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Graphite demand growth: the future of lithium-ion batteries in EVs and HEVs

Suzanne Shaw
Senior Analyst
Roskill Information Services
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Summary

- Overview of the graphite market
- Lithium-ion battery trends and applications
- Lithium-ion batteries in EVs and HEVs
- Recent and future trends in the uptake of EVs and HEVs
- Graphite consumption in lithium-ion and other batteries
- What does the future hold for the graphite industry?
- Summary
Overview of the graphite market
Global graphite demand, 2012

- Electrodes: 34%
- Refractories: 20%
- Foundries: 5%
- Lubricants: 6%
- Friction products: 2%
- Batteries: 4%
- Recarburising: 1%
- Graphite shapes: 4%
- Others: 24%

Source: Roskill estimate
Note: 1-Including specialty synthetic products
Regional demand for graphite, 2004-2011 (kt)

Source: Roskill estimate
Regional demand for graphite by end-use, 2011

Source: Roskill estimate
Global graphite market overview, 2012

- Global demand for graphite was 2.50Mt and production 2.26Mt (constrained amorphous production in Hunan)
- Batteries accounted for ~95,000t of graphite demand (68% natural and 32% synthetic)
- By far the largest graphite demand for use in batteries comes from Asia, around 50-55%
- Graphite demand is recovering as we come out of the global economic downturn
- Future demand could increase significantly if EVs and HEVs take off
The role of lithium-ion batteries
# Lithium-ion Vs. NiMH

## Typical properties of NiMH and Li-ion battery systems

<table>
<thead>
<tr>
<th></th>
<th>NiMH</th>
<th>Li-ion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal voltage (V)</strong></td>
<td>1.2</td>
<td>3.7</td>
</tr>
<tr>
<td><strong>Positive electrode</strong></td>
<td>Nickel hydroxide</td>
<td>Lithium-cobalt oxide</td>
</tr>
<tr>
<td><strong>Electrolyte solution</strong></td>
<td>Potassium hydroxide</td>
<td>Organic electrolyte</td>
</tr>
<tr>
<td><strong>Negative electrode</strong></td>
<td>Hydrogen absorption alloy</td>
<td>Carbon</td>
</tr>
<tr>
<td><strong>Energy density</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Wh/l)</td>
<td>200</td>
<td>370</td>
</tr>
<tr>
<td>(Wh/kg)</td>
<td>80</td>
<td>170</td>
</tr>
<tr>
<td><strong>Temperature range (°C)</strong></td>
<td>-20 to 60</td>
<td>-20 to 60</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>heavy duty use</td>
<td>heavy duty use</td>
</tr>
<tr>
<td></td>
<td>no heavy metals</td>
<td>high voltage</td>
</tr>
<tr>
<td></td>
<td>high capacity</td>
<td>no memory effect</td>
</tr>
<tr>
<td></td>
<td>charge cycle of 500</td>
<td>low self-discharge</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
<td>portable OA equipment</td>
<td>portable OA equipment</td>
</tr>
<tr>
<td></td>
<td>portable AV equipment</td>
<td>portable AV equipment</td>
</tr>
<tr>
<td></td>
<td>power tools</td>
<td>radiotelegraphic systems</td>
</tr>
<tr>
<td></td>
<td>medical instruments</td>
<td>cameras</td>
</tr>
<tr>
<td></td>
<td>electric cars</td>
<td>electric cars</td>
</tr>
</tbody>
</table>

Source: Roskill estimate
Global secondary battery production (M cells)

Source: Roskill estimate
Global secondary battery production

Source: Roskill estimate
Regional secondary battery production (M cells)

Source: Roskill estimate
Global secondary battery consumption, 2012

- 3C: 89%
- Power & motive: 8%
- Heavy duty: 2%
- Transport: 1%

Source: Roskill estimate
EV and HEV applications for lithium-ions
Different HEV and EV technologies

- **HEV** – hybrid electric vehicle:
  - battery supplements engine
  - recharge using excess energy from vehicle
  - several types: full, power assist, mild/micro

- **PHEV** – plug-in hybrid electric vehicle:
  - recharge from external source
  - small engine to charge battery during use

- **EV** – electric vehicle:
  - powered only by battery
  - recharge from external source
  - limited distance
Why use batteries in cars?

- HEVs/EVs offer better fuel efficiency
- Operating costs are also lower for HEVs/EVs (although initial purchase cost is higher)
- Increasing environmental legislation on a global scale
- Consumers choosing to be green
- Battery systems are smaller and lighter than a traditional engine
## Energy density of vehicle fuels and batteries

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Nominal energy density (Wh/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>28,000</td>
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<tr>
<td>Gasoline</td>
<td>12,300</td>
</tr>
<tr>
<td>Natural gas</td>
<td>9,350</td>
</tr>
<tr>
<td>Coal (bituminous)</td>
<td>8,200</td>
</tr>
<tr>
<td>Methanol</td>
<td>6,200</td>
</tr>
<tr>
<td>Lithium-ion battery (various types)</td>
<td>110-160</td>
</tr>
<tr>
<td>Nickel-metal hydride battery</td>
<td>60-120</td>
</tr>
<tr>
<td>Lead-acid battery (sealed)</td>
<td>30-50</td>
</tr>
</tbody>
</table>

Source: Electric Vehicle Technology and Cadex Electronics
## EU Emission standards for passenger vehicles (g/km)

<table>
<thead>
<tr>
<th>Directive</th>
<th>Date</th>
<th>CO</th>
<th>THC</th>
<th>NMHC</th>
<th>NOx</th>
<th>HC+NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 1</td>
<td>Jul 1992</td>
<td>2.72</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.97</td>
<td>0.14</td>
</tr>
<tr>
<td>Euro 2</td>
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<td>1.0</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.7</td>
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<tr>
<td>Euro 3</td>
<td>Jan 2000</td>
<td>0.64</td>
<td>...</td>
<td>...</td>
<td>0.50</td>
<td>0.56</td>
<td>0.05</td>
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<tr>
<td>Euro 4</td>
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<td>0.50</td>
<td>...</td>
<td>...</td>
<td>0.25</td>
<td>0.30</td>
<td>0.025</td>
</tr>
<tr>
<td>Euro 5</td>
<td>Sep 2009</td>
<td>0.500</td>
<td>...</td>
<td>...</td>
<td>0.180</td>
<td>0.230</td>
<td>0.005</td>
</tr>
<tr>
<td>Euro 6</td>
<td>Sep 2014</td>
<td>0.500</td>
<td>...</td>
<td>...</td>
<td>0.080</td>
<td>0.170</td>
<td>0.005</td>
</tr>
<tr>
<td>Petrol vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 1</td>
<td>Jul 1992</td>
<td>2.72</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.97 (1.13)</td>
<td>...</td>
</tr>
<tr>
<td>Euro 2</td>
<td>Jan 1996</td>
<td>2.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.5</td>
<td>...</td>
</tr>
<tr>
<td>Euro 3</td>
<td>Jan 2000</td>
<td>2.3</td>
<td>0.20</td>
<td>...</td>
<td>0.15</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Euro 4</td>
<td>Jan 2005</td>
<td>1.0</td>
<td>0.10</td>
<td>...</td>
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<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Euro 5</td>
<td>Sep 2009</td>
<td>1.000</td>
<td>0.100</td>
<td>0.068</td>
<td>0.060</td>
<td>...</td>
<td>0.005²</td>
</tr>
<tr>
<td>Euro 6</td>
<td>Sep 2014</td>
<td>1.000</td>
<td>0.100</td>
<td>0.068</td>
<td>0.060</td>
<td>...</td>
<td>0.005²</td>
</tr>
</tbody>
</table>

Source: DieselNet
Trends in vehicle production
World: Production of cars and light vehicles (M units)

Source: Roskill estimate
Regional estimated cumulative HEV sales, 2011

Source: Roskill estimate
USA: Sales of HEVs and PHEVs by major manufacturer

Source: Arnold Magnetic Technologies
Overview of the current EV/HEV market

- HEV/EVs account for just 1-2% of total vehicle production

- The USA is home to the largest number of alternative energy vehicles, followed by Japan and Europe

- China was seen as the future, but growth has been slower than expected

- Only 1 Prius was sold in China in 2010, while sales of high-status sports utility vehicles increase (of 13.8M vehicle sales in China in 2010, 6% were SUVs – a 24% growth in SUV sales on 2009)

- Global sales recovered in 2011 following the global economic downturn and increased through 2012
Future growth of EVs and HEVs
Factors affecting future growth of EVs/HEVs

• Growth rates not as high as some suggest – China is not the future once predicted

• Withdrawal of incentives has already occurred in the USA and new incentives are unlikely in the current economic climate

• However, total vehicle production is increasing

• Continued concern over environmental issues both from consumers and stricter government legislation

• Higher uptake of EVs/HEVs likely from 2015/16 once the global economy recovers. Already seeing increased diversity of models available from manufacturers

• Production of EVs/HEVs could reach 5-8M vehicles by 2020
Forecast sales of BEV, PHEV and HEVs by major manufacturer, 2016

Source: JL Mag
Global forecast production of EVs/HEVs (000’ units)

Source: Roskill estimate
What does this mean for graphite consumption?
Major uses of graphite in batteries and fuel cells

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Use of graphite</th>
<th>Types of graphite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium-ion</td>
<td>Anode - main host material</td>
<td>Primary synthetic, spheroidal flake</td>
</tr>
<tr>
<td>Primary alkaline</td>
<td>Cathode - additive</td>
<td></td>
</tr>
<tr>
<td>Lead-acid</td>
<td>Anode/cathode - additive</td>
<td>Primary synthetic, purified flake and purified expanded flake</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>Bi-polar plates - main filler material</td>
<td></td>
</tr>
</tbody>
</table>

Source: Roskill estimate
Graphite in Lithium-ion batteries

- Both high purity synthetic and natural graphite can be used.

- Natural flake must undergo a high level of expensive processing to change it into spherical-shaped, high-purity graphite.

- High performing spherical graphites are increasingly produced at a price similar to those of synthetic graphite and so competition is increasing between the two materials.

- Lithium-ion batteries are one of the few industries where natural and synthetic graphite compete.

- The final often comes down to choice come down to price and availability, which may depend on the location of the lithium-ion anode manufacturer – i.e. are you closer to a mine or a synthetic plant.
Production of spherical graphite

Mining 2,000kg, 5% C

Mechanical separation 198kg, 50% C

Flotation 105kg, 95% C

Milling 99kg, 95% C

Spheroidisation 33kg, 95% C

Purification 28.5kg, 99.5% C

Surface treatment 30kg (for 1 EV car)

Source: Superior Graphite
Global graphite consumption in batteries, 2012 and 2016f

Source: Roskill estimate
What does the future hold for the graphite industry?
Global graphite demand, 2016

Source: Roskill estimate

Note: 1-Including specialty synthetic products
Natural graphite production by region

![Graph showing natural graphite production by region from 2010 to 2016.
Legend:
- Green: Asia
- Red: S. America
- Light green: N. America
- Purple: Europe
- Light blue: Africa and Middle East]
Summary

• In 2012, around 80% of the graphite used in batteries was consumed in lithium-ion batteries

• Graphite consumption in batteries to increase to 114,000t by 2016 mainly due to lithium-ion batteries in consumer products, but to some extent from EV/HEV production

• Accelerated growth after 2015/16 as lithium-ion batteries take an increasing market share from NiMH batteries in HEVs

• Growth in EVs/HEVs underpinned by the desire to increase efficiency and decrease emissions, both from the consumer and from governments

• Demand will increase both for synthetic and for natural graphite and is already encouraging the development new flake deposits and synthetic capacity
Natural & Synthetic Graphite: Global Industry Markets & Outlook

Make the right business decisions

Get accurate answers from independent experts

Contact Suzanne Shaw
suzanne@roskill.co.uk