Graphite Anodes in Lithium-Ion Batteries

Presentation Outline
- Lithium-Ion Anodes
- Natural and Artificial Graphite
- Anode Forecast
- US and EU Growth
- Conclusions
AVICENNE PROFILE
Information for Growth - Powering your company’s market strategy with in-depth research and strategic consulting

- Creation: 1992, by Ali MADANI
- Headquarter: Paris
- Liaison Office: Japan, USA, China
- AVICENNE Energy Director: Christophe Pillot
- 4 consultants
  - A Madani
  - C Pillot
  - JP Salvat
  - A Yassari
- 2 Senior advisors
  - X Zhang
  - M. Sanders
- Database: >20 000 contacts in the battery value chain

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When a lithium-ion battery is being charged, lithium ions move from the positive cathode to the negative anode through the polymer membrane. During discharging, the lithium ions pass back from the anode to the cathode. In the process, electrons are sent to an electronic device, powering it in the process.

A anode is typically made by mixing active material powder, binder powder, solvent and additives and pumping this slurry to a coating machine.

An anode, based on Graphite as the active material is processed in the same way.

Graphite anodes are being used ubiquitously as the traditional anode material for lithium-ion batteries. It is generally observed that an anode needs to be protected with an SEI layer that prevents anode degradation is required to prevent cell failure and improve safety.

Experimentation and limited commercialization of higher capacity anodes has begun to improve cell capacity.

The anode stores the lithium ions through electrochemical intercalation; a sequence by which the lithium ions are put into or pulled from pore locations inside the anode material structure.

Source: HITACHI Chemicals
ANODE ACTIVE MATERIALS
235,000 TONS IN 2020

LIB Anode Materials

Source: A. Jossen, IRES 2007

Source: Hitachi Chemical

LIB Anode market, (Tons)

Source: Sanyo, March 2013
**Natural Graphite: CAGR 2015-2030:** +10% IN VALUE, +14% IN VOLUME

### Natural Graphite demand details

**Demand:** Smaller growth because new app. Need artificial Gr and Chinese LIB choose mostly artificial Gr. This demand may change if the price decrease is more important for NG compare to AG.

**Price:** The price will decrease fast because the supply is huge. Already over supply in China (Capacity: BTR 30 000 Tons, Zichen: 10 000 Tons, Sinuo: 8 000 Tons, Qingdao: 8 000 Tons, Kimwan: 5 000 Tons...). Then, a lot of new projects in China and Canada: Focus Graphite > 40000 Tons/year (2020*), Northern Graphite > 20 000 Tons/year (after 2018*), Syrah Resources Ltd. > 80 000 Tons (2020*)

### NG Volume in 2020

- **Shenzhen BTR:** 28%
- **Hitachi:** 13%
- **Shinzoom:** 8%
- **Others:** 18%
- **POSCO Chemtech:** 3%
- **Mitsubishi:** 18%
- **XFH:** 5%
- **ShanShan:** 6%
- **Others:** 18%
- **China:** 70%
- **Others:** 30%

**Typical Product**

- $D_0= 16 \mu m$
- $350 \text{ mAh/g}$
- 5% irreversible cap.
- BET: $1 \text{ m}^2/\text{g}$

### NG Price forecasts

**Sources:** AVICENNE ENERGY 2021

<table>
<thead>
<tr>
<th>Year</th>
<th>$/kg</th>
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</thead>
<tbody>
<tr>
<td>2005</td>
<td>17</td>
</tr>
<tr>
<td>2010</td>
<td>14</td>
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<td>2015</td>
<td>8</td>
</tr>
<tr>
<td>2020</td>
<td>6</td>
</tr>
<tr>
<td>2025</td>
<td>5</td>
</tr>
<tr>
<td>2030</td>
<td>5</td>
</tr>
</tbody>
</table>

* Base scenario - ** Realistic scenario

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* Subject to financing
**ARTIFICIAL GR.:** CAGR\textsubscript{2015-2030}: +12% IN VALUE, +16% IN VOLUME

### Artificial Graphite demand details

![Artificial Graphite demand chart](chart1.png)

* Base scenario - ** Realistic scenario

### Artificial Graphite Price forecasts

![Artificial Graphite Price chart](chart2.png)

### Artificial Graphite summary of outlook

**Demand:** The demand will increase fast thanks to xEV market and Chinese market. Long life time requirement involve high level of purity and high consistency, difficult to achieve with Natural Graphite.

**Price** will decrease fast (-3-4%/year) thanks to better process efficiency, new process

**Supply:** Thanks to the best quality, Hitachi will keep the lead but Chinese main suppliers market share will increase (ShanShan mostly).

**Production Capacity:** BTR: 50 000 Tons, Hitachi: 20 000 Tons, ShanShan: >42 000 Tons, Zichen: 35 000 tons, Sinuo: 24 000 tons, XFH 22 000 Tons, Kaijin 15 000 Tons, JFE: 8000 Tons, Showa Denko: 3000 Tons, CHNM: 20 000 tons, ...

Sources: AVICENNE ENERGY 2021

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LIB ANODE MARKET 2000-2030

From ~235 000 tons in 2020 to 1 200 000 tons in 2030 – CAGR 20-30: +17.5% (realistic scenario)

Anode Sales 2000 – 2030

$M and (100s) Mt

Source: AVICENNE ENERGY 2021
US PRODUCTION CAPACITY – TO BECOME 10-15% OF TOTAL: FROM ~45 GWH IN 2020 TO 100 TO 150 GWH IN 2025

**Source:** Avicenne Energy 2021
EU BATTERY VALUE CHAIN PROJECT

The European Union has approved 2.9 billion euros in subsidies from 12 member countries for a second pan-European project to develop the electric battery industry and move away from its reliance on Asian imports.

The EU's executive commission had already cleared a 3.2 billion-euro plan subsidized by seven countries in Dec. 2019 to support research and innovation in a key sector where Europe is lagging behind Asian competitors.

The EU, which expects that demand for batteries will grow quickly in the coming years, said Tuesday that the latest public funding is expected to unlock an extra 9 billion euros in private investment.

- Comprehensive program to support all levels of the value chain
- Not limited to EU based companies
ANODE DRIVERS
Materials Technology

Current Anode Technology:

- LIB Cells initially produced with mostly artificial and amorphous graphite
- Natural Graphite was introduced as a significant cost reduction and major CN suppliers established
- Blended systems of artificial graphite and natural have become common in most high-performance applications including automotive
- Si/Graphite systems were started in research almost 20 yrs. ago, now becoming more common in auto, but not dominating
- SKI Battery Day – Anode roadmap and claiming technology/business leadership over LG and Samsung
- LTO remains niche anode due to low energy density, high costs with limited supply

Market Impact

Current Anode Market

- Performance was good, but costs were high and not available from many suppliers
- Cost were low, but so was quality, many materials were too soft making processing difficult and contamination high limiting use in automotive
- Natural graphite has improved significantly, costs of artificial have fallen to closer to natural, driving blended systems and artificial gaining share
- Si/Graphite systems now reaching 3-7% Si by weight using either SiC or SiOx approach. Some investment in Si production for battery starting in AP, EU and US
- SKI provided info on LG and SDI comparing anode roadmaps, format and growth. SKI recently announced JV with Group 14 to build a plant in Korea for Si.
- LTO will remain niche for high cycle life and other specialty applications only
SK INNOVATION BATTERY DAY

Ni Cathode Direction

Source: SK Battery Day 2021
# MATERIALS ROADMAPS FOR HIGH SI LOADING >6%

<table>
<thead>
<tr>
<th>Year</th>
<th>% of LIB with SiC</th>
<th>Si loading</th>
<th>Anode Prelithiation?</th>
<th>Cathode Prelithiation?</th>
<th>Applications?</th>
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</thead>
<tbody>
<tr>
<td>2017</td>
<td>2.5% (1% - 5%)</td>
<td>2.5% (2% - 3%)</td>
<td>NO</td>
<td>NO</td>
<td>Portable</td>
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<tr>
<td>2020</td>
<td>4% (3% - 10%)</td>
<td>4% (3% - 5%)</td>
<td>NO</td>
<td>NO</td>
<td>Portable</td>
</tr>
<tr>
<td>2025</td>
<td>7% (5% - 20%)</td>
<td>7% (4% - 7%)</td>
<td>YES</td>
<td>NO</td>
<td>Portable</td>
</tr>
<tr>
<td>2030</td>
<td>9% (8% - 25%)</td>
<td>9% (5% - 12%)</td>
<td>YES</td>
<td>NO</td>
<td>Portable, Auto</td>
</tr>
</tbody>
</table>

**Sources:** Interviews July & August 2017
CONCLUSION

- Graphite Market will remain a strong growth opportunity for the next 10 years
- Blended systems of Natural and Artificial Graphite will continue to dominate the lithium-ion battery anodes
- SiC and SiOx blends with graphite will continue to expand, but at a slow level
- Vast majority of supply is China based for natural and artificial graphite.
- Excess capacity in Asia will need to be absorbed by the market to drive regional supply and profitability for new suppliers
- Very little supply for graphite has been established in NA, you will hear from some of the emerging potential suppliers later today.
- Production quality and reliability of supply need to be proven from emerging potential suppliers.
- Solid State batteries have made progress in moving toward pilot production but is not likely to impact the LIB growth significantly in the next 10 years.
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