Lithium ion battery supply chain in an energy storage revolution

University of Oxford, UK
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What is Benchmark?

Subscriptions

Lithium | Graphite
Cobalt | Nickel

Events

GRAPHITE SUPPLY CHAIN 2016
CATHODES 2017
BENCHMARK WORLD TOUR
Where do we operate in the supply chain?

<table>
<thead>
<tr>
<th>Upstream</th>
<th>Downstream</th>
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</thead>
<tbody>
<tr>
<td>Raw Materials</td>
<td>Batteries</td>
</tr>
<tr>
<td>Lithium</td>
<td>Battery Packs</td>
</tr>
<tr>
<td>Graphite</td>
<td>4-7 Wh</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Cells</td>
</tr>
<tr>
<td></td>
<td>Various form factors</td>
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<tr>
<td></td>
<td>(18650)</td>
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<tr>
<td></td>
<td>40-85 kWh</td>
</tr>
<tr>
<td></td>
<td>&gt;500 kWh</td>
</tr>
<tr>
<td>Semi processed</td>
<td>Battery Packs</td>
</tr>
<tr>
<td>Anode</td>
<td>7-10 kWh</td>
</tr>
<tr>
<td>products</td>
<td>Smartphone</td>
</tr>
<tr>
<td>Cathode</td>
<td>Home</td>
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<tr>
<td></td>
<td>EVs</td>
</tr>
<tr>
<td>Separators</td>
<td>Commercial</td>
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How do we do this?

- First hand data collection...

Heilongjiang, Northern China

Hirschau, Germany

Palo Alto, California, US
Convergence of three multi billion dollar industries: Auto, Tech, Energy

2017: The Era of the Semi Mass Market EV begins…

- Model 3 (60-65kWh lithium ion)
- Bolt (60kWh lithium ion)
- LEAF 2017 (60kWh lithium ion)
Emergence of the pure EV

- Battery Size Increases 4x
- Sales from 10,000s to 100,000s

2017:
- Tesla Model 3,
- Chevrolet Bolt
- Nissan LEAF III
  60-65kWh (Lithium ion)

Toyota Prius (1997)
1.3kWh (NMH Hybrid)

Nissan LEAF (2010)
24kWh (Lithium ion NCM)

Niche / Luxury
Semi-mass market

Rate of adoption is changing

US technology adoption rates from 10% to 90%

PC: 30 years
Cell: 13 years
Smartphone: 8 years

Source: BlackRock, Lithium Americas
Rate of adoption is changing: Smartphone

Days to 1 m handset sales

2014: Apple iPhone 6
- 7.2 hours

2007: Apple iPhone
- 72 Days

2005: Nokia N70
- 1 year

Source: Nokia, Apple, Benchmark Mineral Intelligence

Rate of adoption is changing: Tesla EVs

Tesla reservations in first 24 hours

2012: Model S
- 300
- $68,000 to $94,000

2015: Model X
- 8,000
- $110,000 to $144,000*
- $35,000

2016: Model 3
- 180,000

Source: Benchmark Mineral Intelligence, *price not disclosed on first day of reservations
Which battery types will win the EV race?

**Today: Fourth phase of battery commercialisation…**

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
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</thead>
</table>
| Watches Cars | Cell phones  
Power tools  
Personal music | Smartphones  
Tablets  
Laptops  
Hybrid cars | Full Electric vehicles  
Utility/Stationary storage |
| Mercury  
Lead acid | NiMH/Lithium-ion | Lithium-ion / NiMH | Lithium-ion                 |
| 1969 | Late-1990s      | 2006  2007  2010     |                             |

Source: Benchmark Mineral Intelligence
There is more than one type of lithium ion battery…

- Lithium Cobalt Oxide (LCO)
- Nickel Cobalt Manganese (NCM)
- Nickel Cobalt Aluminium (NCA)
- Lithium Iron Phosphate (LFP)
- Lithium Manganese Oxide (LMO)

Battery technology: where are we going?

Source: Panasonic, reproduced by Benchmark Mineral Intelligence
Manufacturing cost profile of a lithium ion battery and pack

**LITHIUM ION CELL**
- Bill of Materials, 60%
- Labor, Manufacturing, Energy, Other
- Margin

**BATTERY PACK**
- Cell Cost, 40%
- Energy Management System
- Other (incl. labor)
- Margin

*Source: Benchmark Mineral Intelligence*
Lithium ion battery demand expectations by 2025 (GWh)

- **A**
- **B**
- Goldman Sachs
- Benchmark
- Cairn ERA

70-75% EVs

Benchmark’s 2025 lithium demand based on battery forecasts

- **A**
- **B**
- Goldman Sachs
- Benchmark
- Cairn ERA

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Benchmark’s 2025 graphite demand based on battery forecasts

Benchmark’s 2025 cobalt demand based on battery forecasts
Rise of the lithium ion battery megafactory continues…

- Annual Cap 2016 (MW h)
- Expanded Capacity (MW h)

- 100GWh
- 35GWh
- 20GWh
The new lithium ion industry is a China story

Tesla is still important – business strategy/vertical integration

Europe is slow

New plants still being constructed in Japan / Korea, but focus on China

Megafactories by region

Megafactories to watch: Gigafactory, Nevada, US

Chemistry: Nickel Cobalt Aluminium (NCA)

- H1 2017 Est Cell Production Capacity: 4GWh
  - = 3,200 tonnes Lithium Hydroxide
  - = 4,800 tonnes Graphite Anode
  - = 600 tonnes Cobalt

- End-2020 Est Cell Production Capacity: 35 GWh
  - = 28,000 tonnes Lithium Hydroxide
  - = 42,000 tonnes Graphite Anode
  - = 5,250 tonnes Cobalt
Megafactories to watch: Dalian, China

Chemistry: Nickel Cobalt Aluminium (NCA)

- H1 2017 Est Cell Production Capacity: 3GWh
  - = 2,400 tonnes Lithium Hydroxide
  - = 3,600 tonnes Graphite Anode
  - = 450 tonnes Cobalt

- End-2020 Est Cell Production Capacity: 9 GWh
  - = 7,200 tonnes Lithium Hydroxide
  - = 10,800 tonnes Graphite Anode
  - = 1,350 tonnes Cobalt

Megafactories to watch: NingDe, China

Chemistry: Nickel Cobalt Manganese (NCM)

- H1 2017 Est Cell Production Capacity: 5GWh
  - = ~3,500 tonnes Lithium Carbonate
  - = ~6,000 tonnes Graphite Anode
  - = ~1,700 tonnes Cobalt

- End-2020 Est Cell Production Capacity: 100 GWh
  - = ~75,000 tonnes Lithium Carbonate
  - = ~120,000 tonnes Graphite Anode
  - = ~11,000 tonnes Cobalt
The result? Battery cell costs continue decline…

2000 to 2015: 12-14% a year

2016-2020: 15-20% a year

Lithium ion cell costs ($/per kWh)

Is there enough lithium?
Battery raw materials have hit the headlines

Why has lithium hit the headlines?

Lithium Carbonate
$12,313/tonne (March 2017)

Lithium Hydroxide
$17,000/tonne (March 2017)
Lithium Price Performance Year by Year

Lithium Carbonate (ex-China) Price Trend: Average YoY

1 year where prices declined in a decade

Source: Benchmark Mineral Intelligence Data, Lithium Price Assessments

Is there enough lithium?

World Lithium Resources (LCE) 210m tonnes
- Argentina 55m tonnes (26%)
- Chile 50m tonnes (24%)
- Bolivia 32m tonnes (15%)
- Australia 30m tonnes (14%)
- China 15m tonnes (7%)

World Lithium Reserves (LCE) 14m tonnes

World Lithium Production (LCE) 180,000 tonnes

Source: USGS
Is there enough lithium?

94,976,569
Cars and Commercial Vehicles sold in 2016

22,871,134
Commercial vehicles

72,105,435
Cars

3,430GWh (150kWh av)
Lithium ion battery production >12,000%

5,047GWh (70kWh av)
Lithium production up 3,735%

2.74m tonnes LCE

6.74m tonnes LCE

Source: OICA

= 50% global reserves
= 3% global resources

How much investment is needed?

$1bn raised

$520m raised

1

= 20,000 tonnes LCE
Should have = 50,000 tpa
1 expensive bankruptcy
2 failed chemical plants
40% misallocated capital

2

= 25,000 tonnes
More to come
Investors more cautious but further down education path

Source:
Benchmark Mineral Intelligence

Lithium Carbonate Low
Lithium Carbonate High
Lithium Hydroxide Low
Lithium Hydroxide High
What investment is needed?

~$400m

Brine Mine

Hard Rock Mine

~$500m

25,000 tpa
Battery Grade
Lithium Plant

25,000 tpa of feedstock that needs chemical conversion

Source: House Mountain Partners, Benchmark Mineral Intelligence

What investment is needed?

Incremental Lithium Needed

2020 = 100,000 tonnes LCE =

$1.7bn
50% allocated by end 2017

2025 = 150,000 tonnes LCE =

$2.5bn
0% allocated by end 2017

Source: House Mountain Partners, Benchmark Mineral Intelligence
Where will the most profitable sit?

**Upstream**
- Raw Materials
  - Lithium
  - Graphite
  - Cobalt
- Battery Grade Materials
  - Anode
  - Cathode
  - Separators

**Batteries**
- Cells
- Various form factors (18650)

**Battery Packs**
- 4-7 Wh
- 7-10 kWh
- 40-85 kWh
- >500 kWh

**Downstream**
- Mobile / EV / Utility
- Smartphone
- Home
- EVs
- Commercial

Other trends to watch
Corporate Social Responsibility

Green Batteries' Graphite Adds to China Pollution
Green batteries’ graphite adds to China pollution. As more environmentally conscious Americans do their bit to help clear the air by paying up for an eco-friendly Prius or a sporty Tesla, a damaging form of polluted rain is falling from the skies.

@TeamAizek Not true. The amount of graphite in our car is small, comes from Japan and is mined in a very clean way.

THE COBALT PIPELINE
Tracing the path from deadly hand-dug mines in Congo to consumers’ phones and laptops

Child Labor Revelation Prompts Apple to Make Supplier Policy Change
Recycling

Tesco aims for battery raw material recycling by 2020

Lithium tops supply chain concerns as the Gigafactory nears launch; nickel, aluminium and cobalt also targeted for recovery

Where will Gigafactory’s batteries be used?

- Tesla seeking to recycle its batteries post 2020
- Gigafactory cells will not have second life in utility storage post 80% capacity
- No major plans in place yet, just an initiative for spent batteries

Recycling

- Recycling about responsibly disposing of batteries
  - Extracting hazardous waste
  - Forcing companies to think about manufacturing

- Not likely to be about raw material supply
  - Cobalt opportunity
  - Nickel opportunity
  - Lithium & Graphite unlikely before 2023 (economics)

Credit: Bloomberg
“Change occurs when people are busy discussing whether change will occur.”