



# **DERA Industrieworkshop Lithium Batterierohstoffe für Lithiumionenbatterien**

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- Founded 1895
- More than 100 years experience in industrial and specialty minerals processing
- Family owned
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High Purity Alumina – Niobium and Tantalum – Clay Minerals - Feldspar - Fluorspar





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**M.Plan International Limited at Bay Street, Toronto**



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- Micon International Limited (Micon)
- Dorfner Anzaplan (Anzaplan)

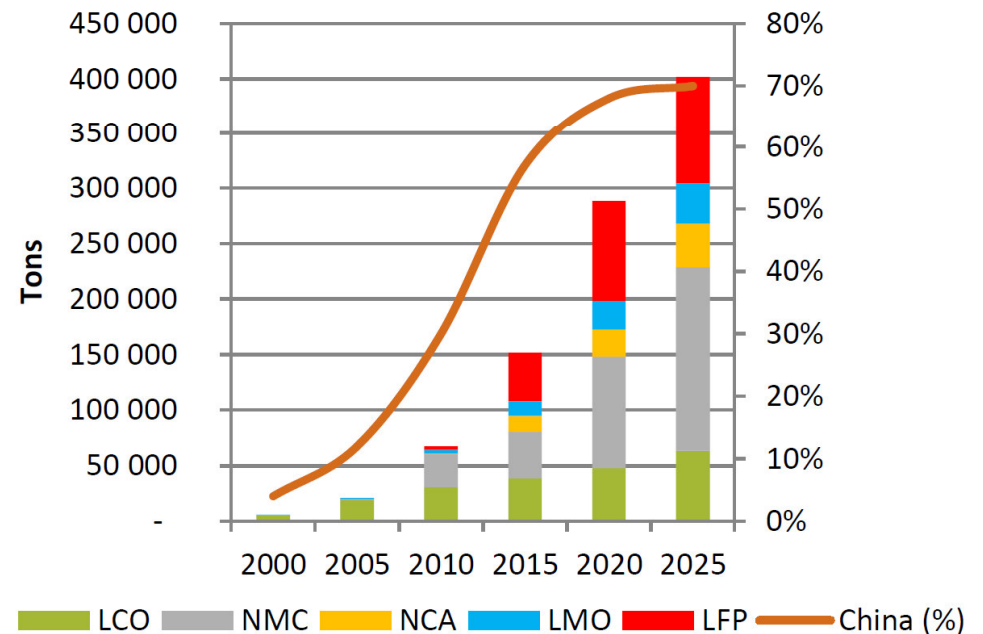
have combined their knowledge and expertise in M.PLAN International Ltd. ([www.mplaninternational.com](http://www.mplaninternational.com)) to support the seamless development of industrial minerals, specialty minerals and rare metals projects from prospect to final product specification.



# LIBattery Raw Materials

## Nickel, Lithium, Cobalt, Manganese, Alumina and Graphite

- Cathode
  - LCO -  $\text{LiCoO}_2$  (Tablets, Smartphones)
  - NCA -  $\text{Li}[\text{Ni}_x\text{Co}_y\text{Al}_z]\text{O}_2$  (Tesla S)
  - NMC -  $\text{Li}[\text{Ni}_x\text{Mn}_y\text{Co}_z]\text{O}_2$  (BMW, Mitsubishi, Toyota, Honda ...)
  - LMO -  $\text{LiMn}_2\text{O}_4$  (z.B. BMW, Nissan)
  - LFP -  $\text{LiFePO}_4$  (e-buses, industrial)
- Anode
  - **Graphite** - spherical/natural and synthetic
- Separator
  - High Purity **Alumina** (HPA)



Source: Avicoenne Energy 2017

## Demand Scenario

### Strong growth of specialty minerals and metals in batteries

Year	LCE (t)	Co (t)	Natural Cg (t)	Mn (t)	Ni (t)	Al (t)
	All	Battery	Battery	Battery	Battery	Battery
2015	193,750	53,043	55,194	34,546	15,934	200
2020	304,767	89,316	103,081	51,670	32,881	463
2025	399,760	120,660	156,312	58,871	54,595	838

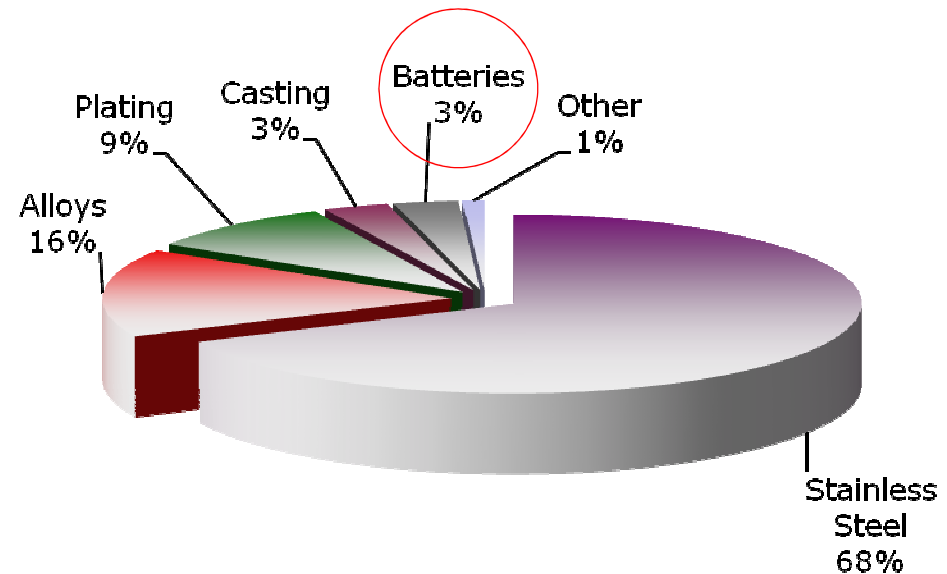
Source: Stormcrow (2016)

- From 1990 to 2015 the share of **Cobalt** used in the batteries market increased from 1% to 49%.
- World consumption of **Lithium** compounds is expected to increase from 178 kt (2015) to 328 kt LCE (Roskill Base Case) up to 534 kt LCE (Deutsche Bank) in 2025.
- In Batteries demand for **Graphite** is set to grow up to three fold.
- NMC battery technology (111) drives demand in **Nickel** chemicals (532-622-811).

## Nickel

### How important is the battery market for Nickel mines ?

- Mine output for Nickel in 2016 is 1.986 kt (S&P), forecast to stay flat at 2.092 kt in 2019.
- Over two-thirds of nickel is used in stainless steel, the primary focus of nickel producers.
- Nickel for batteries represents only a 3-4% of the market, with the majority still used in NiMH and NiCd batteries.
- But: Batteries having a 71% share in nickel chemicals consumed.

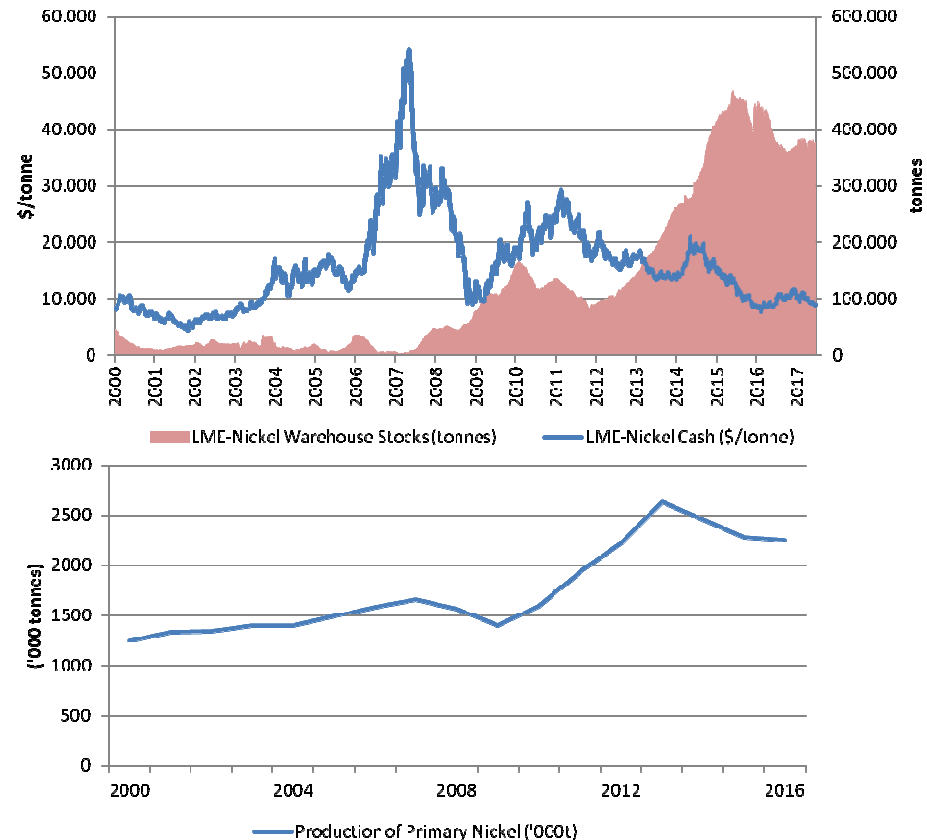




# Nickel

## Nickel production under pressure

- After consecutive price crashes in 2007, 2011 and 2014 nickel price slips from 9.638 USD/t average in 2016 to 8.910 USD/t mid June 2017.
- World mine production January to April was 574 kt, down by 60 kt on the same period last year (Argus).
- LME warehouse stock is 377 kt (June 2017).
- Over 70% of Cobalt producing nickel mines were losing money in 2015/2016.
- A series of nickel operations have since been put on care and maintenance amid low prices.

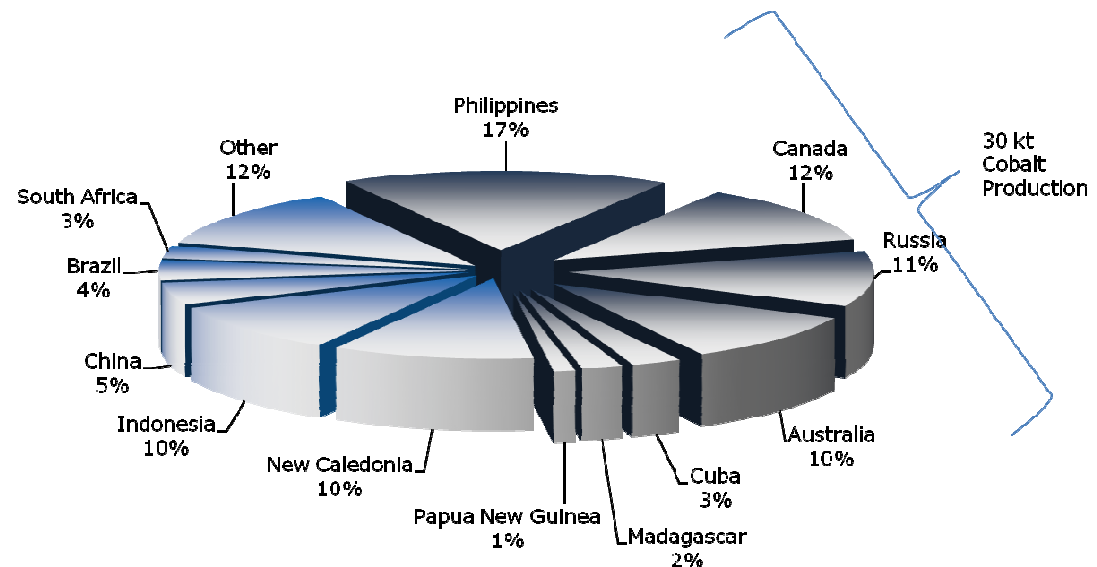


Sources: USGS, S&P Global (SNL) 2017

# Nickel

## Limited attention for Cobalt by-products

- Cobalt output from primary Nickel sources is only 30 kt or **1,4%** from 1.986 kt (2016) total Nickel production.
- However, 30 kt of cobalt means almost **one third** of overall cobalt supply is from nickel mines.
- Thus, nickel production is of high importance for cobalt supply but cobalt by-product is of far less significance for primary nickel mines.



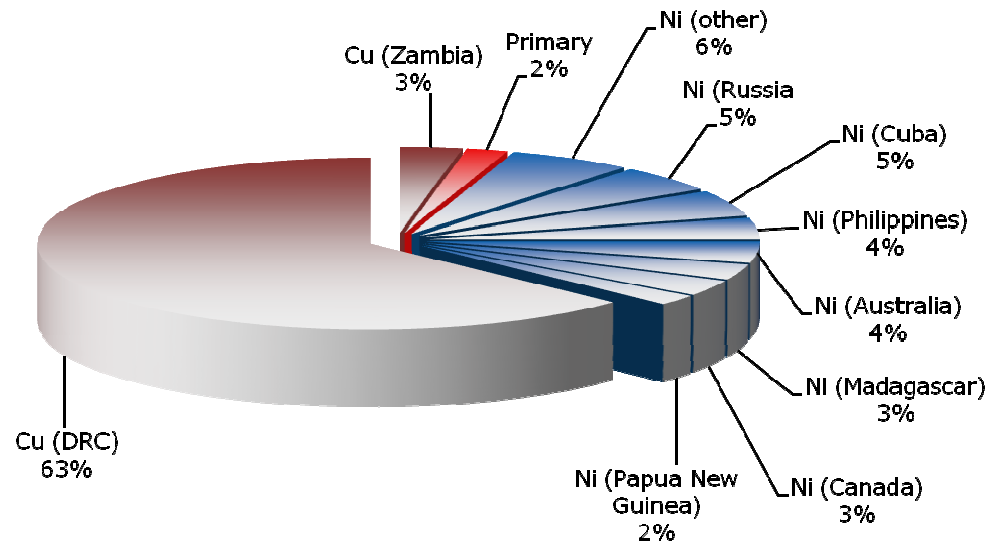
**Total nickel mine output 2016: 1.986 kt**

Source: S&P Global (SNL) 2017

# Cobalt Supply

## By-product from Nickel and Copper mines

- Primary cobalt supply is led by copper mining in the DRC.
- Nickel sources are more widespread and balanced.
- Only one primary cobalt mine is in production (Bou Azzer/ Morocco) with limited supply.

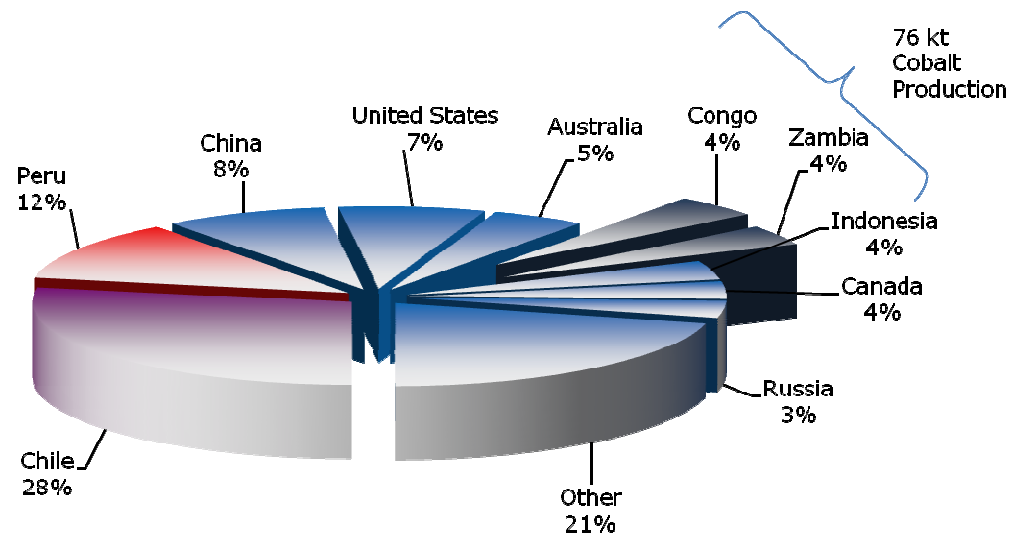


Source: Argus 2017

## Cobalt supply in the context of copper production

Only few Copper producing countries recover Cobalt as by-product

- **Mine output for Copper** in 2016 is 19.917 kt (S&P 05/2017) forecast to rise moderately to 20.971 kt in 2019; prices may rise in this period from 4.868 to 6.347 USD/t.
- Cobalt output from primary copper sources is only 76 kt or **0,38%** of mined copper and thus insignificant for most copper producers.
- Supply is highly inflexible in the short run, and even in the long run because cobalt is recovered as a by-product.
- Producers cannot significantly adjust cobalt output quickly to respond to changing market conditions.



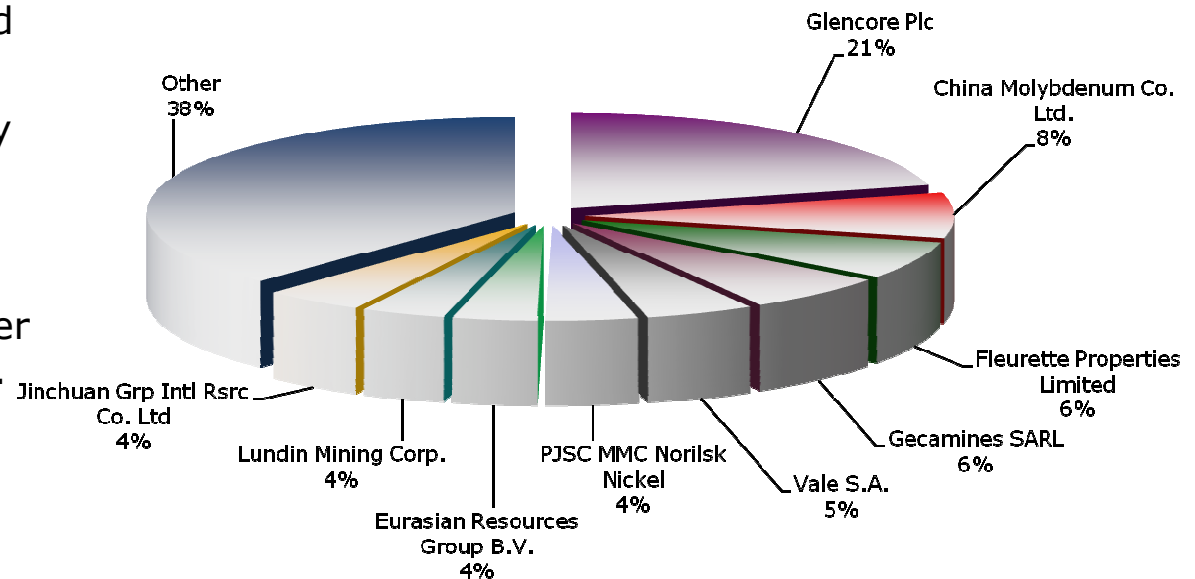
**Total copper mine output 2016: 19.917 kt**

Source: S&P Global (SNL) 2017

## Global Mined Cobalt

### The Majors (2016)

- Mine production is dominated by a couple of major players
- Supply chain is dominated by the DRC (mining) and China (refining).
- In 2016 Glencore's Mutanda was the largest single supplier of cobalt, 34% of DRC share.
- Just followed by China Molybdenum's recently acquired Tenke Fungurume mine, 22% of DRC share.



Source: S&P Global (SNL) 2017



## Cobalt Supply

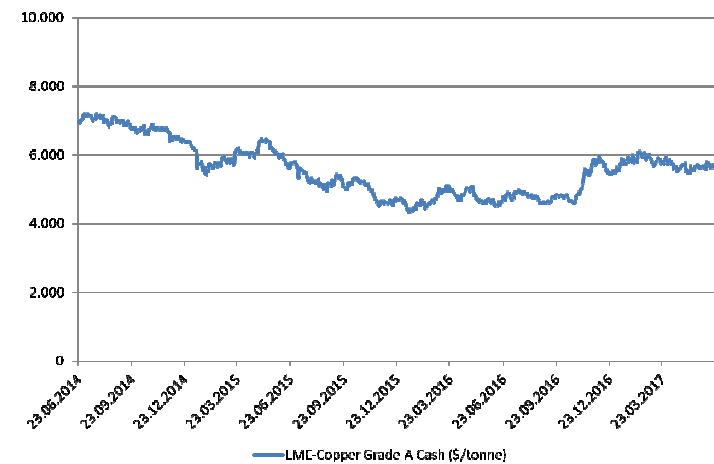
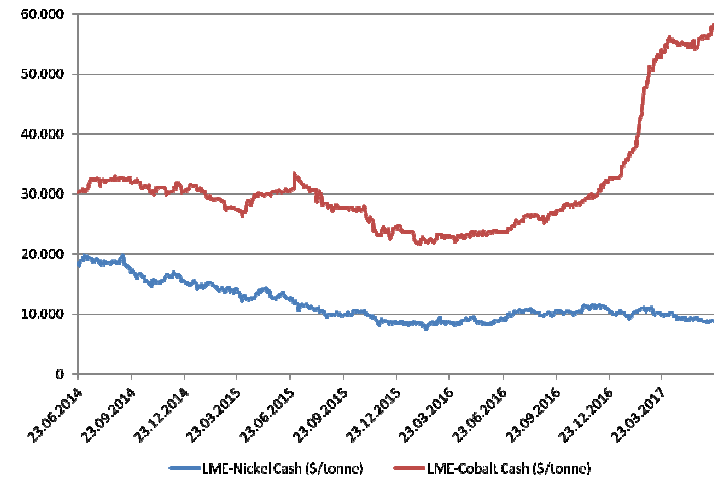
### The majors move

- In February 2017, **Glencore** purchased the remaining 31% stake in the Mutanda Cobalt deposit and a 10.25% stake of Katanga Mining from **Fleurette Properties Limited**. After paying USD 0.96 billion the major miner now owns 100 percent of Mutanda Mining and about 86.33% of Katanga Mining (TSX:KAT).
- In November 2016, **Freeport-McMoRan Inc.** announced the completion of the sale of its 70 percent interest in TF Holdings Limited ("TFHL") to **China Molybdenum Co., Ltd.** for USD 2.65 billion in cash. TFHL is a Bermuda holding company that indirectly owns an 80 percent interest in Tenke Fungurume Mining S.A. (DRC).
- Near term expect value to remain distributed along the supply chain from DRC as **Glencore's** Katanga mine and **Eurasian Resources Group** (ERG) tailings reprocessing operation in the DRC, the Metalkol Roan Tailings Reclamation project (RTR), will increase supply in 2018 and end 2019 and refining expansion is underway in China.

# Cobalt Supply

## The majors move

- Large Ni laterite projects continue to ramp up such as Goro, Ramu River, Ambatovy, Taganito.
- New satellite operations including Sicominex, Kamoya, Nova-Bollinger, El Boleo, Mwambashi, are scheduled to come online.
- Kamoya recently started ore commissioning, Nova-Bollinger reporting 93% complete construction.
- Schedule is somewhat dependent upon nickel and copper prices with copper prices fairing better than nickel (some Co production may be taken offline).
- If predicted demand is realized, longer term bottleneck will be primary production.

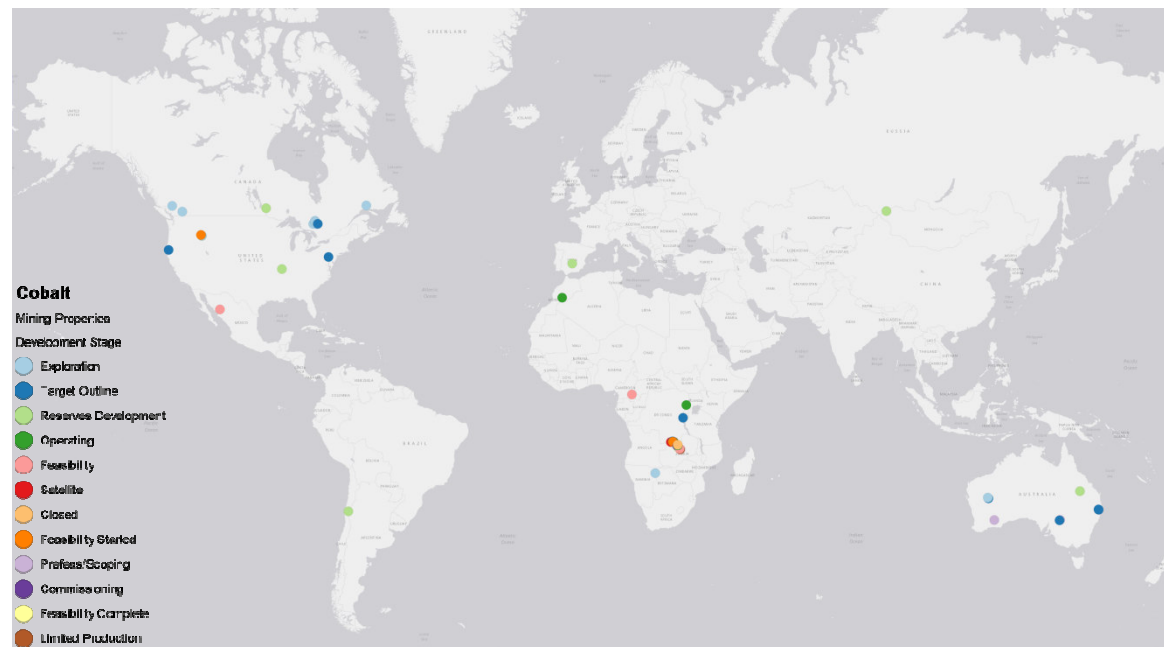


Source: S&P Global 06-2017

# Cobalt Supply

## The next wave

- Today 46 primary cobalt projects worldwide are trying to enter the cobalt supply space.
- Hot spots are located in North America, Africa and Australia.
- eCobalt Solutions (Idaho) and Fortune Minerals (NICO) are the most advanced (almost) single play cobalt juniors.



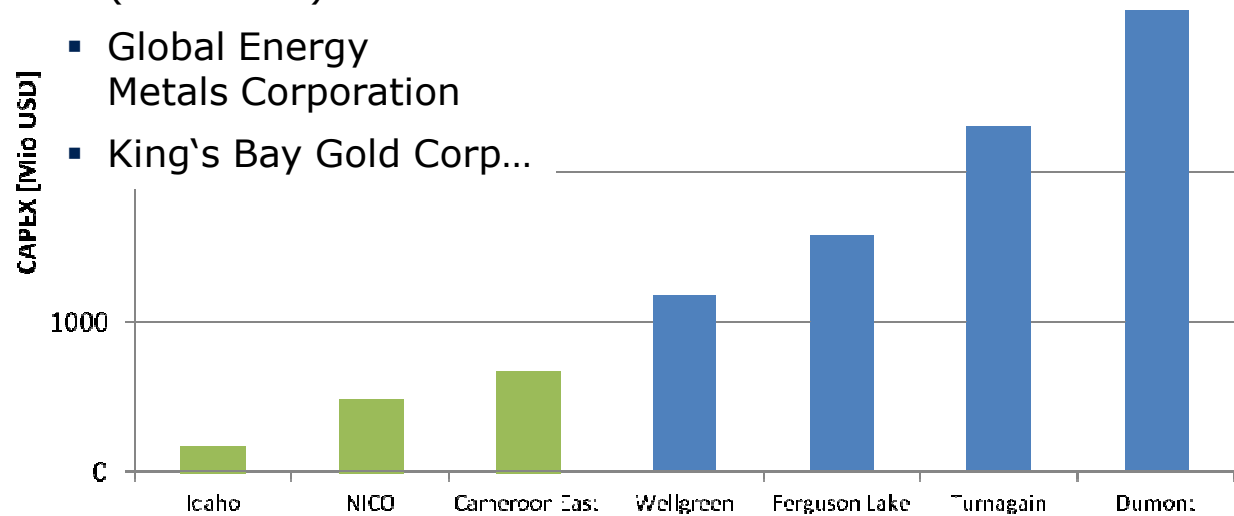
Source: S&P Global (SNL) 02-2017

# Cobalt Supply

## Next wave of projects at an advanced stage

- Fortune Minerals
- eCobalt
- Geovic Mining Corporation
- CleanTeq Holdings (Syerston) Ni-Sc-Co
- Hard Creek Nickel Corp
- Wellgreen Platinum
- Canadian North Res
- RNC Minerals (Dumont)
- Ardea Resources Ltd.
- Aeon Metals Limited

- LiCo Energy Metals
- Platina Resources (Owendale) Sc-Co
- Global Energy Metals Corporation
- King's Bay Gold Corp...

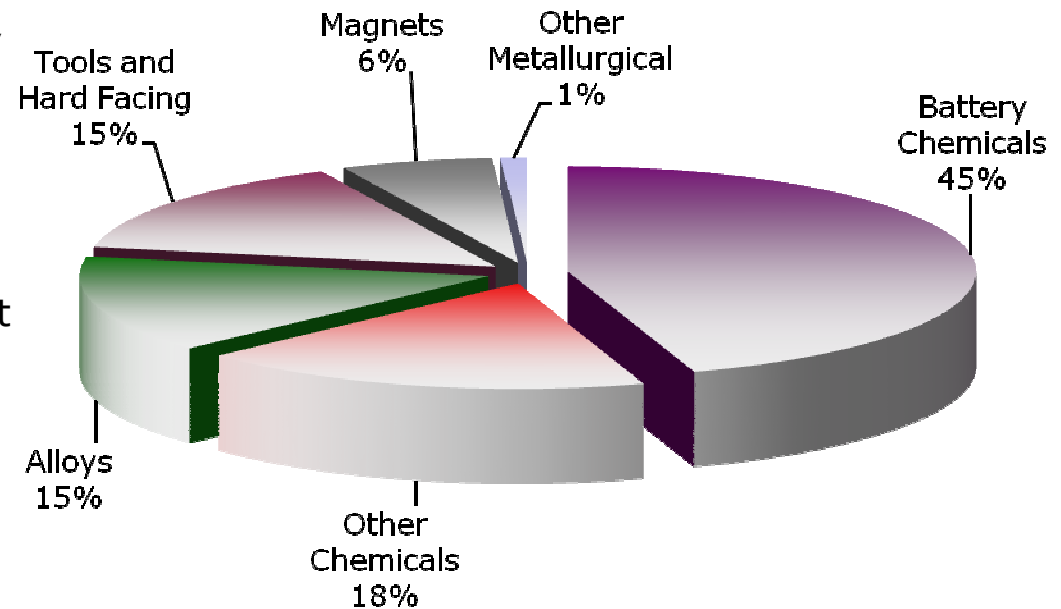


Source: Corporate Presentations & Economic Studies 05-2017

## Cobalt Applications

### Non metallurgical (chemical) uses dominate

- Mined cobalt is refined largely by Chinese facilities (Huayou Cobalt, GEM Group, Jinchuan Corp.) and Western companies such as:
  - Freeport Cobalt (Kokkola, FIN),
  - Glencore (Nikkelverk, NOR),
  - Umicore (Belgium)
- Cobalt for metallurgical uses account for 37% in 2016 and include super alloys while non-met uses (63% in 2016) include batteries.
- Cobalt consumption in batteries is set to rise from 53 kt (2015) to 120 kt (2025).





# Cobalt Supply

## Refineries: Cobalt chemicals for batteries

- **Cobalt Hydroxide** is produced for the manufacture of **NiCd** and **NiMH** cells, which are used in a range of applications including portable electronics and electric vehicles
- **Cobalt sulphate** is predominantly used in **NCA and NMC cells**, which are used in EVs and power tools.
- **Cobalt oxide** is predominantly used in the manufacture of **LCO batteries**, which are used for laptops, cellphones, etc.

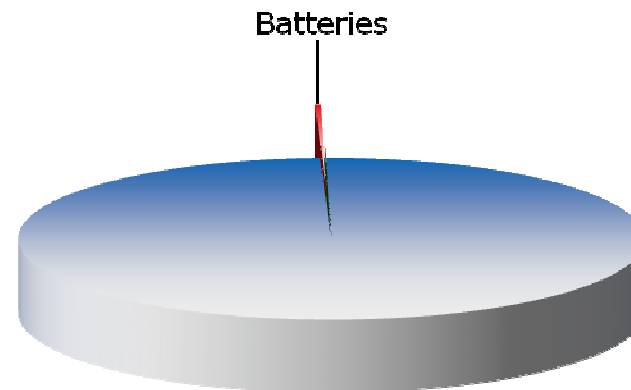
Battery (NMC/NCA) Grade Cobalt Sulphate Material Specifications		
Element	Chinese National Standards GB/T 26523 - 2011	Typical Battery Grade Cobalt Sulphate
Co	20-20.5%	20.50%
Ca	50-500 ppm	50 -100 ppm
Cd	10-50 ppm	≤5 ppm
Cu	10-50 ppm	≤20 ppm
Fe	10-50 ppm	≤20 ppm
K	n/a	50-100 ppm
Mg	200-500ppm	50-100 ppm
Mn	10-50 ppm	<5 ppm
Na	n/a	50-100 ppm
Pb	10-50 ppm	≤10 ppm
pH	4.5 - 6.5	5.6-6.8
Zn	10-50 ppm	≤50 ppm

Source: Demand for nickel chemicals; Roskill 2015

## Manganese

### No worries

- Global Mn-production is about 18 Mt today (mainly for the steel industry).
- An estimated 50kt for batteries is not of concern assuming there is sufficient capacity to make electrolytic manganese dioxide.



Source: Stormcrow 2016

# Lithium

## Facts and Figures

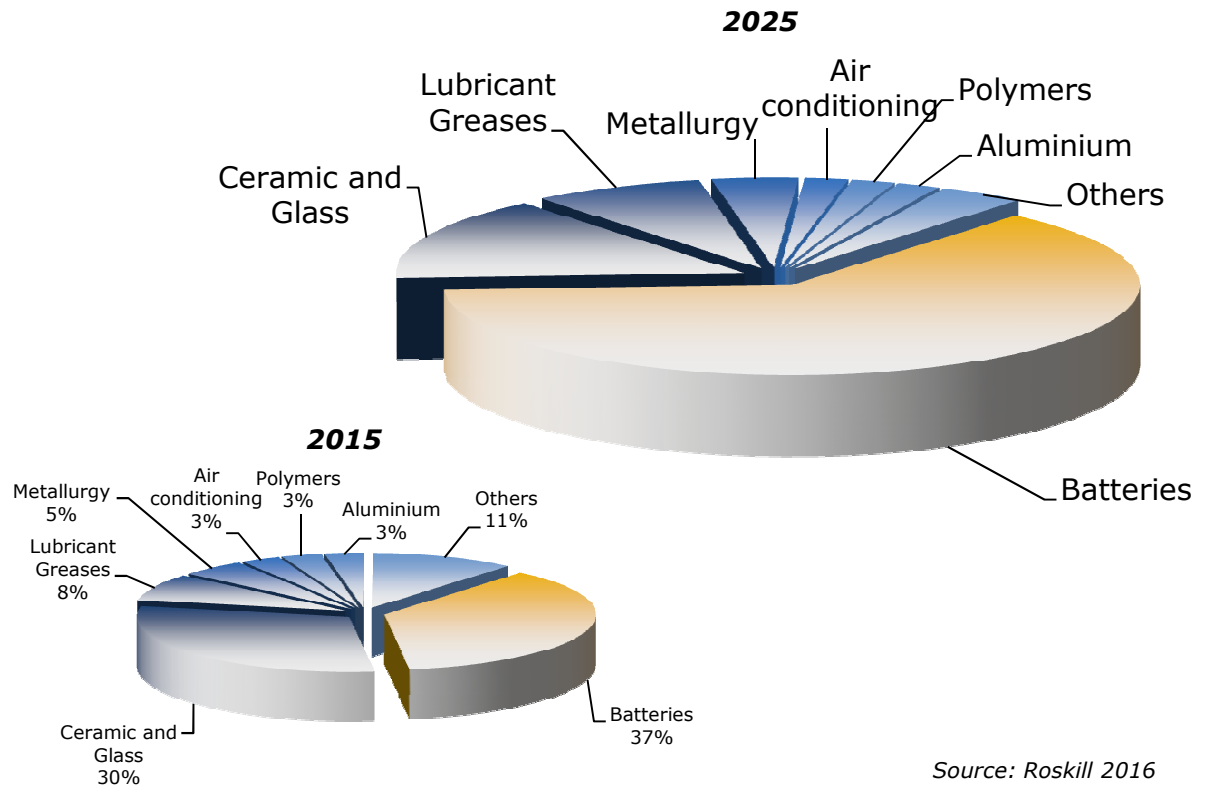
- **Source:**
  - brine and hard rock deposits
- (Single play) fertilizer, niobium-tantalum/add-on
- Main markets: glas, ceramics and batteries (chemicals)
- Two main battery products:  $\text{Li}_2\text{CO}_3$  and  $\text{LiOH}$
- Overall market size (LCE): 195.000 t, B2B
- Technology shift:
  - a)  $\text{Li-OH}$  becomes more prominent in high performance (high nickel) batteries
  - b)  $\text{Li-OH}$  processing by electrolysis (Nemaska, Neometals)
  - c) Alternative mineral sources under investigation (petalite, lepidolite, zinnwaldite and clays)



# Lithium Demand by Application

## Energy storage become the dominant application

- Growth in lithium consumption is significant with batteries accounting for +60% of global demand in 2025.
- Overall CAGR for Lithium from 2013 to 2025 is 6,4% (Roskill 2016).
- The rechargeable battery sector is forecast to register a CAGR of 10,8% (12.6% by Stormcrow) through 2025, while traditional markets follow gross GDP (3-4%).



Source: Roskill 2016

# Lithium

## Processing Brines and Hard Rocks

Innovations address:

- Direct Extraction from Salars to reduce processing time and avoid large scale precipitation pond investment.
- Direct Li-OH processing of hard rock leach by electrolysis.
- Processing of less energy intensive or higher grade feed minerals.

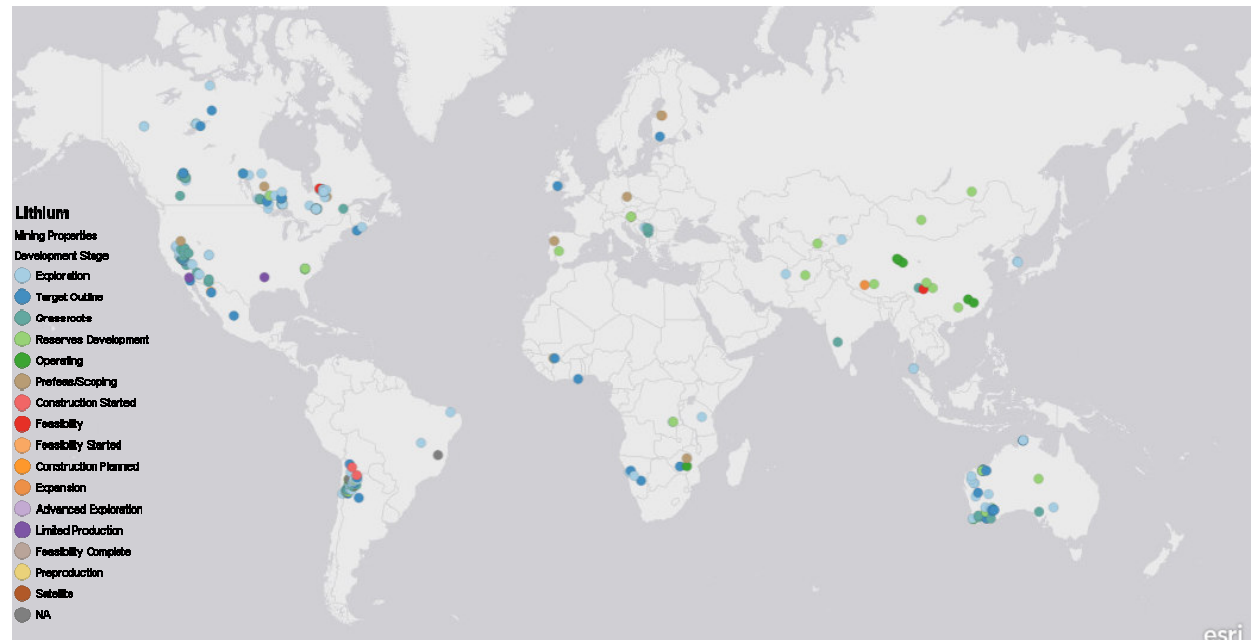
Deposit	Lithium Brine (Salars)	Spodumene Ore (Hard Rock)
Process	<ul style="list-style-type: none"> <li>• Pumping</li> <li>• lithium enrichment by solar evaporation</li> <li>• Concentrated brine solutions are processed to produce <math>\text{Li}_2\text{CO}_3</math> and <math>\text{LiOH}</math></li> </ul>	<ul style="list-style-type: none"> <li>• Comminution</li> <li>• Mineral concentration</li> <li>• Calcination/roasting</li> <li>• Leaching</li> <li>• Leach solutions are processed to produce <math>\text{Li}_2\text{CO}_3</math> and/or <math>\text{LiOH}</math></li> </ul>



# Supply

## Active lithium projects worldwide

- Hard rock deposits are widespread, including in Europe.
- In contrast, *brine resources* are locally concentrated due to their specific genesis and climatic requirements.
- Hot spots are located in Canada, Nevada, South America and Western Australia and Africa.

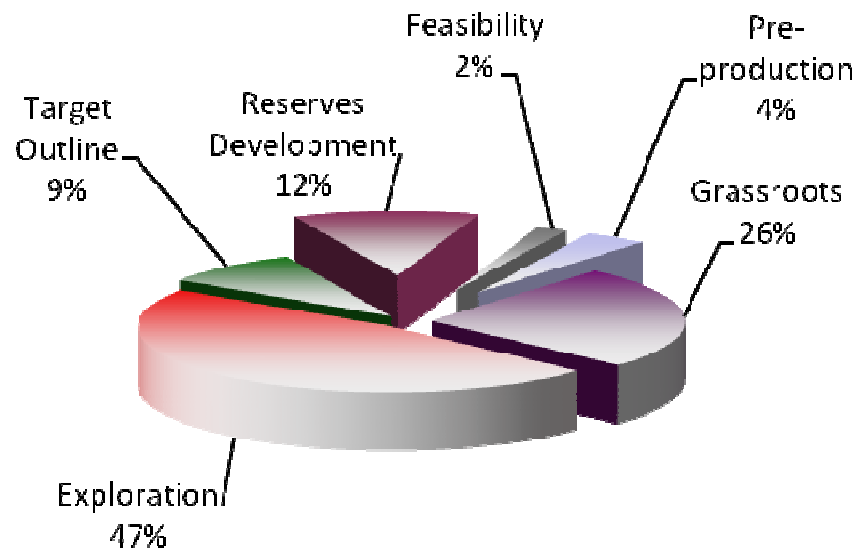


Source: S&P Global (SNL) 02-2017

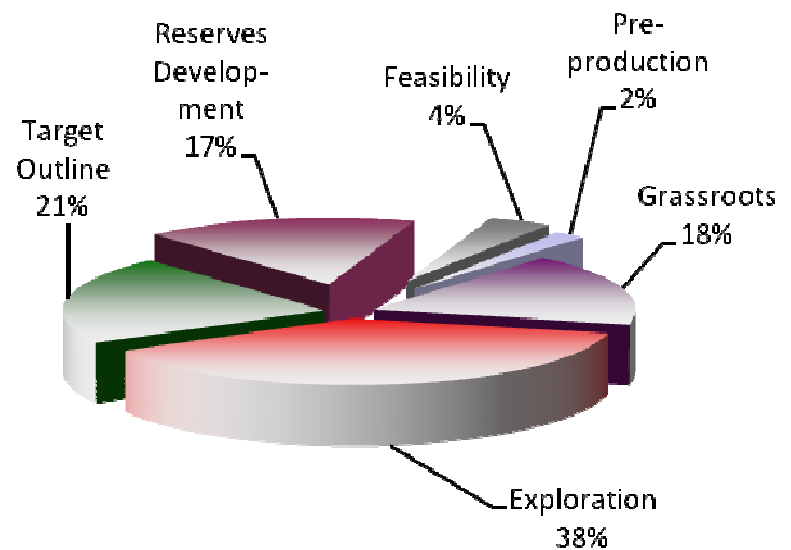
# Supply

## Development stages of Lithium projects worldwide

**Brines**



**Hard Rock**

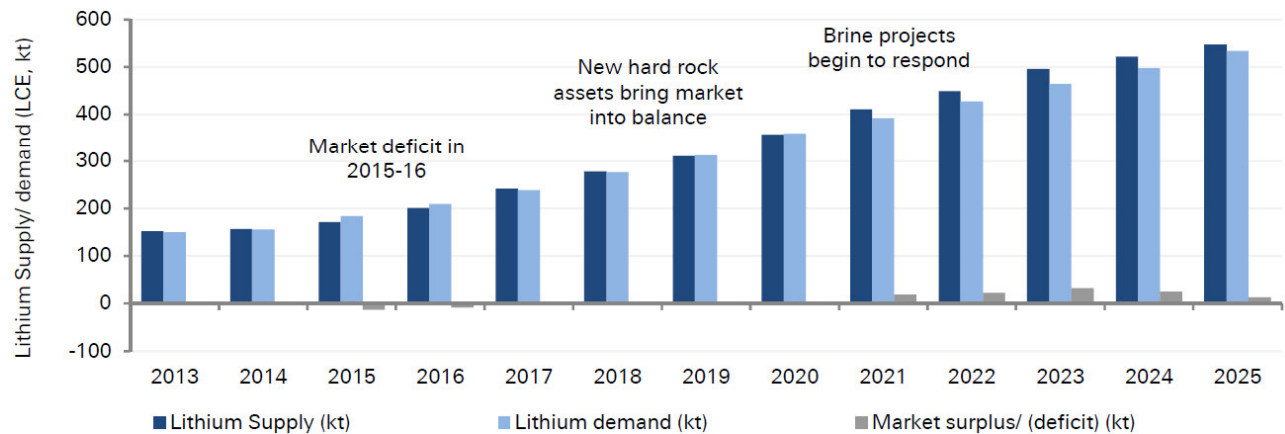


Data by S&P Global (SNL) 10-2016

# Lithium Balance

## Scenarios – one example

- Most scenarios forecast **hard rock deposits responding earlier** than brine resources to bring market into balance.
- This graph is just one example with several variations by different market research organizations.
- Taking into account reasonable utility rates market is in **tight balance until 2020** probably with a market surplus afterwards.



Source: Deutsche Bank 2016

## Lithium Demand by Application

### Traditional markets face competition

- Important traditional markets, however, specifically in the glass and ceramics industries, mainly rely on Li-mineral concentrates (spodumene and petalite) – especially at low iron (technical grade).
- Only a limited number of deposits worldwide are able to deliver low iron lithium minerals while offering enough reserves.
- Today glass ceramic sector faces concentration on only one deposit for low iron spodumene (Greenbushes/ Australia) and one for petalite (Bikita/Zimbabwe).
- Lithium minerals conversion phases increasing supply risks in mineral concentrates for this industry.



Source: Schott AG

## Lithium Supply

### The majors move

- November 2016, Albemarle and CORFO signed a contract modification including
  - Construction of new plant for battery grade lithium carbonate (Plant 3).
  - Fixed a new extractive lithium quote (262,132 t Li).
  - Establish a 27 year period for the expiration of exploitation rights (2017 –2044).
  - Option to build a lithium hydroxide plant (5,000 t).
- In January 2017 **Albemarle** finalized the acquisition of a 15,000 tpa lithium salt plant in China, with upgrade and expansion plans to 25,000 tpa lithium hydroxide by 2018.
- In February 2016 **Albemarle** was granted the long-awaited permit to increase its lithium brine extraction rate at its operations in Chile associated with a new, **20 kt lithium carbonate production plant at La Negra.**



## Lithium Supply

### The majors move

- March 2016 Chile's **Sociedad Química y Minera de Chile (SQM)** announced it would be entering a joint venture with **Lithium Americas** to own a 50% stake in **the Cauchari-Olaroz** lithium project in Jujuy, Argentina. An updated feasibility study will follow a staged approach **with 20 kt expanded to 40 kt per annum LCE** over time.
- September 2016 the company also announced its intend to **increase the lithium hydroxide capacity by 7,5 kt** by the end of 2017 to double its current production.
- In August **FMC**, the third major brine producer, said it would accelerate plans to **triple its lithium hydroxide capacity to 18 kt** after it signed a supply deal with a large electric vehicle manufacturer.
- In October 2016 **Tianqi Lithium** broke ground at the Kwinana lithium hydroxide plant planned to process spodumene concentrate from the Greenbushes mine. The new facility is planned to have a production capacity of **24 ktpa lithium hydroxide**, with first production scheduled for 2018. It also indicated it intends to increase concentrate production levels at Greenbushes, in conjunction with JV partner Albemarle.

## Lithium Supply

### On the edge

- **Orocobre** is ramping up production at its 17.5 kt Olaroz brine project in Argentina.
- **Galaxy** made its first 10.000 t spodumene shipment from the Mt Cattlin deposit in Australia to Lianyungang at the beginning of this year with 160 kt production in 2017.
- Meanwhile, the nearby Mt Marion spodumene mine, co-owned by **Neometals Ltd**, **Mineral Resources Ltd** and **China's Ganfeng Lithium**, made its maiden shipment in the end of 2016. In September Neometals announced the signing of a MOU to further progress the development of a downstream lithium chemical plant in the Eastern Goldfields of WA.
- Korean steel-maker **Posco** started commercial production of lithium carbonate in Gwangyang by mid February 2017, with a 2.500 tpy capacity plant.
- **Nemaska** started commissioning of its Phase I plant by the end of November, with early shipments of Lithium Hydroxide Samples to Customers in Q1 and Q2 2017.

## Lithium Supply

### Next wave of projects in the advanced stage

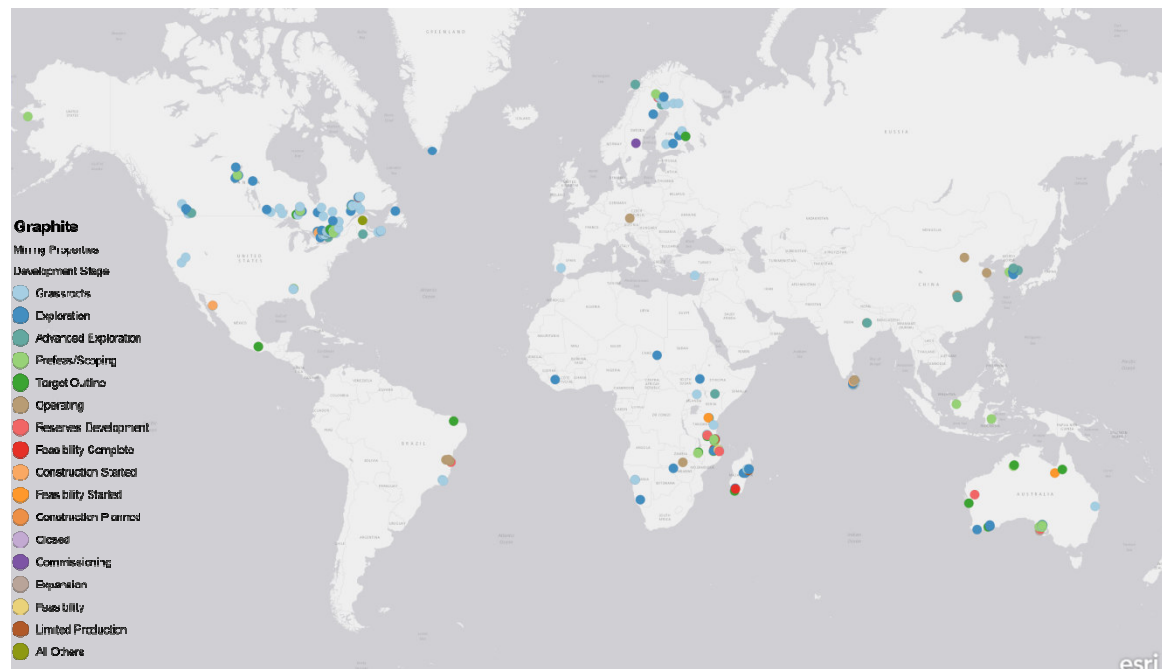
- Pilbara Minerals
- Altura Mining
- Rio Tinto
- Lithium Australia
- Pure Energy Minerals
- Bacanora minerals
- Avalon Advanced Materials
- AMG Lithium Brasil
- Dakota Minerals
- European Lithium
- European Metals
- Keliber Oy
- Critical Elements Corp.
- Sayona Mining Limited
- Zhongjin Lingnan Mining
- Lithium X Energy Corp.
- Simbalik Group
- Sichuan Mineral Industry
- ...

*Data by S&P Global (SNL) 10-2016*

# Graphite Supply

## Active graphite projects worldwide

- S&P Global provides information on 165 graphite projects worldwide.
- Hot spots are located in North America, Africa, Australia and northern Europe.

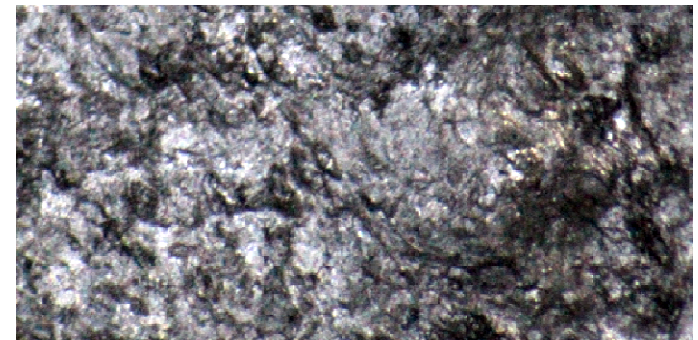


Source: S&P Global (SNL) 02-2017

# Graphite

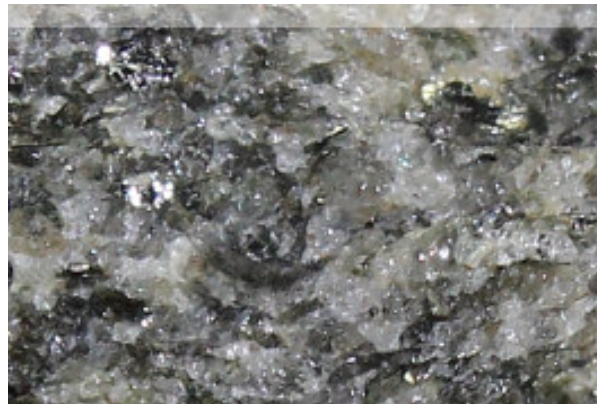
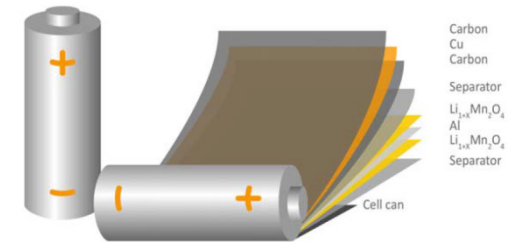
## Facts and figures

- Source: hard rock deposits
- Flake, Amorphous and Vein Graphite deposits
- Single Play
- Two main battery products: spherical/natural and synthetic graphite
- Main markets: refractories, batteries
- Market size (natural): 2,3 (1,1) Mtpa, B2B
- Technology shift:
  - a) Research going on to increase anode capacity by using silicon coatings or titanates
  - b) Thermal treatment alternative to chemical purification

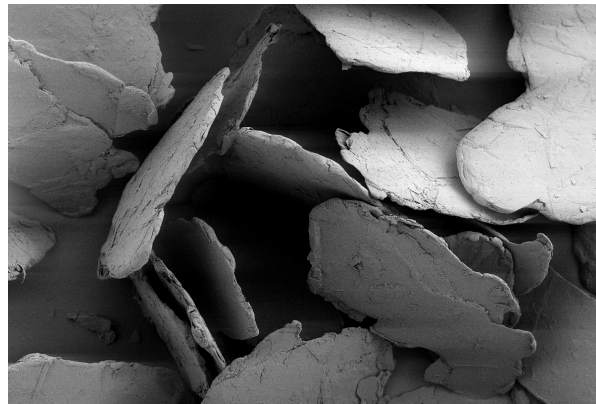


# Graphite

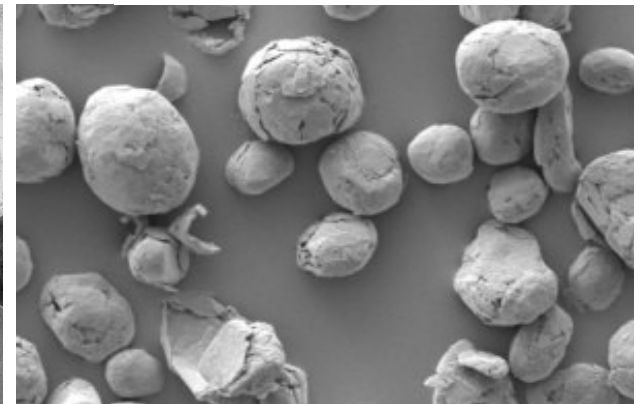
## Processing



Flake Graphite Deposit:  
Hard Rock Mining



Hard Rock Feedstock (ROM):  
Mineral Liberation and  
Graphite Concentration  
Flake Graphite

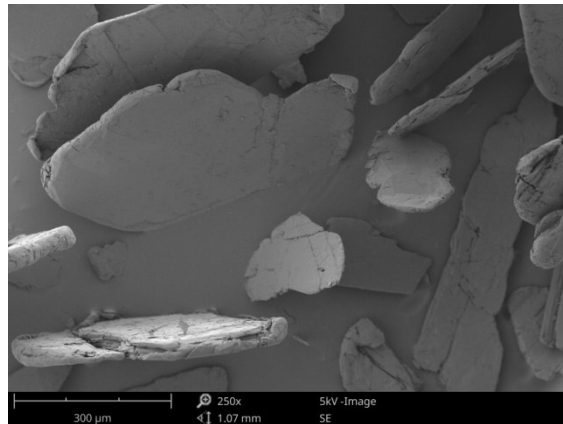


Preprocessed Flake  
Graphite Concentrate:  
Spheroidization and  
Purification, (Coating)  
Spherical Graphite;  
battery grade

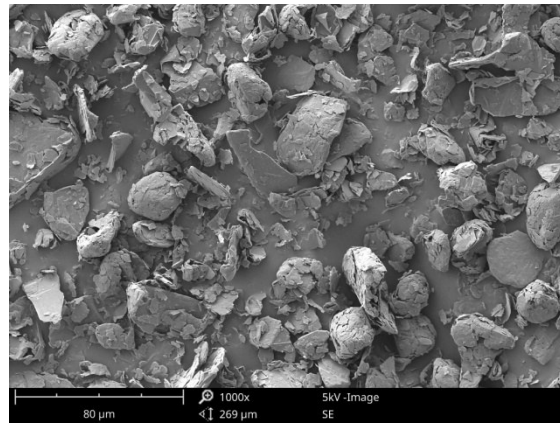


# Spherical Graphite

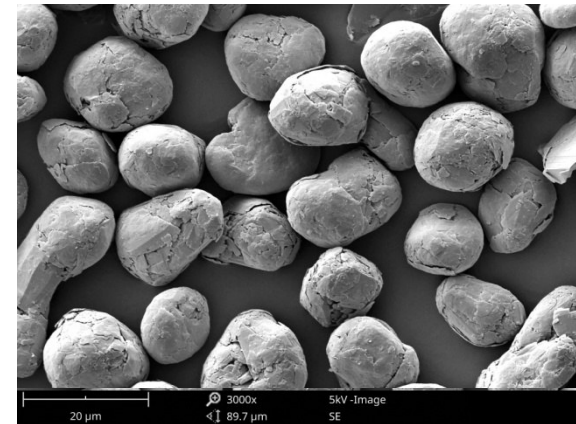
## Comparison of Feed Material, Intermediate product and Final product



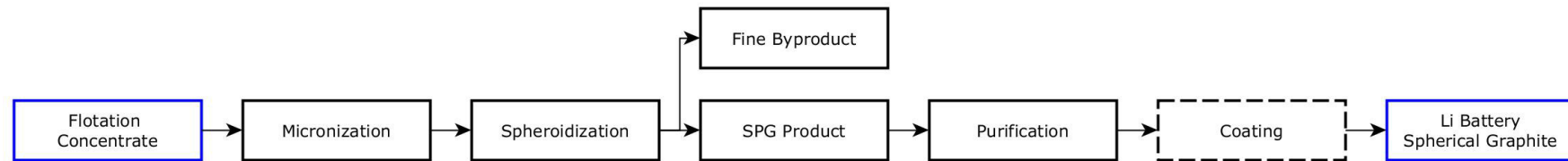
Feed Material



Intermediate product example



Final product  
Yield: 30-60 wt.-%



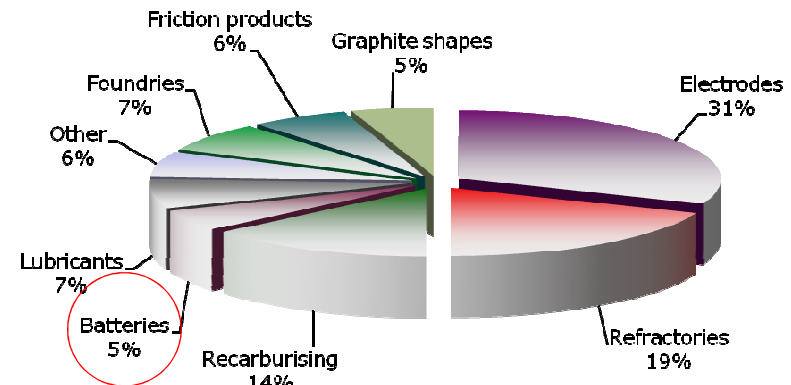


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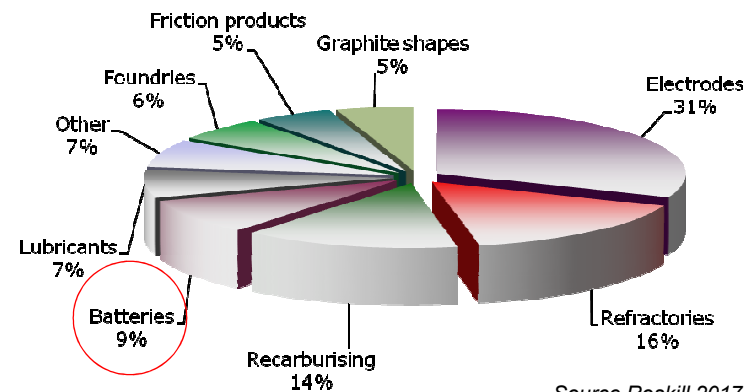
## Demand

- Batteries account for just 12% of natural graphite and 2% of synthetic graphite demand in 2016.
- Lithium-ion batteries will grow to account for 9% of total graphite demand by 2026 as traditional markets remain slow.
- Due to steel industry remaining depressed raw material flake graphite prices have been falling since early 2012 and are currently too low to stimulate new production.
- In contrast CAGR of Chinese refined battery grade spherical graphite is 27% in the last five years.

Graphite demand by application, 2016 (2.3 Mt)



Graphite demand by application, 2026 (3.0 Mt)

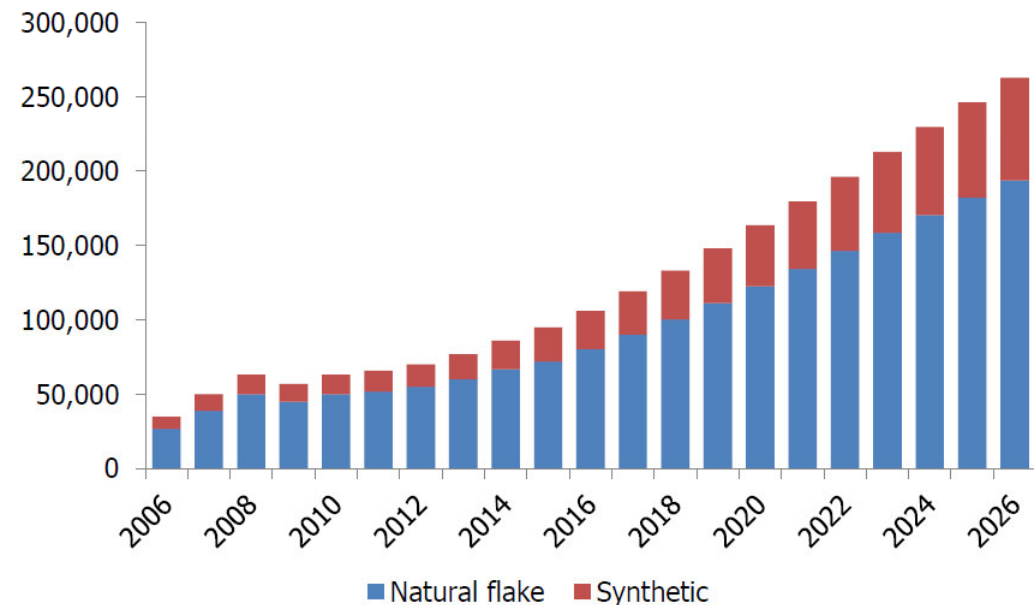


Source Roskill 2017

# Graphite

## Forecast consumption of crude graphite in lithium-ion batteries, 2016 to 2026 (t)

- Roskill forecasts CAGR of 10% in graphite demand from lithium-ion batteries over the next ten years.
- Growth dominated by natural graphite due to cost advantages.
- China is by far the largest source of graphite for natural flake graphite accounting for around 67% of production in 2015 and 57% in 2016 due to closures.
- Flake feedstock to rise from 110 kt (2015) to +300 kt in 2025 (Benchmark Minerals).

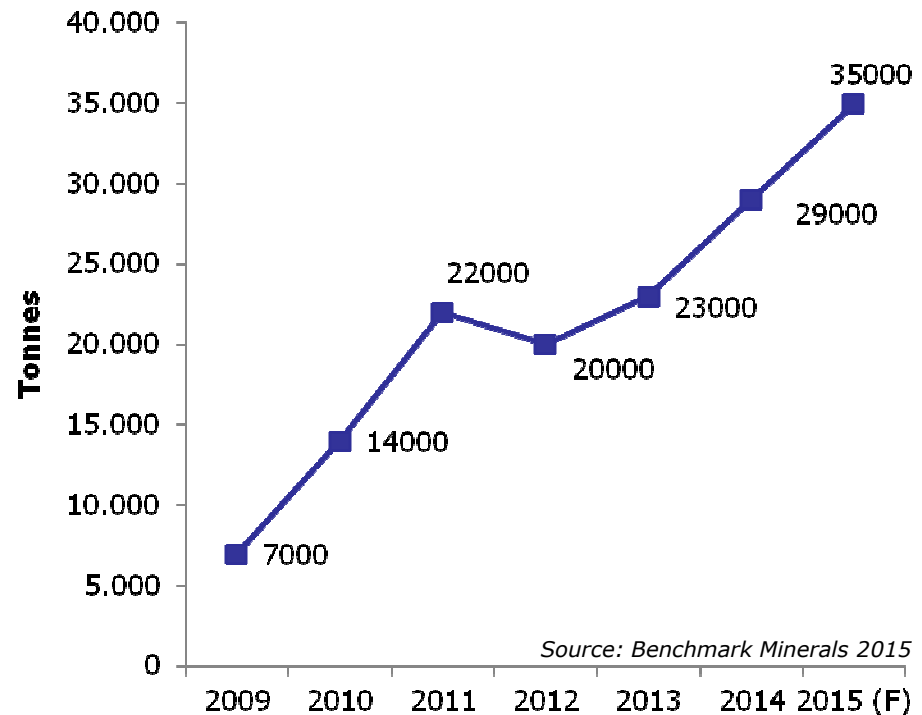


Roskill 2017

# Graphite

## China Spherical Graphite Exports Rising

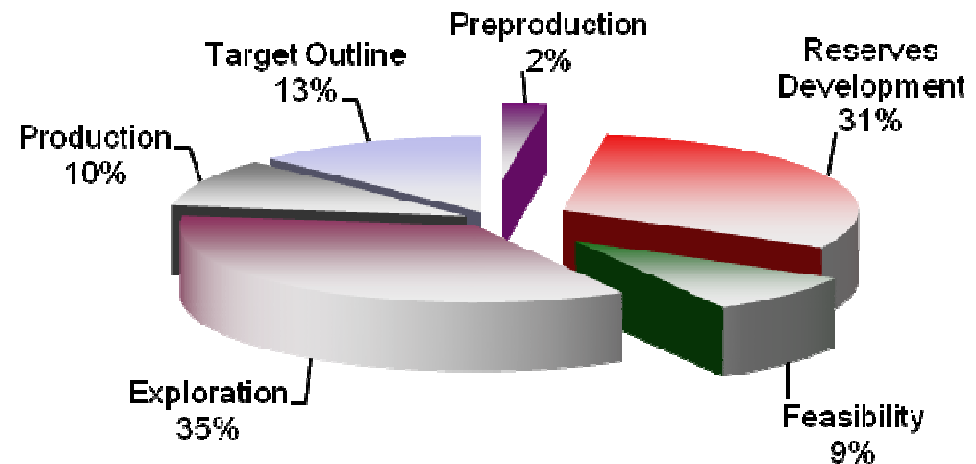
- China will continue to dominate as it increases lithium-ion battery production and consumption.
- 2016 estimates count 44.200 tpa of purified spherical graphite production (almost all from China) with increasing Chinese domestic consumption.



# Graphite Supply

## Project development stages

- With the main consumers for graphite (steel industry) remaining depressed, falling prices and batteries having only limited impact of the overall natural graphite demand, juniors face difficulties to gain benefit from the batteries rise.
- At present, China produces almost 100% of the world's spherical (battery grade) graphite.
- So this is the product that juniors need to prove that they can achieve.



Data by S&P Global (SNL) 02-2017

## Graphite Supply

### Next wave of projects in the advanced stage

- Sovereign Metals Ltd.
- Mason Graphite Inc.
- Focus Graphite Inc.
- Walkabout Resources Ltd.
- Energizer Resources Incorporated
- Battery Minerals Limited
- Graphitecorp Limited
- Volt Resources Limited
- Canada Carbon Inc.
- Nouveau Monde Graphite Inc.
- Zenyatta Ventures Limited
- Triton Minerals Limited
- Renascor Resources
- Graphex Mining Limited
- Graphite One Resources
- Alabama Graphite
- Lincoln Minerals
- Black Rock Mining Limited
- Kibaran Resources Limited
- Lomiko Metals Inc.
- Battery Mineral Resources Limited
- Great Lakes Graphite Inc.
- Talga Resources Limited
- ...

*Data by S&P Global (SNL) 02-2017*


## Summary

- Battery market is of limited significance for **nickel** production (3-4%).
- But: Batteries having a 71% share in nickel chemicals consumed.
- New nickel mines are multi-billion projects, while mine production is forecast to stay flat.
- **Cobalt** supply is highly inflexible because cobalt is recovered as a by-product of the nickel and copper mining which is dominated by a couple of major players (mining) and China (refining).
- If predicted demand is realized, longer term bottleneck will be primary cobalt production
- **Lithium** production must be increased in coming years to serve rising battery demand and bring market into balance.
- Most scenarios forecast hard rock deposits responding earlier than brine resources.
- New demand in the downstream lithium chemicals sector is expecting high grade lithium specifications and specifically exceeding short term LiOH production.
- With the main consumers for **graphite** (steel industry) remaining depressed, falling prices and batteries having only limited impact of the overall natural graphite demand juniors face difficulties to benefit from the batteries rise.
- At present, China produces almost 100% of the world's spherical (battery grade) graphite. So this is the product prove juniors need to achieve.

# ANZAPLAN Services

For more information download our Whitepapers on [www.anzaplan.com](http://www.anzaplan.com)

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**Cobalt Processing**

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Introduction

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Sediment-hosted Stratiform Cu-Co Deposits

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Ni-Co Laterites

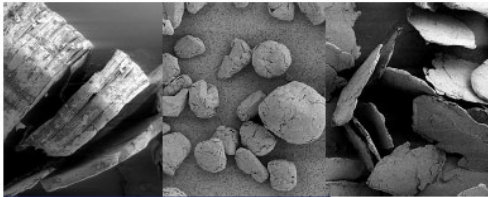
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Ni-Sulfide Deposits

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ANZAPLAN's Experience

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**Graphite Processing**

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Pre-processing

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Physical Processing

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Chemical and Thermal Processing


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Refinement

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Anzaplan Services

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**Conversion of Spodumene to Lithium Chemicals**

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Input material and Calcination

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Leaching

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Refinement

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ANZAPLAN services