Battery Market Development for Consumer Electronics, Automotive, and Industrial: Materials Requirements and Trends

Christophe PILLOT
Director, AVICENNE ENERGY

Presentation Outline
• The rechargeable battery market in 2014
• The Li-ion battery value chain
• Li-ion battery material market 2014 - 2025
• Forecasts & conclusions
AVICENNE ENERGY: RENOWNED TO HAVE REALISTIC FORECASTS

HEV powered by Lithium ion battery forecasts from 2008 to 2014

EV sold, in million units, worldwide, 2010 - 2020

THE BATTERY MARKET IS REALLY DYNAMIC

Cellular Phones sold per Year (Million)

- LI-ion
- NiMH

Portable PC sold per Year (Million)

- LI-ion
- 230 M Tablets
- 170 M Portable PCs

Tons of Li-ion Cathode per year

Li-ion 18650 cell price ($/Wh)

Source: AVICENNE ENERGY Analyses 2015
THE WORLDWIDE BATTERY MARKET
1990-2015

Lithium Ion Battery: Highest growth & major part of industry investments

Source: AVICENNE ENERGY, 2015

2015: Estimations

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Qinghai EV Rally 2015
June 15-18, Xining, China
THE WORLDWIDE BATTERY MARKET
1990-2015

Lithium Ion Battery: Highest growth & major part of the investments
Lead acid batteries: By far the most important market (90% market share)

Source: AVICENNE ENERGY, 2015
2015: Estimations
THE WORLDWIDE BATTERY MARKET
1990-2015

60 BILLION US$ in 2014 – Pack level
5% AVERAGE GROWTH PER YEAR (1990-2014)

SLI: Start light and ignition batteries for cars, truck, moto, boat etc...
PORTABLE: consumer electronics (cellular, portable PCs, tablets, Camera, ...), data collection & handy terminals,
PPOWER Tools: power tools but also gardening tools
INDUSTRIAL
• MOTIVE: Forklift (95%), others
• STATIONARY: Telecom, UPS, Energy Storage System, Medical, Others (Emergency Lighting, Security, Railroad Signaling, Diesel Generator Starting, Control & Switchgear,

AUTOMOTIVE: HEV, P-HEV, EV

OTHERS: Medical: wheelchairs, medical carts, medical devices (surgical power tools, mobile instrumentation (x-ray, ultrasound, EKG/ECG, large oxygen concentrators
1- Pack: cell, cell assembly, BMS, connectors – Power electronics (DC DC converters, invertors...) not included

Source: AVICENNE ENERGY, 2015
THE WORLDWIDE BATTERY MARKET IN 2014: US $ 60 BILLION

Battery market in 2014 (M$)

1- Pack level: Pack including cells, cells assembly, BMS, connectors – Power electronics (DC DC converters, invertors…) not included.

Source: AVICENNE ENERGY, 2015
LI-ION IN 2014
MAIN APPLICATIONS: CELLULAR, NOTEBOOK

5 400 M cells –46 000 MWh
13 600 M$ (2)

CAGR 2004/2014
+21 % per year in Volume
+14% per year in value

Li-ion Battery sales,
MWh, Worldwide, 2000-2014 (1)

Table: Cell level

- 5 400 M cells
- 46 000 MWh
- 13 600 M$

- CAGR 2004/2014
  - +21 % per year in Volume
  - +14% per year in value

(1) 2015 estimation data
(2) Cell level
LI-ION IN 2014
MAIN APPLICATIONS: CELLULAR, NOTEBOOK

5 250 M cells – 45 000 MWh
13 300 M$ (2)

CAGR 2004/2014
+20 % per year in Volume
+14% per year in value

Battery Market
Development for
Consumer Electronics,
Automotive, and
Industrial: Materials
Requirements and
Trends

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(1) 2015 estimation data
(2) Cell level
BATTERY PRICE IS DECREASING DRASTICALLY

In 10 Years 80% price decreasing despite a fluctuating Co price

Average LIB cell price ($/Wh)

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Production capacity 2009/2011: from 150 to 250 M cells/month

18650 oversupply ratio is decreasing thanks to TESLA

Source: LME
LI-ION VALUE CHAIN – MARKET DEMAND

**CATHODE**
- 105,000 T in 2014
- Revenues: 2.5 B$
- CAGR 04/14: +16%

**ANODE**
- 57,000 T
- Revenues: 0.8 B$
- CAGR 03/13: +14%

**ELECTROLYTE**
- 44,000 T
- Revenues: 0.68 B$
- CAGR 04/14: 20%

**SEPARATOR**
- 695 M m²
- Revenues: 1.15 B$
- CAGR 04/14: 18%

**BINDER**
- 7,100 Tons
- Revenues: 0.2 B$
- CAGR 08/13: 15%

**ANCILLARY**
- Revenues: 0.7 B$

**CELL MANUFACTURERS**
- Revenues: 13.6 B$
- Gross margin: <10%

**PACK MANUFACTURERS**
- Revenues: 19.6 B$
- Gross margin: <10%

**OEMs**
CATHODE ACTIVE MATERIALS NEEDS BY CHEMISTRY

Cathode active materials for LIB in Tons, 2000-2014 (Demand)

LEADERS:

NEW ENTRANTS ON THE FIELD:

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CATHODE ACTIVE MATERIAL FORECASTS 2000-2025

Cathode active materials 2000-2025 - Tons

- Portable devices: 2013-2025: +11% per year in volume
- HEV
  - 4.8 M HEV/year in 2020 - 35% LIB
  - 6.8 M HEV in 2025 90% LIB
- P-HEV
  - 0.4 M P-HEV/year in 2020, 0.7 M in 2025
    100% LIB
- EV
  - 1M EV/year in 2020, 1.5M/year in 2025
    100% LIB
- Industrial & stationary
  - 2013-2025: +16% per year

Cathode active materials in 2014: > 100 000 Tons

- LCO 10%
- LMO 20%
- NMC 25%
- NCA 9%
- LFP 10%

Cathode active materials in 2025: > 300 000 Tons

- LCO 26%
- LMO 9%
- NCA 14%
- NMC 25%

Assumption: Tesla keep NCA chemistry and have a relative success (200 000 EV sold per year in 2025 – TESLA forecast 500 000)

LFP part could be higher thanks to explosion of Chinese EV market
ANODE ACTIVE MATERIALS

> 55 000 TONS IN 2014

LIB Anode Materials

Source: A. Jossen, IRES 2007

LIB Anode market, (Tons)

Source: Hitachi Chemical

Source: Sanyo, March 2011

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ANODE FOR LIB IN 2014

Natural graphite become a commodity

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LEADERS:

NEW ENTRANTS ON THE FIELD:

Note: MCMB: Mesocarbon Microbeads

Carbon for LIB anodes by type (2014)
SEPARATOR MARKET
MAJOR PLAYERS

In February 2015, ASAHI announced that they will acquire all Polypore shares in the Energy Storage segment: Asahi Kasei to pay around $2.2 billion to purchase Polypore’s battery separator business.

Separator market in volume (Mm²) by suppliers – CAGR 04/14: +16%  

Separators market shares in 2014 in volume – > 650 M²

Source: AVICENNE ENERGY Analyses

NEW ENTRANTS ON THE FIELD:

Evonik, TEIJIN, HIFUTURE, UBE-MAXELL (…)

LEADERS:

Asahikasei, Celgard, Toray, Ube, SK, Sumitomo, Jinhui, TDK, TONEN, ENTEK, Green, Senior, Other Wet, Other Dry, Celeniy, HIFUTURE, Ube-Maxell (…), Dow, Dupont, LG Chem, Mitsubishi.
ELECTROLYTE SUPPLIERS/CUSTOMERS
44 000 TONS IN 2014

LIB electrolyte market, Tons, CAGR 2004/2014: +23%

LIB electrolyte supplier, market share in 2014

LEADERS:
MITSUBISHI
panaX etec
UBE
JINNIU

NEW ENTRANTS ON THE FIELD:
LG Chem
BASF
DUPONT
DAIKIN

Note: (1) GTHR: Zhangjiagang Guotai-Huarong

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LIB ELECTROLYTE MARKET 2005-2014

Electrolyte maker sales 2005-2014

(1) Full electrolyte formulation in-house
(2) Panax-Etec bought Samsung Chiel activities in 2010
CELLULAR PHONES
FORECASTS 2010-2025

Cellular phones demand (M Units)
CAGR 2010-2025: +6%

LIB cells demand 2014-2025
Polymer penetration: 50% -> 75%

Cellular Phones market Drivers
Emergent market
Renewal ratio increase
Smartphone penetration increase

LIB cells for cellular phones trends
Laminates ratio increase
Increase of Thickness
Increase of >1400 mAh capacity
PORTABLE PCS FORECASTS 2010-2025

Portable PCs demand (M Units)
2014-2025 – Almost stable

- Mature market stable or decreasing
- Growth driven by Emerging market
- Ultrabook is increasing (20\(^{(1)}\) to 60% in 2013\(^{(2)}\))
- ASP decreasing (<499$ Portable PCs increase from 25% in 2010 to 33% in 2012

(1) Samsung & AVICENNE (2) Intel

LIB cells demand 2014-2025
Polymer penetration: 20% -> 40%

- Thinner cells
- Polymer penetration increasing from 7% in 2010 to 28% in 2025
- > 2800 mAh for Premium/corporate
- 2.2 Ah for consumer, emerging market

Source: AVICENNE ENERGY Analyses
2025 LIB FORECASTS FOR PORTABLE ELECTRONIC DEVICES

2000-2025 LIB market, MWh, by application (3C)

2000-2025 LIB market, M cells, by form factor (3C)

Source: AVICENNE ENERGY Analyses

(1) Source: Takeshita, Battery Japan 2013 BJ-3 conference Slide p 4
WHY X-EV?

MAJOR DRIVER: CO₂ regulation worldwide: From 2013 to 2014
Oil price decrease but HEV sales increase by 5%, P-HEV by 30% and EV by 60%

Petroleum consumption worldwide 1960-2030

Source: Energy Information Administration, US Government

Gasoline Price – US$ / Gallon

Source: http://www.eia.doe.gov/emeu/steo/pub/contents.html

Note
1 WTI: West Texas Intermediate
HEV WORLDWIDE IN 2014
2 M HEV

HEV sold per year, M units, worldwide, 2000 - 2014

Penetration of hybrids in the global sales, 2000-2014

Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
Micro hybrid not included

Growth 2013-2014: +5%
From 1,9 M to 2 M HEV
P-HEV & EV SALES 2010-2014 (YEARLY)

Source: AVICENNE ENERGY Analyses
LIB MANUFACTURING INVESTMENTS 2009-2015

10-12 B$ WORLDWIDE  >50 GWh invest from 2011 to 2014
< 7 B$ invested from 2014 to 2017 by TESLA (5), BYD (1,2), ATL (1)

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Source: AVICENNE ENERGY Analyses 2015
SAFETY ISSUES

Li-ion and LMP are not thermally stable what raises serious safety concerns

**Background**
In the 80’s, lithium metal batteries were put into the markets (Moli Energy). Their further development has for a long time been slow because of a low cycle efficiency and safety issues: High chemical reactivity and a low melting point enable strong chemical reactions, even explosions. In the charging-discharging process, lithium metal can form dendrite and accumulate on electrodes. The growing lithium dendrite could puncture the separator and result in an internal short circuit.

- **CONSEQUENCES:** Except BOLLORE, all the companies developing Li metal batteries cancelled their projects

**Mobile**
Li-ion batteries for mobile devices mostly used a Lithium Cobalt Oxide Cathode and liquid electrolyte.
In case of overcharging or short-circuit (contact between anode & cathode) a chain reaction starts: heating & gasing -> fire (“Thermal runaway”)

**CONSEQUENCES:** In 2006, SONY had to recall millions of portable PCs for total costs of 400 million USD, more than there profit-to-date

**Automotive**
With new cathode chemistry, most of the automotive today on the markets experienced safety concerns:

1. BYD Taxi in China with a lithium iron phosphate cathode
2. GM Volt in the US with a LG Chemical battery using LMO cathodes (as a result of a crashed tested Chevrolet Volt caught three weeks after the testing !)
3. PRIUS P-HEV in the US (converted from HEV Prius by a local engineering company without any authorisation by Toyota)

**Aircraft**
Boeing 787: The fire that burned near the tail of a parked Boeing 787 in Boston was caused by an overheating Lithium ion battery pack. The battery fire could have been hot enough to melt the carbon-fiber reinforced plastic that makes up the plane’s shell.

**CONSEQUENCES:** All the 787 worldwide are grounded. Considerable losses for Boeing.
SAFETY IS A SINE-QUA-NON SELECTION CRITERIA FOR BATTERY TECHNOLOGIES

Some technologies are already out of the game due to stability issues

<table>
<thead>
<tr>
<th>Cathode</th>
<th>LCO</th>
<th>NMC</th>
<th>LMO</th>
<th>LFP</th>
<th>High V</th>
<th>Sulfur</th>
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<tbody>
<tr>
<td>SAFETY</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>xEV ?</td>
<td></td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Anode</th>
<th>Graphite</th>
<th>Hard Carbon</th>
<th>Soft Carbon</th>
<th>LTO</th>
<th>SiC</th>
<th>Li Metal</th>
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<tr>
<td>SAFETY</td>
<td>NO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>xEV ?</td>
<td>YES</td>
<td>YES</td>
<td>No (1)</td>
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<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Liquid</th>
<th>Additive</th>
<th>Gel Polymer</th>
<th>5 V</th>
<th>Polymer membrane</th>
<th>Solid</th>
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</thead>
<tbody>
<tr>
<td>SAFETY</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td></td>
<td>YES</td>
<td>&gt; 2025</td>
</tr>
<tr>
<td>xEV ?</td>
<td>YES</td>
<td>YES</td>
<td>No</td>
<td></td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Separator</th>
<th>PP, PP membrane</th>
<th>- coating</th>
<th>Non woven</th>
<th>Polymer membrane</th>
<th>Solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAFETY</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>&gt; 2025</td>
</tr>
<tr>
<td>xEV ?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>

BMS
- Most of the BMS function is to manage the safety of the cell & the battery pack:
  - Overcharge management
  - Over voltage management

Packaging
- Use “safer” material in the pack:
  - Flame retardant,
  - High shock resistance

Thermal
- Thermal management improve both the safety and the life time

Very Safe(Unsafe)

(1) Low energy density; mostly developed for stationary applications, or LV start light & ignition batteries

The lithium ion technologies that win will win partly on their safety argument, possibly sacrificing some energy density.
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TIME TO MARKET FOR NEW MATERIALS IN LIB INDUSTRY

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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>CATHODE</td>
<td>LCO</td>
<td>NMC/NCA</td>
<td>LMO</td>
<td>LiNiMnO₂</td>
<td>5v spinel</td>
<td>Sulfur</td>
<td>Air</td>
</tr>
<tr>
<td>ANODE</td>
<td>Graphite</td>
<td>Li₄Ti₅O₁₂</td>
<td>Soft Carbon</td>
<td>Li₄Ti₅O₁₂</td>
<td>C/Alloy Composite</td>
<td>Li Metal</td>
<td>Si Alloys</td>
</tr>
<tr>
<td>ELECTROLYTE</td>
<td>LiPF₆ + Org. solvents</td>
<td>LiPF₆ free electrolyte</td>
<td>Gel-polymer electrolyte</td>
<td>5v electrolyte</td>
<td>Polymer membrane</td>
<td>Solid Electrolyte</td>
<td></td>
</tr>
<tr>
<td>SEPARATORS</td>
<td>Polyelefin</td>
<td>Polyelefin+ ceramic coating</td>
<td>Cellulose</td>
<td>Cellulose</td>
<td>Cellulose</td>
<td>Cellulose</td>
<td>Cellulose</td>
</tr>
</tbody>
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AVICENNE ENERGY - CONFIDENTIAL INFORMATION
LIB CELL BILL OF MATERIALS

**NISSAN LEAF**

- **Cu Foil**
- **NMC**
- **LFP**
- **AI & Ni**

**BOLLORE BLUE CAR**

- **AI Foil**
- **POE**
- **PVDF**
- **LiTFSi**

**GM VOLT**

- **Cu Foil**
- **NMC**
- **LFP**
- **PP3 Dry + coating**

**BMW ACTIVE HYBRID 5**

- **Cu Foil**
- **NMP**
- **PP3 Dry**
- **AUPP laminate foil**

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AVICENNE ENERGY - CONFIDENTIAL INFORMATION
LI-ION BATTERY COST
2014-2020

LIB cell average cost (36Ah pouch)
(EV design; LMO/NMC cathode)

LI-ION BATTERY PACK COST
FOR EV

(1) Active materials only

* For Production > 100 000 packs/year
EV, P-HEV, EV 2025 FORECASTS

Scenario 2: thanks to very high incentives, China could change the game

S1: HEV, P-HEV & EV market forecasts up to 2025

S2: HEV, P-HEV & EV market forecasts up to 2025

25 kEV were sold in China in 2013. More than 55 kEV was sold in only one month in December 2014! Full Year 2014 sales: 77 kEV

2010 2014 2015 2020 2025

Million cars

EV in China
P-HEV in China
HEV in China
EV
P-HEV
HEV

0,9 0,35 0,17 3,2 5
0,9 1,9 2,1 3,2 5

Million cars

0 1 2 3 4 5 6 7 8 9 10

2010 2014 2015 2020 2025

Qinghai EV Rally 2015
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TOTAL BATTERY DEMAND 2025 FORECASTS

Scenario 2: thanks to very high incentives, China could change the game

EV, HEV & P-HEV Battery needs (MWh)
CAGR 2014-2025: +16% / S2:+22%

Total battery demand (MWh)
CAGR 2014-2025: +11% / S2: +13%
35 MILLION MICRO-HYBRIDS CAR IN 2020

Micro-hybrids car market
2010-2020

Micro-hybrid batteries
- Powered today by Advanced lead acid batteries (sometimes in conjunction with super capacitors)
- LTO will also penetrate this market (Toshiba -> Suzuki)
- Panasonic develop new NiMH cell to address the micro-hybrid market

Advantages of micro-hybrid compared to HEV
- Much more profitable than full HEV: 8 to 10 times less expensive than full HEV to save 5% gasoline instead of 20% (4 times less)
- Much more impact on CO2

<table>
<thead>
<tr>
<th>Micro-hybrid</th>
<th>Full HEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>Advanced lead acid</td>
</tr>
<tr>
<td>Cost ($)</td>
<td>300</td>
</tr>
<tr>
<td>Fuel saving</td>
<td>5%</td>
</tr>
<tr>
<td>Million Vehicle sold per year in 2020</td>
<td>35</td>
</tr>
</tbody>
</table>
HEV, P-HEV AND EV REALITY OF THE MARKET WILL BOOST MICRO HYBRID AND ADVANCED LEAD ACID BATTERIES

2010

STANDARD CAR
88.5%

MICRO HYBRIDS
10%

MILD HEV
0.5%

FULL HEV
1%

2015

Standard Lead acid Batteries

Advanced Lead acid

NIMH

2020

STANDARD CAR
< 44%

MICRO HYBRID
> 50%

FULL HEV
4%

2010

2015

2020

AFTER

ULTRA BATTERY

Li-ion

Li-Air, Li-S, Fuel Cells
“OTHER APPLICATIONS”
10 B$ POTENTIAL MARKET¹

Battery market in 2012 (M$)

Battery market in 2020 (M$)

Source: AVICENNE ENERGY, 2013

For Power tools, NiCd batteries are used rather than lead acid batteries.

1- Pack level
LI-ION CELL & PACK MARKET DETAILS

2014 - 2025

- Portable: from 29 to 65 GWh
- Automotive: from 10 to 60 GWh / S2: 100 GWh
- Others: from 7 to 32 GWh

Li-ion cell market (B$)

Li-ion Pack market\(^1\) (B$)

1. Pack: cell, cell assembly, BMS, connectors – Power electronics (DC DC converters, invertors...) not included
2. Others: Batteries for Power tools, E-bikes, Industrial, medical...

S2: Chinese EV market explosion

Source: AVICENNE ENERGY Analysis 2014
TAKEAWAYS

Battery Market 2010-2025
CAGR = +10%

- Li-ion battery is driven today by Portable PCs & electronic devices (smartphones, tablets)
- For HEV, the battery technology is today the NiMH
- In 2012, most of the car makers (except Toyota) switch to Li-ion
- P-HEV & EV will be powered by Li-ion: 6 B$ market in 2015 - 11 B$ in 2020 & 15 B$ in 2025
- EV expectations attract large Chemical companies
- New materials are needed to meet Automotive standards
- HEV will account for less than 5% of the automotive sales in 2020
- P-HEV & EV < 2% by 2020
- Micro-hybrid will achieve >50%
- Lead acid battery will be the first market in 2025 in volume & value
- A very small EV market in the automotive world will represent a huge market for batteries
- New LIB applications: UPS, Telecom, Forklift, Medical, Residential ESS, Grid ESS: CAGR > 15% in the next 15 years
- In 2020, Energy storage will represent less than 5% of the total battery market
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