

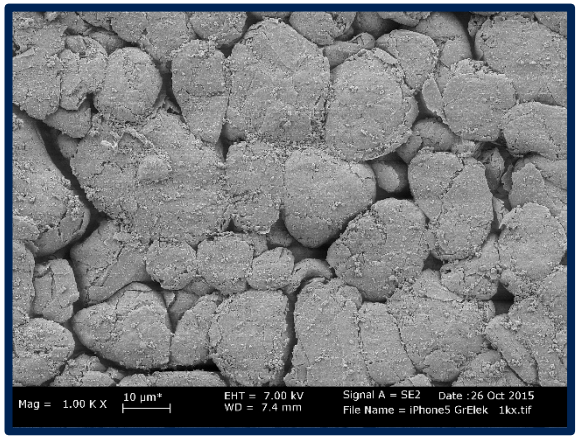

Processing Considerations for Specialty Materials Project Development

Presented by Aron Cleugh

November 29th, 2017

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Presentation Outline

- M.Plan Introduction
- Li-Ion Battery Basics
- Graphite Anodes –> Product Quality
- Graphite Metallurgy and Mineralogy
- Implications for Project Development
- (24 Slides)

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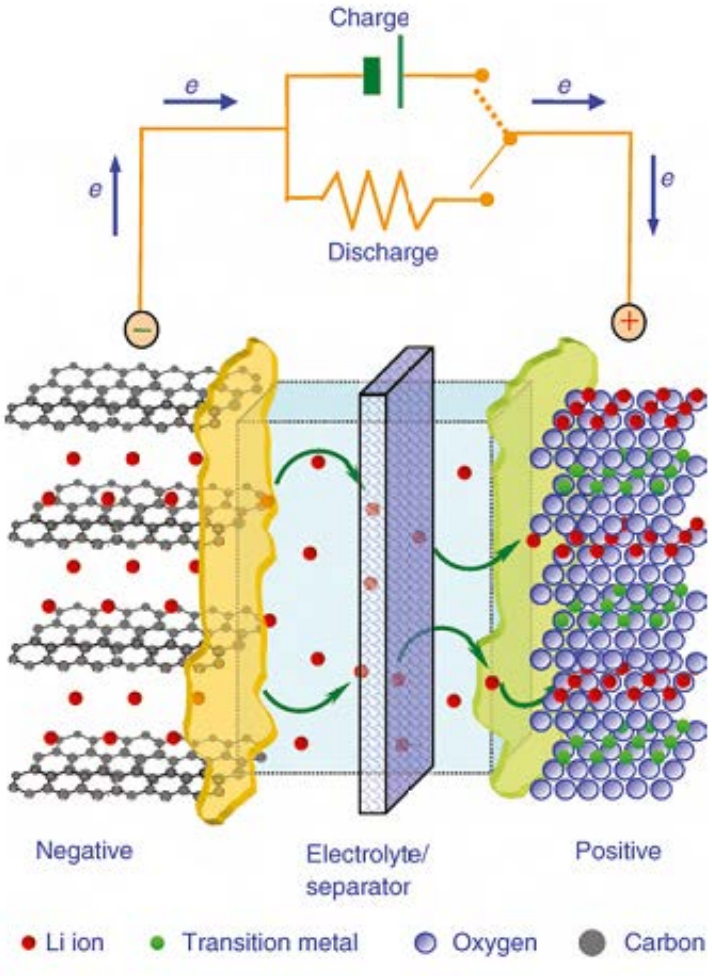
Li-ion Cell

Anode
(Graphite)



Cathode
(Transition metal oxides, Mn, Co, NiCoAl, NiMnCo, $FePO_4$)

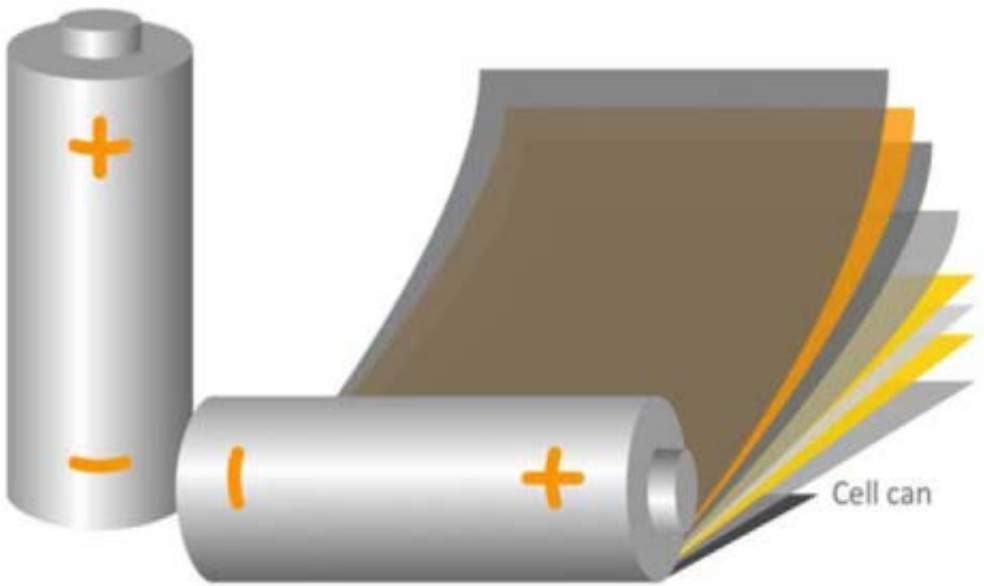
$$LiC_6 + CoO_2 \leftrightarrows C_6 + LiCoO_2$$

Taken from K. Xu. Encyclopedia of Electrochemical Power Sources, Elsevier, 2010

Li-Ion Battery

Graphite Anode

- material of choice for most battery designs
- there is ~20 times more graphite than lithium in a lithium ion battery



Graphite
Cu
Graphite

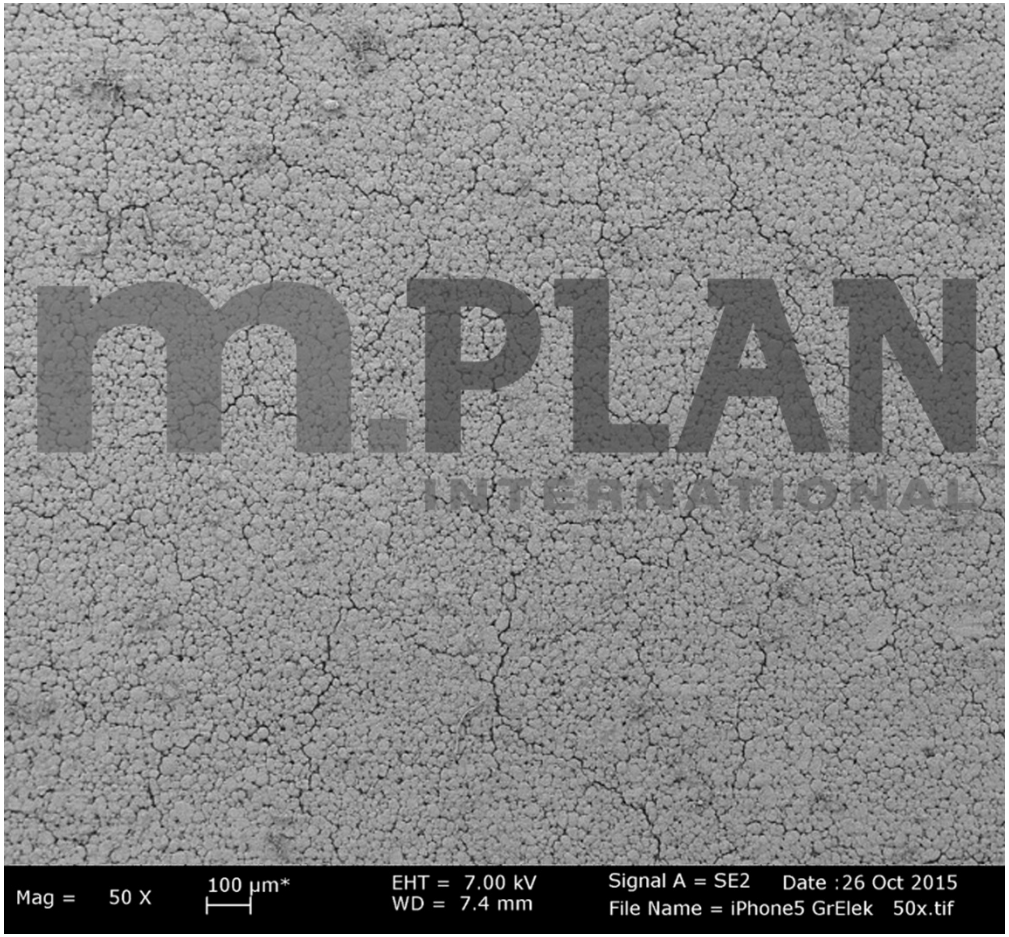
Separator

Li_xTMO_4
Al
Li_xTMO_4

Separator

Source: Bundesministerium für Wirtschaft und Energie 2015

Graphite Anode



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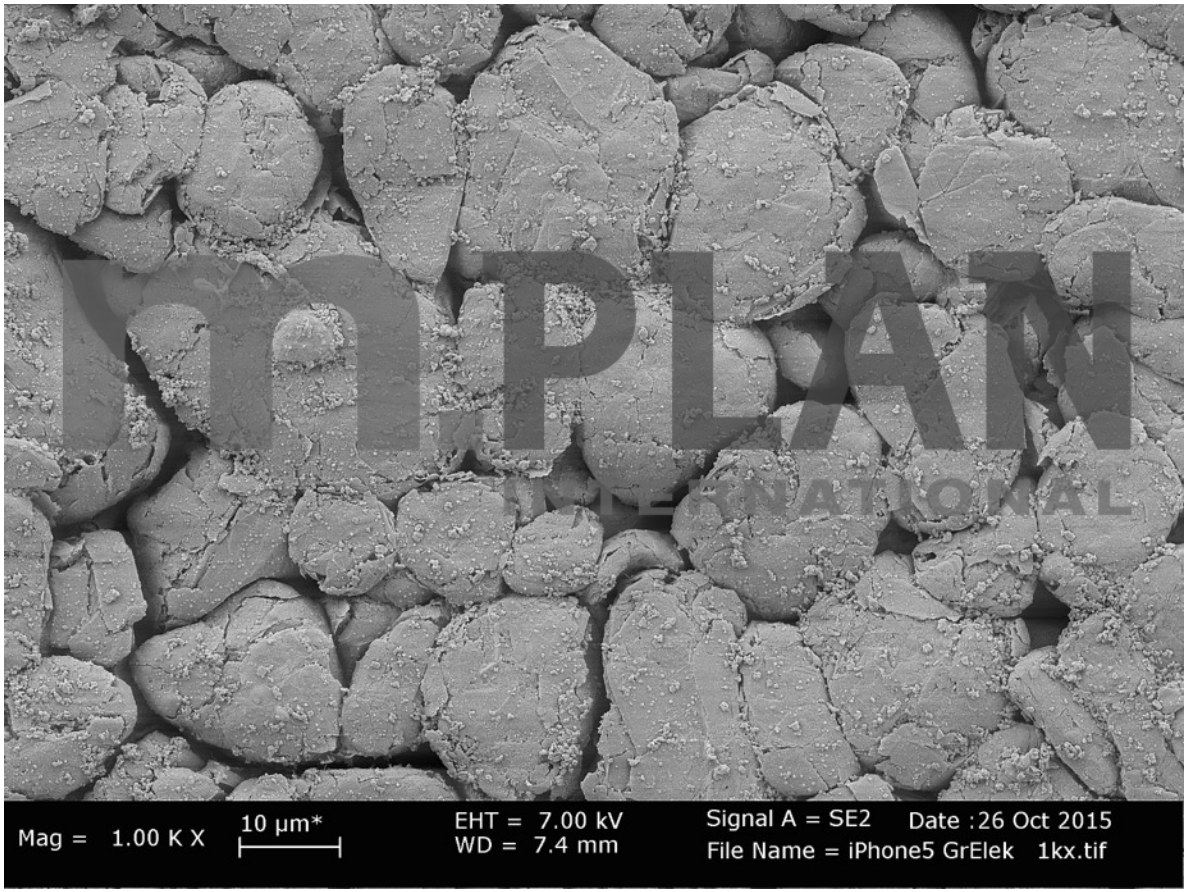
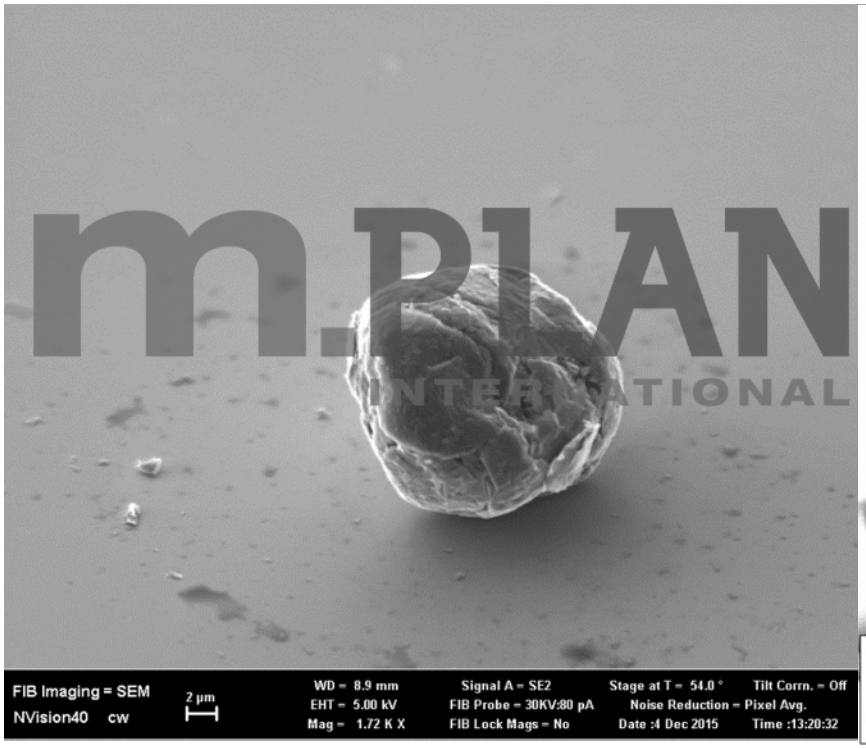
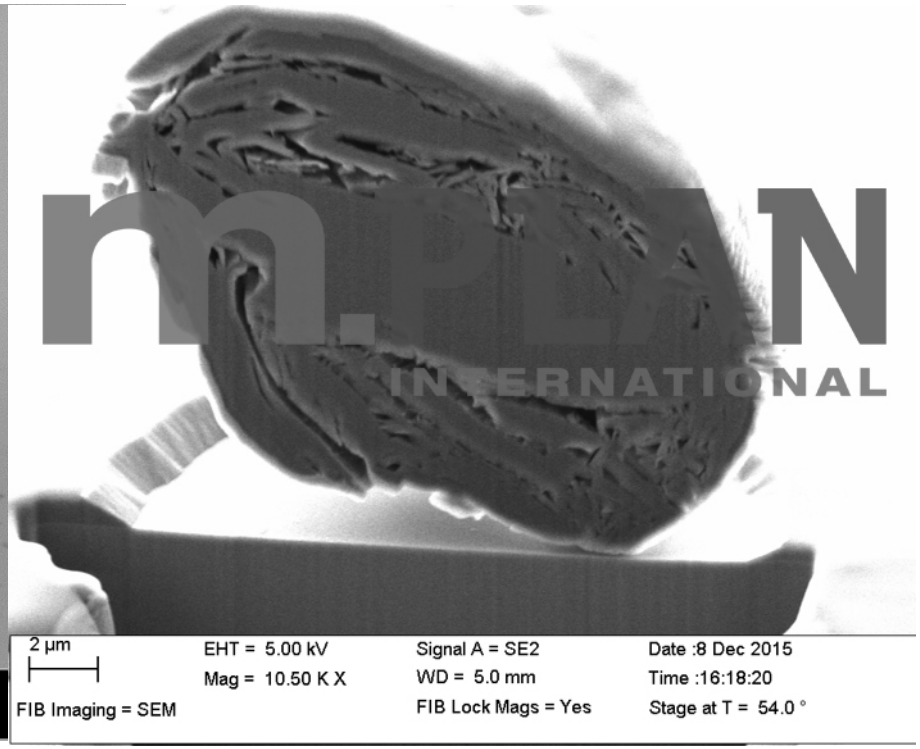
Graphite Anode Surface

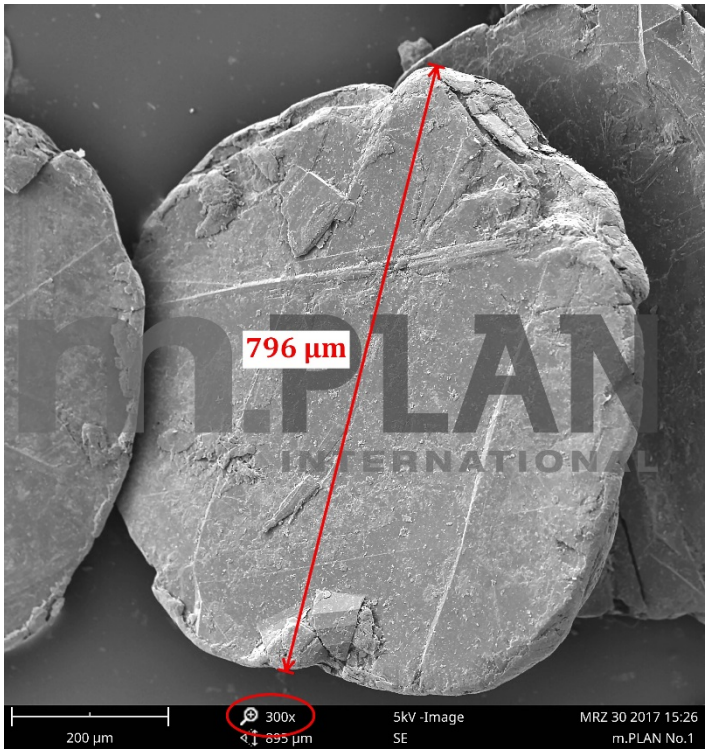


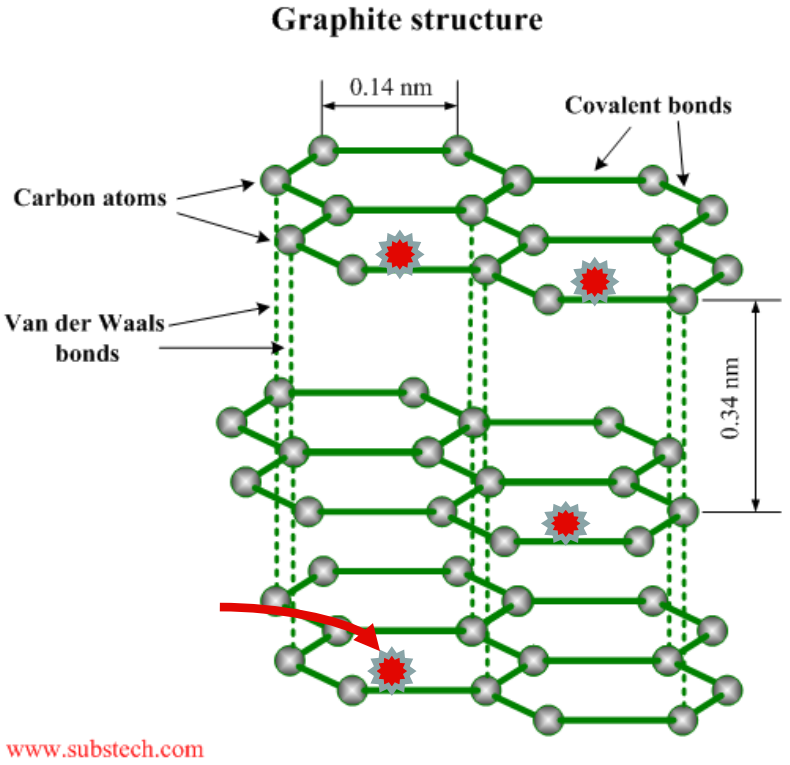
Scanning Electron Microscopy of Graphite Sphere



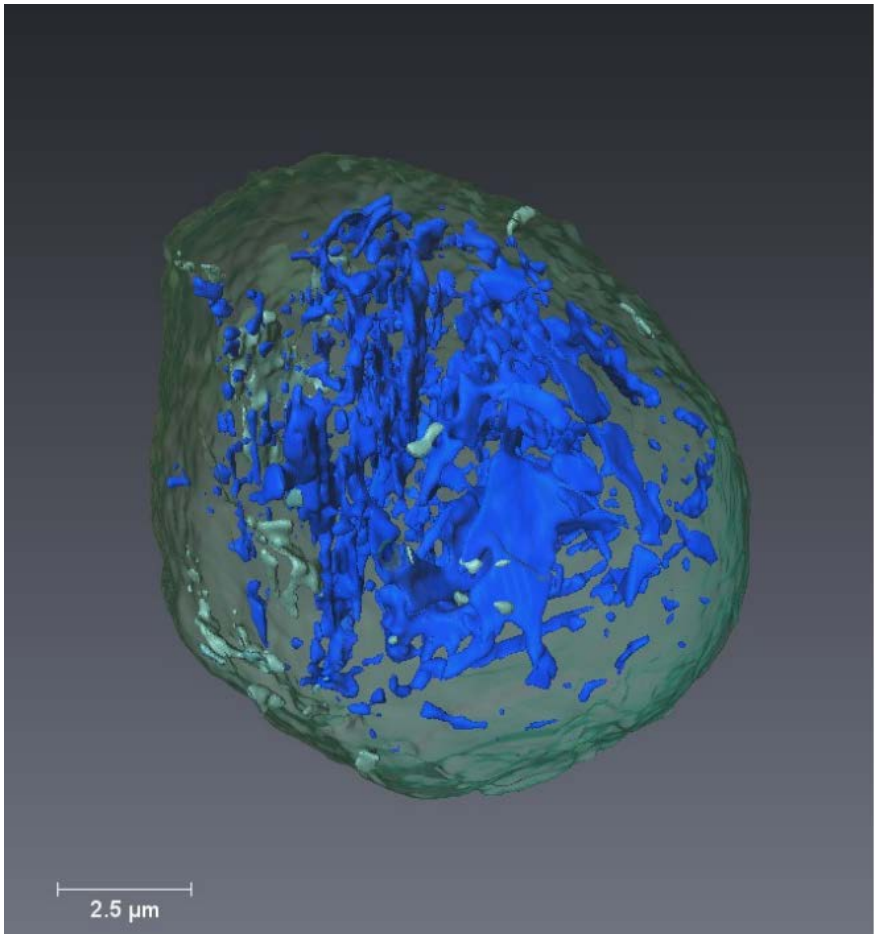


Lithium Ion Battery Performance





Spherical Graphite



Total Volume: 666 µm³

Total Porosity: 4.85%

Manuel Mundszinger, Manfred Rapp, Ute Golla-Schindler, Mario Wachtler, Ute Kaiser ; FIB-tomography of graphite anode particles for lithium ion batteries. The 16th European Microscopy Congress, Lyon, France. http://emc-proceedings.com/abstract/fib-tomography-of-graphite-anode-particles-for-lithium-ion-batteries/. Accessed: April 5, 2017

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Spherical Graphite General Requirements

- Good packing density (sphere)
- Easy Li ion access (edges)
- Minimal “non-edge” surface area

Sample Specifications

d50 µ	d90/d10 µ	Tap Density	SSA m^2/g	Ash %	Moisture %	Impurities %
10 - 25	< 3	≈ 0.9 for finer SPG	≈ 3 - 7	< 0.05	< 0.1	< 0.05

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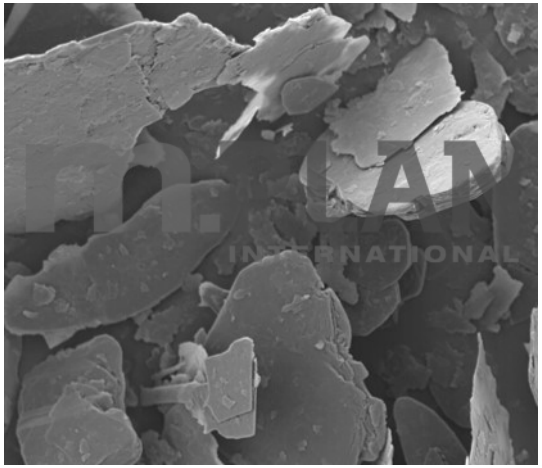
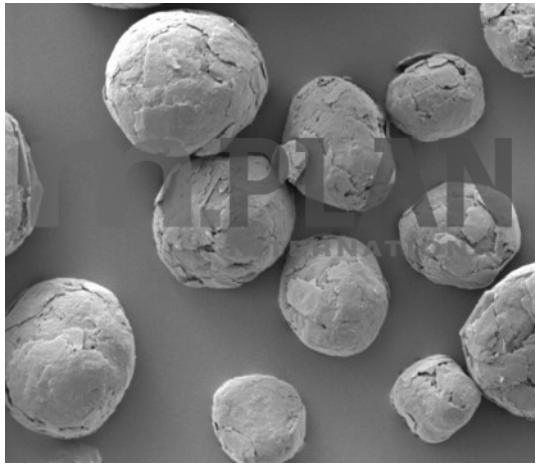
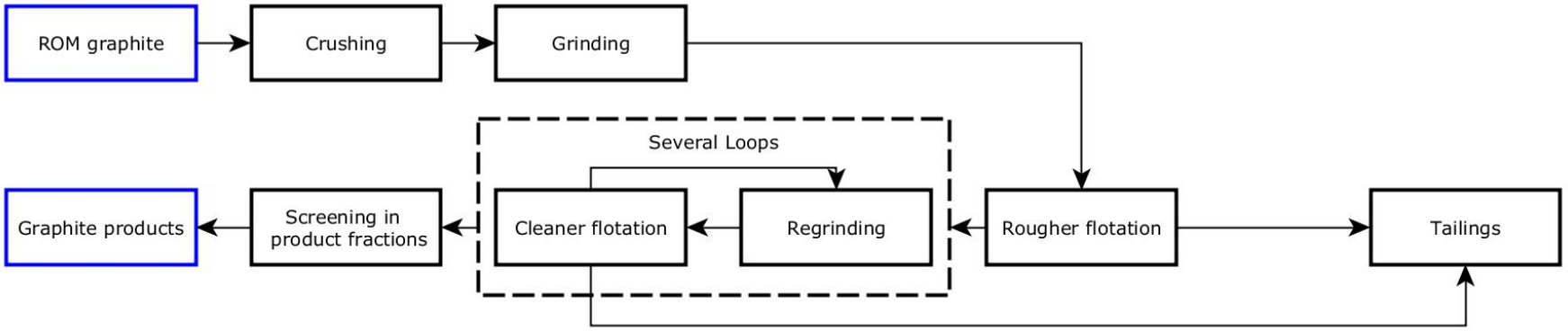
METALLURGY - Spherical Graphite Processing

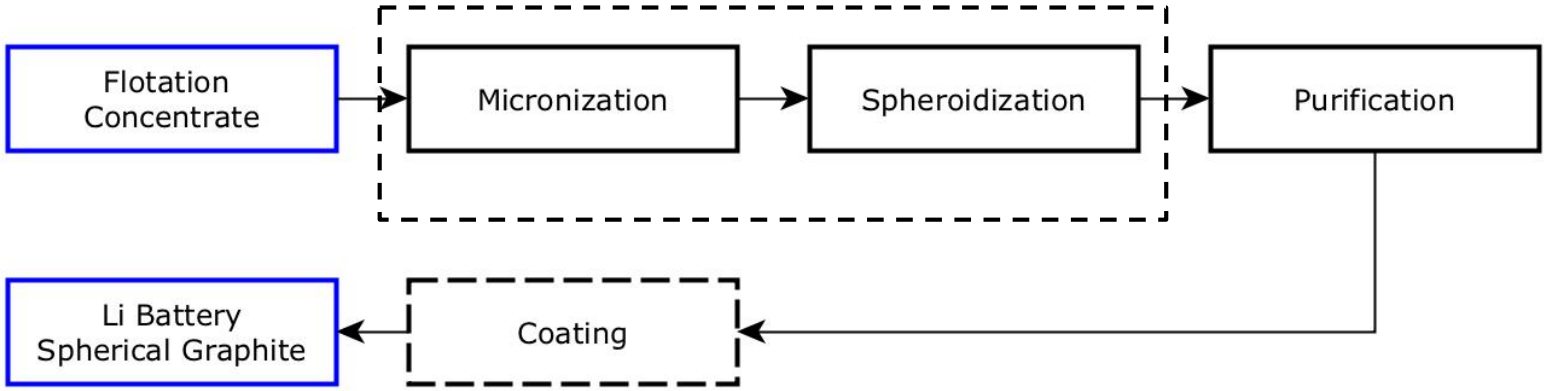




Graphite Processing - Beneficiation



Graphite Processing – Spheroidizing & Refining

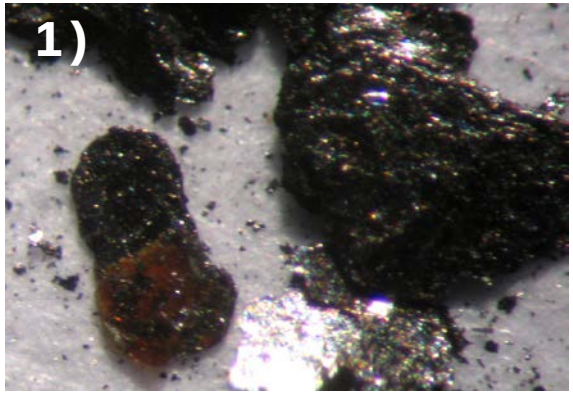


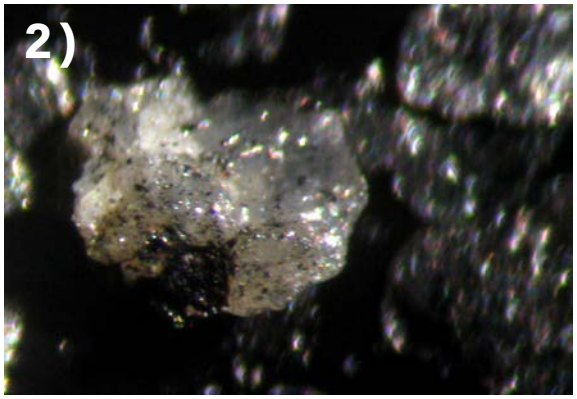
Graphite Mineralogy and Metallurgy

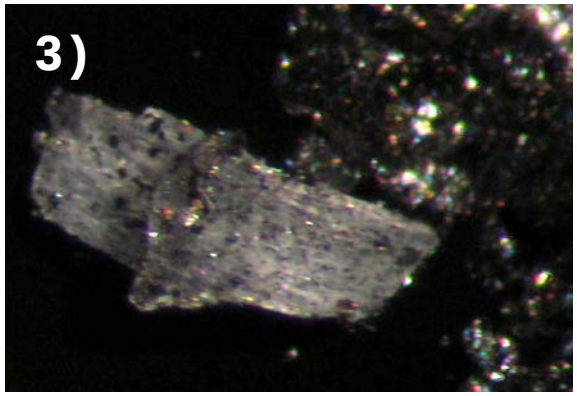
- Liberation is key for separation
- The finer the more liberated but there are challenges that hamper this process
- Fine grinding adds processing costs and reduces size distribution (and value of product)

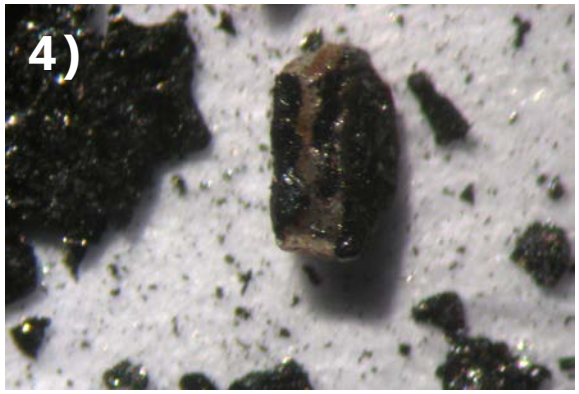
Challenges in Mineral Processing

1) Intergrowth with gangue minerals
2) Graphite patch on surface
3) Graphite sprinkled on surface
4) Gangue mineral masked by graphite (overgrinding)



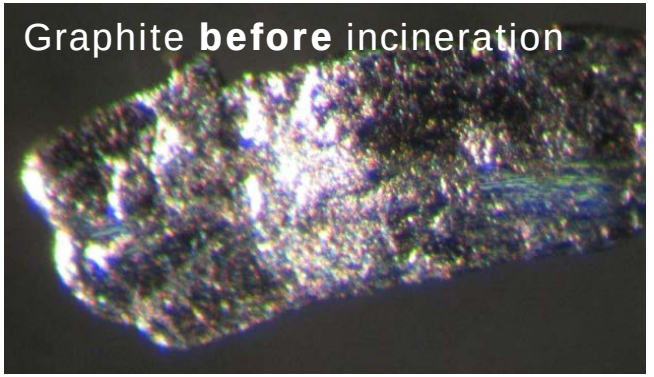






Graphite Mineralogy and Metallurgy

- Chemical purification needs to be tailored:
- Caustic baking at elevated temperature dissolves impurities such as feldspar, quartz and mica followed by acid washing.
- Alternative HF leaching followed by hydrochloric acid washing step depending on nature and ultimate level of purity by efficient removal of silicates.



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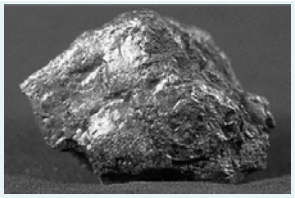
Graphite Mineralogy

Graphite Type		Characteristics
Amorphous		Amorphous is microcrystalline type of natural graphite, placed in seems with crystals not visible to the naked eye. Purity ranges 70 to 90%.
Flake		Flake type is found as disseminated free flakes within a graphite deposit. Typical flake sizes range between 75 to 850 µm with grades ranging between 1 to 30%. Flotation produces concentrates typically +85%.
Vein		Crystalline vein type consists of flake like to lumpy particles up to large and jumbo sizes. Purity is typically in the range of 80 to +95%.

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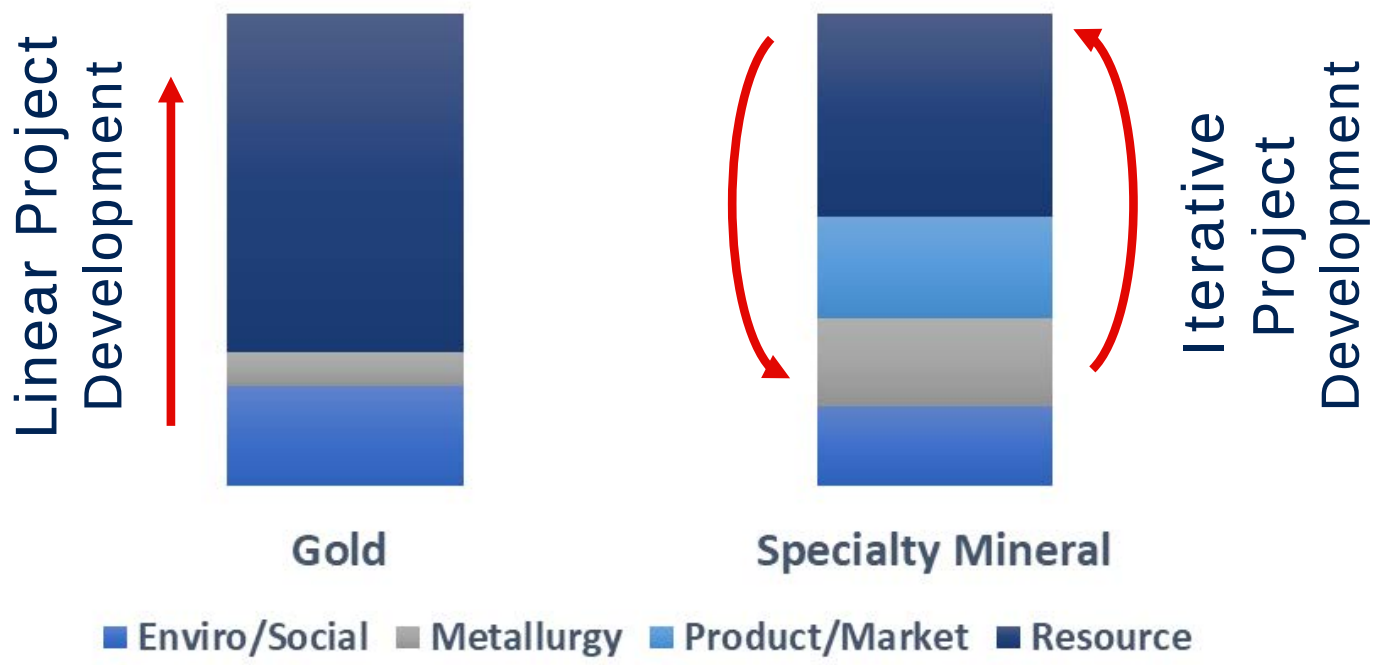
Development Phase Investment Risk



Development Phase Project Definition

Mine & Process Data

Proven reserves	15,000,000	tonnes @ 7.0% C grade
Probable reserves	10,000,000	tonnes @ 7.0% C grade
Grade (graphitic carbon)	7	% average head grade over LOM
Waste to ore ratio	0.8 : 1	
Processing rate	800,000	t/a
Mine life	31	years
Recovery	90	%

Construction Capital Costs (millions)

Capital Cost	US$ 150
Contingency	US$ 25
Total	US$ 175

- **Final product?**
- **Market size?**
- **Market price over LOM?**
- **Industry operating cost curves?**
- **Benchmarks?**

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ESTIMATION OF MINERAL RESOURCES and MINERAL RESERVES – CIM BEST PRACTICE GUIDELINES

- The consideration of the physical and chemical properties of the subject mineral
- The spatial relationship of these properties within the mineral occurrence
- The relationship of the physical and chemical properties of the mineral to the available markets

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- “For minerals that are defined by a specification, the Mineral Resource or Ore Reserve estimation must be reported in terms of the mineral or minerals on which the project is to be based and must include the specification of those minerals.”

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