	Dem. Rep. Congo	Glencore PLC (100.00)	27.30	103.83	275.19	413.23	289.95	323.32	163.23	1,568.75
Zimplats	Zimbabwe	Zimplats Holdings Ltd. (100.00)	0.10	426.83	313.58	48.44	619.31	180.00	79.57	1,667.73
Voisey's Bay	Canada	Vale SA (100.00)	1.80	209.29	127.33	43.03	325.21	903.99	75.95	1,684.80
Kalatongke	China	Xinjiang Xinxin Mining Industry Co. Ltd. (100.00)	0.00	283.90	228.96	59.83	422.74	623.03	75.71	1,694.16
Moa Bay	Cuba	Sherritt International Corp. (50.00) General Nickel Co SA	3.20	17.87	220.76	645.73	584.39	285.34	0.00	1,754.10
Kevitsa	Finland	Boliden AB (100.00)	0.30	244.66	185.09	45.79	157.62	1,154.44	0.00	1,787.59
Sichuan La-La	China	China State-Owned Mining Enterprise (100.00)	0.10	125.41	347.93	65.25	322.36	618.90	327.74	1,807.59
Bafokeng-Rasimone	South Africa	Royal Bafokeng Platinum Ltd. (100.00)	0.10	1,105.38	136.61	140.00	449.06	2.13	13.15	1,846.33
Kamoto SX-EW	Dem. Rep. Congo	Katanga Mining Ltd. (75.00) Democratic Republic of the Congo (25.00)	11.10	149.91	604.31	132.77	673.23	12.70	291.84	1,864.76
Tenke Fungurume	Dem. Rep. Congo	China Molybdenum Co. Ltd. (56.00) BHR Newwood Investment Management Ltd. (24.00) Gécamines SA (20.00)	18.70	90.17	290.35	336.73	756.03	314.25	86.25	1,873.79
Taganito	Philippines	Nickel Asia Corp. (65.00) Pacific Metals Co. Ltd. (33.50) Sojitz Corp. (1.50)	3.10	88.34	170.14	342.95	436.35	838.74	0.00	1,876.53
Leinster	Australia	BHP Group (100.00)	0.10	382.95	132.11	12.59	107.92	1,285.25	12.98	1,933.81
Tulaergen	China	China State-Owned Mining Enterprise (100.00)	0.10	336.71	353.68	92.63	379.59	719.67	109.43	1,991.71
Trojan	Zimbabwe	Bindura Nickel Corp. Ltd. (100.00)	0.10	321.36	126.51	24.67	260.93	1,152.97	111.04	1,997.48
Jinchuan	China	Jinchuan Group Co. Ltd. (100.00)	1.60	558.32	96.42	11.96	165.36	1,168.24	39.97	2,040.28
Nova-Bollinger	Australia	Independence Group NL (100.00)	0.70	326.68	117.28	22.53	151.76	1,404.82	72.05	2,095.13

Property	Country	Equity Owner(s) (Ownership %)	Paid Cobalt (kt)	Cost (USD Cents/lb)						
				Labour	Power	Reagents	Other On-site	TC/RC + Shipment	Royalty	Total Cash Cost
Ramu	Papua New Guinea	Metallurgical Corp. of China Ltd. (56.97) Jilin Jien Nickel Industry Co. Ltd. (11.05) Jiuquan Iron & Steel (Group) Co. Ltd. (11.05) Highlands Pacific Ltd. (8.56) Jinchuan Group International Resources Co. Ltd. (5.93) Mineral Resources Development Corp. (3.94) Local Interest (2.50)	3.30	122.82	202.64	284.75	607.99	849.43	48.02	2,115.66
Punta Gorda	Cuba	Cubaniquel (100.00)	0.60	32.36	265.83	1,254.83	228.99	353.33	0.00	2,135.35
Terrafame	Finland	Terrafame Oy (100.00)	0.40	292.56	195.26	872.05	286.90	533.56	0.00	2,180.32
Forrestania	Australia	Western Areas Ltd. (100.00)	0.00	425.94	62.26	26.72	151.39	1,443.63	74.69	2,184.63
Manitoba Division	Canada	Vale SA (100.00)	0.20	751.70	87.72	37.41	509.39	867.51	0.00	2,253.73
Raglan	Canada	Glencore PLC (100.00)	0.50	551.17	180.74	14.95	933.86	434.76	142.70	2,258.18
Mimosa	Zimbabwe	Impala Platinum Holdings Ltd. (50.00) Sibanye Gold Ltd. (50.00)	0.20	252.74	240.20	118.31	1,224.36	351.07	87.48	2,274.16
Rio Tuba	Philippines	Nickel Asia Corp. (60.00) Pacific Metals Co. Ltd. (36.00) Sojitz Corp. (4.00)	1.50	185.92	155.54	626.53	485.70	840.83	0.00	2,294.51
Mt Keith	Australia	BHP Group (100.00)	0.20	341.18	404.61	48.86	189.80	1,335.60	37.64	2,357.70
Kylylahti	Finland	Boliden AB (100.00)	0.00	1,247.23	303.39	39.62	899.27	115.66	0.00	2,605.16
Murrin Murrin	Australia	Glencore PLC (100.00)	3.20	509.34	480.71	689.98	597.90	170.67	158.82	2,607.42
Ambatovy	Madagascar	Sumitomo Corp. (47.67) Korea Resources Corp. (22.50) Private Interest (12.83) Sherritt International Corp. (12.00) POSCO (2.73) STX Corp. (1.00)	2.90	846.70	297.66	622.90	689.74	129.22	59.40	2,645.61
Ontario Division	Canada	Vale SA (100.00)	0.50	825.99	94.98	55.87	823.40	949.02	0.00	2,749.26
Goro	New Caledonia	Vale SA (95.00) SPMSC (5.00)	1.90	287.83	297.66	1,186.23	258.79	718.83	0.00	2,749.34
Nchanga	Zambia	Volcan Investments Ltd. (79.40) ZCCM Investments Holdings PLC (20.60)	0.20	1,079.66	204.84	119.74	506.83	699.60	214.43	2,825.11
Nkomati	South Africa	African Rainbow Minerals Ltd. (50.00) PJSC Norilsk Nickel Co. (50.00)	0.30	1,114.55	278.97	172.92	427.73	1,121.76	2.34	3,118.28
Alex	China	Xinjiang Xinxin Mining Industry Co. Ltd. (100.00)	0.00	457.73	274.80	130.23	445.32	1,609.90	389.77	3,307.75
SLN	New Caledonia	Eramet (56.00) Société Territoriale Calédonienne de Participation Industrielle (34.00) Nippon Steel Nisshin Co. Ltd. (10.00)	0.30	633.81	1,049.57	132.69	733.32	761.00	0.00	3,310.39

Source : S&P Global Market Intelligence

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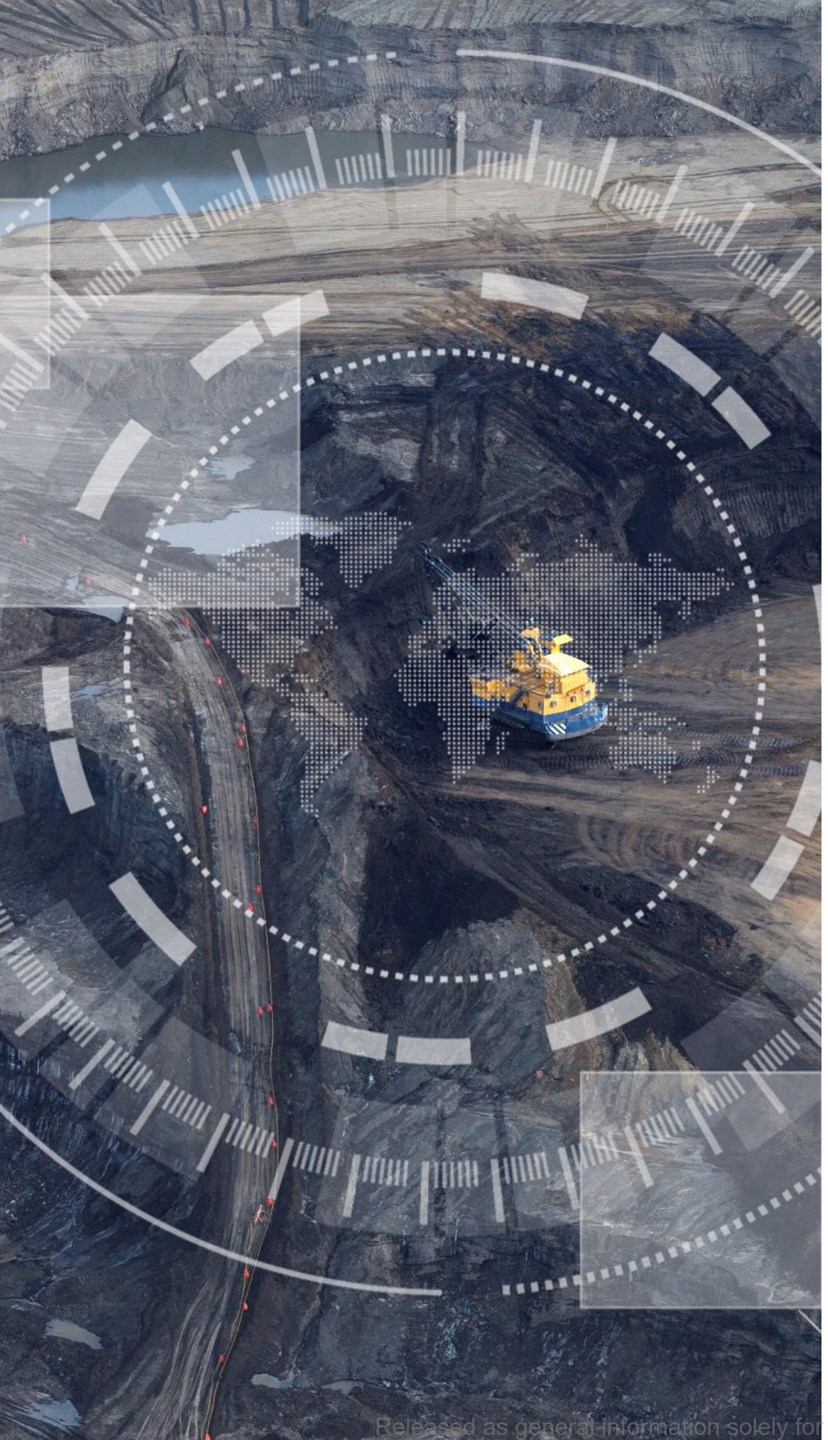

COBALT CONCLUSIONS

- Global Cobalt supply is dominated by production from the DRC. This has geopolitical risks and does not consistently meet current “ethically sourced” guidelines for some consumers
- Substitution, decreased contents and subsidy removal are likely to impact on offtakes and price
- Potential for large laterite sources but requires large capital investment in a volatile market

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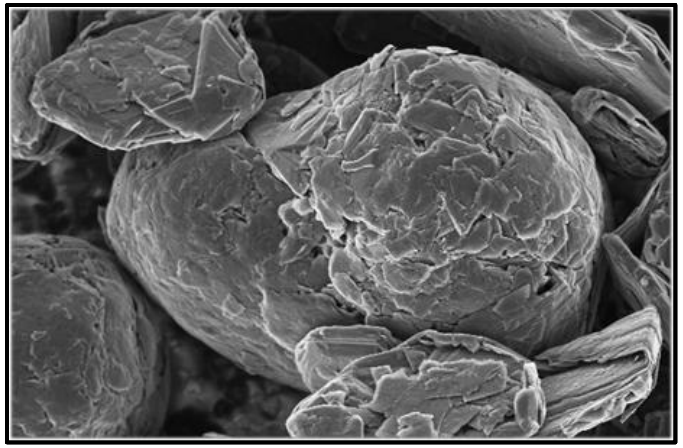
GRAPHITE GEOLOGY

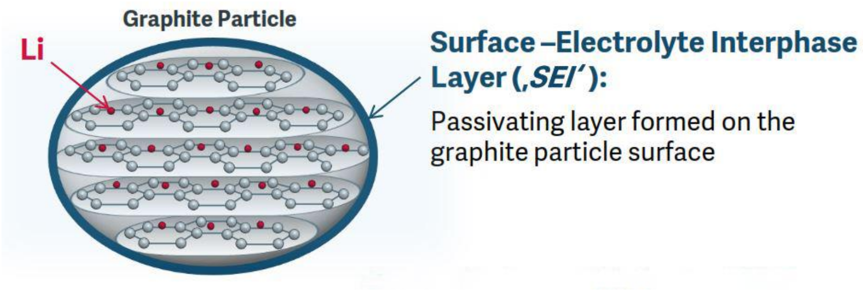
GRAPHITE

Basics

- Natural or synthetic graphite for battery anodes?
- Large flakes are not necessarily a guarantee of good battery properties; relevant properties include;
  - Product purity (low Fe, Ca, S, Si, Ni, Zn, Cr, Al, Cu, V are very important)
  - Tap density (density of tapped powdered graphite indicates how much can be packed into an anode, shape important, target approx. 1g/cc)
  - BET surface area (the surface area of the graphite powder lower the better <5 m^2/g is good)
  - Reversible capacity (the charge that can be taken and reversed for the graphite, mAh/g, theoretical maximum of 372)
  - Irreversible capacity (the charge taken on the first cycle but never reversed, mAh/g, as low as possible , 5 is relatively good)
  - D002 (degree of graphitisation and interlayer spacing, ideal is 0.3354nm)

Spherical Graphite





Source : Graphite Powder Processing, SGL Group, Nov 2014

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GRAPHITE

Deposit Characteristics

- Natural battery graphite occurs in flake graphite deposits
- High grade metasedimentary rocks - thermal metamorphism of organic material in the original sedimentary rocks
- Typical graphite grades range from 4% to 20% Cg
- Sizes range from a few to 100's of million tonnes
- World Resource and Reserves > 800Mt of recoverable! (USGS 2017)
- Planar to folded and faulted - great impact on the mineability of the deposit
- Flake size, grade and impurities can vary significantly across a deposit

Source : RPMGlobal

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GRAPHITE

Good Battery Graphite

- Some projects are being characterised only by flake size and grade, however are being promoted for battery usage without a full understanding of their suitability as a battery anodes
- Investors : if a graphite property is promoted as a battery mineral feed ask for the product battery relevant property testing results
- Geologists : do ‘sighter’ (exploratory) tests on these properties on selected samples earlier rather than later in a property’s life so that suitability is not an assumption
- While ‘sighter’ tests should be completed ASAP, it is unreasonable to expect full product specification at the Resource stage. There should be statements in the Resource announcement commenting on the stage of investigation and risk

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GRAPHITE

Future and Risks

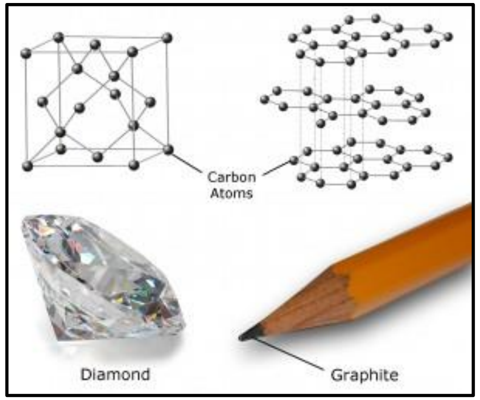
- The Resources / Reserves and Exploration potential are HUGE!
- Future over production?
- Good project characteristics include:
  - Early producer projects
  - Low cost jurisdictions, good infrastructure and low political/social risks
  - Near surface and simple geometry projects
  - Good battery graphite properties - test early
  - Off-take agreements with major consumers
  - A team that knows what they are doing in this space
- Most are typical mining industry risks, however there needs to be a strong emphasis on off-take and product characteristics

GRAPHITE PROCESSING

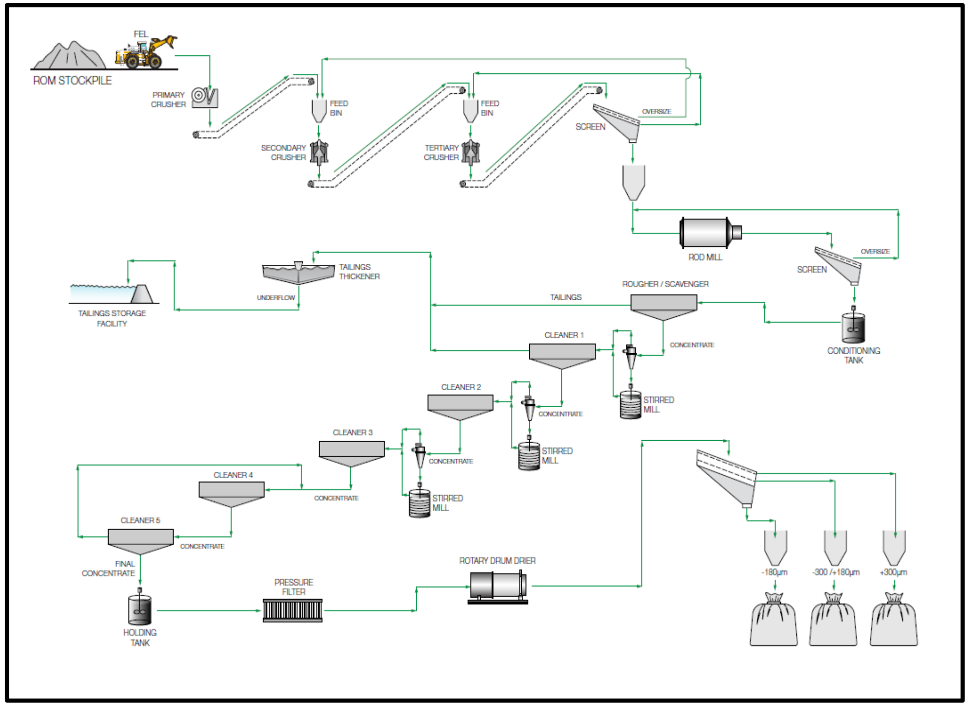
GRAPHITE PROCESSING

EXTRACTION FROM THE ORE

- An allotrope of carbon – so already pure
- Mineralogy : mainly associated 'silicates' with occasionally pyrite
- Flotation is used to separate graphite from other minerals present
  - Graphite is a natural 'floater' – water repellant surface (hydrophobic)
  - Flotation enhanced with the addition of a hydrocarbon (kerosene, diesel oil, etc.)
  - Several stages flotation are used in conjunction with attritioning of the intermediate concentrates
    - Removing impurities (e.g. silica and occasionally pyrite) form the edges of the graphite flakes
  - Silica depressants often employed in latter stages of cleaning
- Maintenance of flake size is important
  - Premium for larger flakes arises from tendency to have fewer impurities
    - higher grade and less downstream processing required
  - Several stages of size reduction typically employed : three stages of crushing followed by rod milling
  - Classification (sizing) is important – screening used where ores have coarser flake sizes
- Aim to produce a concentrate >94% Cg as coarse as possible



Source : American Welding Society website



Source : RPMGlobal

GRAPHITE PROCESSING

ORE EXTRACTION ISSUES

- Fine mineralogy requires a fine grind size
  - Slower floating : larger circuit (capex)
  - Depressants may be required (control silica and pyrite)
  - More stages of cleaning (>4/5)
    - Not readily amenable to column cleaning
- Secondary/weathered ores
  - Presence of clay
  - May require de-sliming
  - Lower slurry density : larger circuit (capex)
- Not easy to manage processing circuit
  - Unlike base metal sulphide separations :
    - No On-Stream Analysis (OSA) available
    - Difficult to run by 'eye'
  - Require constant feed properties and a quick final concentrate assessment technique
- Processing flowsheets could be more sophisticated
  - Dedicated cleaning circuits for different streams (based on size)
  - Other adaptations from base metal sulphide flotation flowsheets

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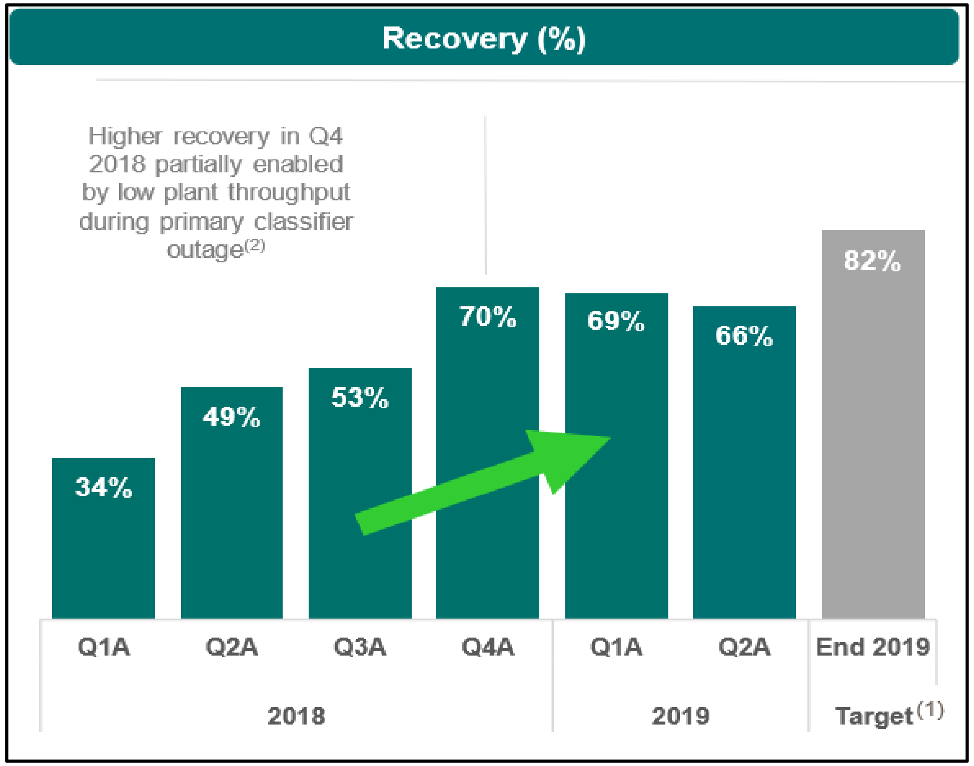
GRAPHITE PROCESSING

TROUBLES IN PARADISE?

- Quick to production in late 2017
- Nearly two years on, still unable to meet Feasibility Study projections
- Recently upgraded the processing plant
- Experienced problems with equipment (including fires), throughput, recovery and concentrate grade



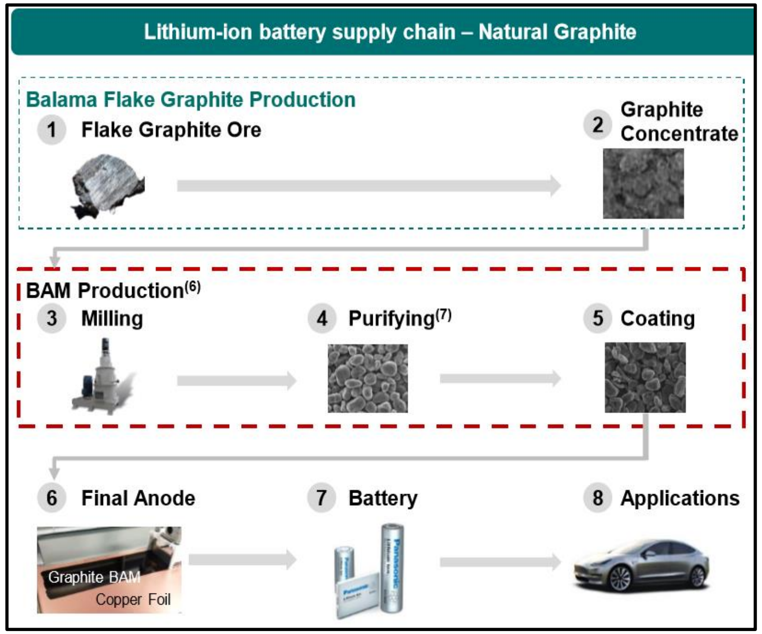
Source : Syrah Presentation, Diggers and Dealers, August 2019

GRAPHITE PROCESSING

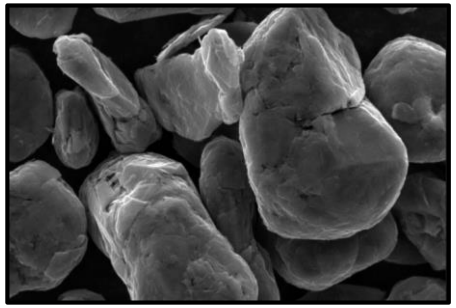
DOWNSTREAM PROCESSING

- Battery market requires specific properties

  : Purity (>99.99+% Cg) and size (<20 microns : surface area and packing density)
- Concentrate is subjected to spheriodisation
  - Graphite flakes converted to a spherical shape by blasting particles against each other at high speed using air
  - Numerous stages; product very fine, typically less than 20 microns
  - Increases purity : typically >97% Cg
  - Yield is important : Chinese typically achieve 20% final product, 80% carbon black; Syrah believe that they can achieve 50% with coarser feed
- Leaching
  - Two stages : remove silica and any sulphides
  - Commonly undertaken on spheroidised product but sometimes prior to spheroidisation
  - Silica : historically hydrofluoric acid; typically caustic digestion; extraction with chlorine gas proposed
  - Sulphides (mainly pyrite) : nitric acid
- Surface treatment
  - Proprietary process
  - Surface coating (carbon source)



Source : Syrah, website



Source : Superior Graphite, website (field 20 microns)

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GRAPHITE CONCLUSIONS

- Battery commodity demand is dynamic – predictions are uncertain
- Graphite product properties should be addressed at an early stage of exploration to find whether there are reasonable expectations for battery use
- Large graphite Resources exist; there is a race to production with the potential for eventual over supply
- There have been some notable failures in graphite operations
- As for all mining ventures, there is a need to cautiously assess all aspects of a project, including the management

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THANK YOU

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