Lithium-Ion Batteries

- Convert electrochemical energy to electricity
- High energy density compared to other chemistries
Slow Progress in Lithium-Ion Batteries

- Slow annual energy density improvements of 5 - 8%
- Not keeping pace with equipment demands
Anode Chemistry Options

- Graphite has been industry standard since inception
- Silicon offers 12x improvement in theoretical capacity over graphite
 Silicon Anodes Drastically Increase Energy Density

- A 25% energy density improvement represents a step change
Challenge of Silicon Anodes

- Large change in volume upon cycling causes large mechanical stress and fracturing of silicon particles
- Results in loss of electrical contact with electrode matrix and severe capacity fading
A Partial Solution: Silicon Nanoparticles

- Nanoscale particles mitigate problems with volume expansion
- Repeated cycling still leads to loss of electrical contact

Traditional Polymer Binder

- **Charging**
  - Expansion of silicon particles

- **Discharging**
  - Loss of electrical contact due to shifting
The Solution: Conductive Polymer Binder

- Flexible, conductive polymer binder binds to silicon tightly
- Minimizes loss of electrical contact

Traditional Polymer Binder

- Charging
- Discharging

LBNL Polymer Binder

- Charging
- Discharging
Opportunities for Silicon Anode in Diverse Markets

- Personal Electronics
  - Longer Battery Life
  - Increased Portability
  - Improved Design

- Defense & Aerospace
  - Lighter Field Loads
  - High Energy Density
  - Longer Range, Less Weight

- Power Tools
- Transportation
Commercial Opportunities for Silicon Anode

Power Tools
Personal Electronics

Advantages

Increased Battery Life
Less Volume
Efficiency Requirement
300 cycles ≈ 1 year
2009 Revenues $13 Billion
Market Growth Medium

Advantages

Increased Range
Lower Weight
Efficiency Requirement
5000 cycles ≈ 10 years
Market Revenues $.71 Billion
Market Growth High
The Race is On: Panasonic Developing Silicon Anode for 2012

Panasonic's silicon-packin' batteries boast 30 percent capacity boost, hit stores in 2012

By Joseph L. Unke

Tesla to Use High-Energy Batteries from Panasonic

A new partnership could help the automaker increase the range of its vehicles.

By Kevin Bullis

Panasonic, the maker of high-performance electric vehicles, is working with Panasonic, the battery and consumer electronics giant, to develop its next generation of batteries. The partnership is intended to help Tesla lower the cost of its batteries and improve the range of its vehicles.

Tesla Motors, the maker of high-performance electric vehicles, is working with Panasonic, the battery and consumer electronics giant, to develop its next generation of batteries. The partnership is intended to help Tesla lower the cost of its batteries and improve the range of its vehicles.

Sure, not a day goes by without some sort revolutionary (if not just plain silly) announcement regarding fuel cells, and once again it looks like it's Panasonic's turn. According to Nikkei, the company will begin volume production of Li-ion rechargeable batteries that use a silicon alloy anode sometime in fiscal 2012. While Si alloy batteries have a tenfold theoretical improvement in current cells that utilize graphite, Panny claims that its device will have a linear capacity of close to thirty percent -- keeping at least 80 percent of charge recharge cycles. Currently the bad boy is being men, although we could be seeing em in our electric cars by next conference after the break.

Charging up: New batteries could help extend the range of cars produced by Tesla Motors, including the Model S, shown here.

Last month Panasonic announced two high-energy batteries for electric vehicles. These new batteries store as much as 30 percent more energy than its previous lithium-ion batteries, and this increased storage could, in theory, increase a vehicle's range by similar amount, thereby addressing one of the main problems with electric cars. Tesla's Roadster currently has a range of 244 miles and takes three and a half hours to charge with a special charger.

The other major challenge for Tesla is the cost of the battery, which is the most expensive part of its electric vehicles.
Competitive Advantage

SIMPLE & SCALABLE
INEXPENSIVE
DROP-IN TECHNOLOGY
Competitive Advantage

<table>
<thead>
<tr>
<th>Incumbents</th>
<th>Start Ups</th>
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<tbody>
<tr>
<td>3M</td>
<td>nexeon</td>
</tr>
<tr>
<td>(Amorphous Silicon)</td>
<td>(Silicon Nanopillars)</td>
</tr>
<tr>
<td>Panasonic</td>
<td>amprius</td>
</tr>
<tr>
<td>(Silicon Alloy)</td>
<td>(Silicon Nanowires)</td>
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</tbody>
</table>

SIMPLE & SCALABLE
INEXPENSIVE
DROP-IN TECHNOLOGY
Competitive Advantage

• LBNL Polymer Binder can be produced at equivalent cost to traditional binders

• Silicon nanoparticles can be made from metallurgical grade (~98% purity) Si

• Metallurgical grade Silicon available at $1 – $5 per kg

• Anticipated cost parity if Silicon nanoparticles procured for $300 per kg

Economies of Scale • Vertical Integration • Strategic Partnerships
Competitive Advantage

OLD
- Graphite
- Acetylene Black
- Binder

NEW
- Silicon Nano-particles
- Polymer Binder

Anode
- Paste Mixing
- Coating
- Drying
- Calendering
- Slit to Width
- Reeled Stock

Cathode
- Paste Mixing
- Coating
- Drying
- Calendering
- Slit to Width
- Reeled Stock

Winding Core
- Insert Wound Elements
- Hot Weld Bottom Contact
- Vacuum & Heat Drying
- Addition of Electrolyte

Insert Top Parts
- Close & Seal
- Top Cap Welding

SIMPLE & SCALABLE
INEXPENSIVE
DROP-IN TECHNOLOGY
The Technology is Ready for Your Input. License It. Improve It. Sell It.

<table>
<thead>
<tr>
<th></th>
<th>Status</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intellectual Property</strong></td>
<td>• Provisional patent on polymer class and battery system</td>
<td>• Complete prosecution</td>
</tr>
<tr>
<td></td>
<td>• PCT to be filed shortly</td>
<td>• Build IP portfolio around optimized technology</td>
</tr>
<tr>
<td><strong>Coulombic Efficiency</strong></td>
<td>• 99.0% efficiency</td>
<td>• 99.93% efficiency for personal electronics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 99.996% efficiency for electric vehicles</td>
</tr>
<tr>
<td><strong>Cycling</strong></td>
<td>• 100 cycles at 1200 mAh/g with no capacity fade</td>
<td>• &gt; 300 cycles for personal electronics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• &gt; 5000 cycles for electric vehicles</td>
</tr>
<tr>
<td><strong>Nanoparticle Optimization</strong></td>
<td>• No systematic testing completed</td>
<td>• Optimize particle size and purity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Investigate scalable nanoparticle production</td>
</tr>
</tbody>
</table>
**PERSONAL ELECTRONICS**

**POWER TOOLS**

**DEFENSE APPLICATIONS**

**ELECTRIC VEHICLES**

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**Commercialization and Optimization**
- License Patented Technology
- Optimize to **99.93%** cycle efficiency
- Secure supply of Si nanoparticles
- Manufacturing Integration
- Safety testing

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**Secondary Market and Commercialization and Optimization**
- Optimize temperature range operability
- Ensure low self discharge
- Ensure low internal impedance

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**Long term market opportunity**
- Optimize to **99.996%** cycle efficiency
- Safety testing
- Secure automotive partners
Team Members

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