EnerDel, Inc.

- Established in 2004
- Develop, manufacture lithium ion batteries
- Large format lithium ion cells
- Vertically integrated
- Transportation, grid storage, task-oriented
Grid and renewable energy storage

- Large grid storage installations
- Mobile microgrid products
Discussion points

Will one battery chemistry dominate, or are there opportunities for multiple chemistries?

Differences between consumer product batteries and industrial batteries

Evolution from cost per kWh to total cost per kWh throughput
Which chemistry, if any, will dominate?

• Lithium ion
  – family of chemistries

• Flow
  – inorganic
  – organic

• Liquid metal
  – sodium
  – magnesium, antimony
## Lithium ion – a family of chemistries

<table>
<thead>
<tr>
<th>Chemistry (positive, negative)</th>
<th>Energy density</th>
<th>Power density</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCO - graphite</td>
<td>✔ ✔ ✔ ✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>NMC - graphite</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>NMC - hard carbon</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔</td>
</tr>
<tr>
<td>NMC - LTO</td>
<td>✔ ✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔</td>
</tr>
<tr>
<td>LFP - graphite</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
</tbody>
</table>

- There are more types of lithium ion batteries
- All have different characteristics
Flow batteries - inorganic

- Anolyte and catholyte are pumped to the cell
- Long lifetimes
- Low energy density and energy efficiency
- Examples: vanadium, zinc-bromine
Flow batteries - organic

- Organic compounds with redox activity
- Understanding the economics
- In development
- Spent products may be easily disposable

Mann + Hummel website
Liquid metal batteries

- Operating temperature is high: molten metal
- Long lifetime, high energy density
- Energy efficiency may be low
- Can be inexpensive

NGK website
Lithium ion batteries comparison

<table>
<thead>
<tr>
<th>Consumer</th>
<th>Grid storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100s of cycles 2 to 5 years</td>
<td>1000s of cycles 10 to 20 years</td>
</tr>
<tr>
<td>high</td>
<td>Energy density low to high</td>
</tr>
<tr>
<td>low</td>
<td>Power density low to high</td>
</tr>
<tr>
<td>simple</td>
<td>Controls and thermal management</td>
</tr>
<tr>
<td>less</td>
<td>Requirements more</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cost of Energy

- Consumer products
  \[
  COE = \frac{\text{battery cost}}{\text{rated energy}}
  \]

- Grid storage systems
  \[
  COE = \frac{\text{total lifetime cost of ownership}}{\text{energy throughput} - \text{consumed energy}}
  \]

EnerDel, Inc.
Total lifetime cost of ownership

Initial
- Battery system with thermal management
- Site preparation
- Installation

Use
- Operation
- Maintenance
- Repairs

Final
- Decommissioning
- Recycling/disposal
- Cleanup
Energy throughput and consumed energy

• Energy throughput =
  Useable energy * cycle life * round trip efficiency

• Round trip efficiency =
  \[ \frac{\text{energy delivered during discharge}}{\text{energy supplied during charge}} \]

• **Consumed energy** is used during operation
  — Control cabinets, HVAC, pumps, etc.