BATTERY INNOVATION: INCREMENTAL OR DISRUPTIVE?

ALBERT CHEUNG
LI-ION BATTERY PACK COST AND PRODUCTION, 2010-30

Total pack cost ($/kWh) vs. Annual production (MWh)

TODAY’S RANGE: $400–1500/KWH

Source: Bloomberg New Energy Finance
EV LITHIUM ION BATTERY SUPPLY & DEMAND (MWH)

Source: Bloomberg New Energy Finance

<table>
<thead>
<tr>
<th>Year</th>
<th>Annualized Supply Capacity</th>
<th>Declared Annual Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>12,200</td>
<td>2,400</td>
</tr>
<tr>
<td>2012</td>
<td>27,900</td>
<td>8,800</td>
</tr>
<tr>
<td>2013</td>
<td>33,300</td>
<td>16,000</td>
</tr>
</tbody>
</table>

Annualized supply capacity
Declared annual demand

Source: Bloomberg New Energy Finance
COST IS JUST ONE OBJECTIVE

IDEAL BATTERY

- COST
- ENERGY DENSITY
- POWER DENSITY
- SAFETY
- CYCLE LIFE
- CALENDAR LIFE
WHERE WILL GAINS BE MADE?

LFP, NCM, electrolytes, etc. → Raw/processed materials → Battery materials → Cells → Packs → Vehicle Integration

Cost
- Alternative electrodes / electrolytes
- Materials development
- Cell size and format
- Cell design features
- Pack design
- Pack assembly
- Thermal management
- Chassis integration
- Integration with other vehicle systems

Performance
- Process improvement & scale
‘INCREMENTAL’ IMPROVEMENT IN CATHODE CHEMISTRY

NCM is one of several cathode types in use
- Blend of three lithium oxides: nickel / cobalt / manganese
- Major users include Sanyo (Panasonic) and GS Yuasa
- Good energy density
- Moderate safety (not as stable as LFP)

Source: Bloomberg New Energy Finance.
## ‘INCREMENTAL’ IMPROVEMENTS IN CATHODE CHEMISTRY

### CATHODE COMPOSITION

<table>
<thead>
<tr>
<th>Current NCM</th>
<th>LCO</th>
<th>LMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>Co</td>
<td>Mn</td>
</tr>
</tbody>
</table>

### LMO AND LCO PROPERTIES

**LCO: lithium cobalt oxide**
- Older technology (consumer batteries)
- Good energy density
- Poor safety / thermal properties

**LMO: lithium manganese oxide**
- Current technology (e.g. Nissan, GM, LG Chem)
- Good safety / thermal properties
- No expensive cobalt
- Lower energy density

Source: Bloomberg New Energy Finance.
**‘INCREMENTAL’ IMPROVEMENTS IN CATHODE CHEMISTRY**

<table>
<thead>
<tr>
<th>CURRENT NCM</th>
<th>LCO</th>
<th>LMO</th>
<th>FUTURE NCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>Co</td>
<td>Mn</td>
<td>Ni</td>
</tr>
</tbody>
</table>

**POSSIBLE FUTURE BLENDS OF NCM**

- **Less cobalt?**
  - Lower cost
  - Better safety / thermal properties
  - Similar performance

- **More nickel?**
  - Increases energy density

- **More manganese?**
  - Potentially much higher energy density and lower cost
  - Needs better electrolytes and anode
  - Very early stage

**Source:** Bloomberg New Energy Finance.
‘DISRUPTIVE’ CHANGE IN ANODE MATERIALS: SILICON

- Silicon theoretically absorbs 10x as many Li ions as graphite - much higher E density.
- Historic problem: silicon structures suffer from fatigue/pulverisation after a few cycles.
- Solution: nanostructures / nanowires.

- Axeon claims energy density improvement of 35%, Panasonic claims 20%.
- Panasonic and LG Chem aim to launch Si-anode consumer batteries in 2012-13.
- Only small cell formats being commercialised.

Source: Images from Nexeon.
‘DISRUPTIVE’ CHANGE IN ANODE MATERIALS: SILICON

Carbon anode:

$$6C + Li^+ + e^- \leftrightarrow LiC_6$$

Silicon anode:

$$4Si + 15Li^+ + 15e^- \leftrightarrow Li_{15}Si_4$$

Source: Images from Nexeon.
MAX CAPACITY OF 18650-FORMAT LI-ION CELLS (AH)

Source: Bloomberg New Energy Finance, Nikkei.
**CELL AND PACK DESIGN CHOICES**

### NUMBER OF CELLS IN MAIN EV MODELS

<table>
<thead>
<tr>
<th>Model</th>
<th>Number of Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Roadster</td>
<td>6,831</td>
</tr>
<tr>
<td>BMW Mini-E</td>
<td>5,088</td>
</tr>
<tr>
<td>Fisker Karma</td>
<td>315</td>
</tr>
<tr>
<td>Chevrolet Volt</td>
<td>288</td>
</tr>
<tr>
<td>Renault Fluence</td>
<td>192</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>192</td>
</tr>
<tr>
<td>Mitsubishi i-MiEV</td>
<td>88</td>
</tr>
</tbody>
</table>

### CONSIDERATIONS

**18,650 format** (consumer cells, 2-3Ah):
- Leverages decades of experience
- Sophisticated management system needed
- Not as applicable for PHEV

**Larger cells** (up to 50Ah):
- Easier packaging and thermal mgmt
- Greater potential for improvement with experience
- Second life considerations?
OTHER AREAS OF INNOVATION

THERMAL MANAGEMENT
- Air vs. liquid cooling
- Small vs. large cells
- Intra/inter-cell thermal gradients
- Use of CFD and advanced BMS

VEHICLE INTEGRATION
- Bespoke vehicle platforms
- Battery placing and design can impact:
  - Handling
  - Safety
  - Cost

Source: Images from Axeon.
CONCLUSIONS

• There will continue to be innovation at every step of the value chain
• There are no clear lines between ‘incremental’, ‘step-change’ and ‘disruptive’ innovation
• Innovation is non-linear and the experience curve hides many subtleties
• There will be winners and losers

• There are technologies that could ‘re-boot’ the experience curve: lithium-air, magnesium-ion, flow batteries, nanotube electrodes, etc...
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