SILICON FOR ANODES IN LI-ION BATTERIES - AN OPPORTUNITY FOR NORWEGIAN INDUSTRY?

Moozes kick-off 20.03.2017
Ragnar Tronstad
The Elkem Group: two integrated value chains

Elkem Solar

Revenue: 6,6 BNOK
Employees: 2215 (Norway: 270)

REC Solar Singapore

Revenue: 14,6 BNOK
Employees: 3600 (Norway: 1100)

Elkem AS

Revenue: 
Employees:
Innovation focus: New advanced materials

• Lighter, stronger metals. Examples – Si-based alloys for 3D printing.....
• Tailor-made alloys that reduce weight or improve energy efficiency with the customer
• Silicon and silicones for renewable energy
• Battery technology
• Thermal electric materials
Li ion battery and Silicon anodes
LiB manufacturing investments.
Time to market for new materials

<table>
<thead>
<tr>
<th>Year</th>
<th>Cathode</th>
<th>Anode</th>
<th>Electrolyte</th>
<th>Separators</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>LCO</td>
<td>Graphite</td>
<td>LiPF_6 + Org. solvents</td>
<td>Polyolefin</td>
</tr>
<tr>
<td>2005</td>
<td>NMC/NCA</td>
<td>Soft Carbon</td>
<td>LiPF_6 free electrolyte</td>
<td>Polyolefin-ceramic coating</td>
</tr>
<tr>
<td>2010</td>
<td>LMO</td>
<td>Li_{4/3}TiO_{5}</td>
<td>Gel-polymer electrolyte</td>
<td>Cellulose</td>
</tr>
<tr>
<td>2015</td>
<td>LiNiPO_4, 5v</td>
<td>Non Si Alloys</td>
<td>LiPF_6 electrolyte</td>
<td>Tien-woven</td>
</tr>
<tr>
<td>2020</td>
<td>LiNiMnO_2, High voltage</td>
<td>Si Alloys</td>
<td>Polymer membrane</td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td>Sulfur</td>
<td>C/Alloy Composite</td>
<td>Solid Electrolyte</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>Air</td>
<td>Li-Metal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: AVICENNE ENERGY 2016
Silicon in Li ion batteries

Si has the largest Li specific capacity of any known anode material

Silicon is the element with highest Li battery capacity potentials
Results from the IPN SiNODE project: Development of cost-efficient silicon-carbon based anode material for Li-ion secondary batteries
Silgrain® Production at the Bremanger plant
- Elkem battery grade silicon: Silgrain® e-Si

- Silgrain® e-Si capacity expandable up to 6 000 MT/yr
- Elkem Bremanger Silgrain®
  - Unique, patented, green hydro power-based process
  - 85 years of metallurgical competence and production
  - Efficient and highly stable production of large volume
  - Integrated from quartz to finished Silgrain® products
  - Tailored qualities with respect to both size and chemistry

**Raw Materials**
- Quartz (SiO$_2$)
- Reduction materials (Carbon)
- Hydro Power

**Smelting Furnace**
- Carbotermic reduction

**Silgrain® Plant**
- A "wet" chemical refining process to remove impurities and down sized further
- Micronization Process
- Side streams handled

**Silgrain® Products**
- Silgrain® e-Si
- Multiple Silgrain® qualities

**Customers**
- LIB
- Other special applications, Customized sizing and chemistry
Silgrain® e-Si is a low emission product
GHG emissions from production of Solar Grade Si vs. Silgrain® e-Si

- LCA will become increasingly important
- Finding the ‘right’ silicon quality for cost efficient production will be important
- Extremely low CO₂ emission from production of Silgrain® e-Si: < 7 kg CO₂/kg

* SimaPro + Ecoinvent 2.2 used in LCA calculations – Calculation of GHG emission for Silgrain® e-Si is based on data from LCA for Elkem Solar Silicon®
** “Modified Siemens – EU” = "Best case Siemens" - all electricity from Hydro Power, all heat from co-generation power plants
Elkem's battery related R&D projects

- **RCN/IPN (Research Council of Norway) projects:**
  - "SiNODE", 2013-2015; developing a Si-based anode for Li-ion batteries; half cell testings of different chemistries, electrolytes, binders...
  - "SiCanode", 2016 – 19; full cell testings of the “winning” recipe from SiNODE; a SiC–composite anode. Optimization of binders, electrolyte and cathode.

- **RCN/KPN project SiBEC**, “Silicon for Li-batteries – influence of binder, electrolyte and cathode”, 2016-20; a competence project managed by NTNU/Trondheim, Norway.

- Cooperation project with IIT – Genova/Italy and Prof. Bruno Scrosati/Univ. o. Sapienza.
  On half and full cell testings of different Elkem silicon qualities, 2015-17. Post mortem analyses important.

- **Fraunhofer ISE** – testing of Silgrain® e-Si for energy storage batteries.

- Cooperation with **AIST and Tottori University**, Japan on half cell testings of Si-qualities since 2010.

- **Cooperation projects** with a selection of customers worldwide; Battery Grade Si for a variety of Li battery technologies.

- Elkem **internal activities**; powder technology – optimizing powder, sub-micron/nano size, production.
  Finding the best technology.

- Partner in **FME MoZEES** – “Mobility Zero Emissions Energy Systems”.

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Summary

• Market for Li-ion batteries grows fast
• A need for high capacity and high number of cycles for use in electrical vehicles
• Silicon is the element with highest capacity potentials
• Biggest challenge is to minimize consequences of expansion during lithiation
• Elkem has a broad experience with silicon production for different customer demands and demonstrated innovative process development which gives an advantage in Si-anode development.
• Silgrain®e-Si is developed as a battery quality for LIB with potential to meet expected, long-term price levels. Industry relevant quantities are available today.
• Future sale of batteries will be influenced by CO₂ footprint – e-Si has the lowest footprint of available battery grade silicon qualities.
• Norway has an academic society with high silicon competence