The Rechargeable Battery Market and Main Trends 2016-2025

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Director, AVICENNE ENERGY

Presentation Outline
• The rechargeable battery market in 2016
• The Li-ion battery value chain
• Li-ion battery material market
• Forecasts & conclusions
AGENDA

The market in 2016 by technology, applications & battery suppliers

Li-ion components market & value chain
- Raw materials market
- Supplier / customer relationship
- Raw material cost
- New entrants strategy
- Raw material road map 2000-2030

xEV market in 2016
xEV forecasts up to 2025
Industrial, stationary & ESS applications 2016-2025
Rechargeable battery market forecasts up to 2025
AVICENNE ENERGY: RENOWNED TO HAVE REALISTIC FORECASTS

HEV powered by Lithium ion battery forecasts from 2008 to 2016

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

THE BATTERY MARKET IS REALLY DYNAMIC

Cellular Phones sold per Year (Million)

<table>
<thead>
<tr>
<th>Year</th>
<th>Li-ion</th>
<th>NiMH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
<td>165</td>
</tr>
<tr>
<td>2016</td>
<td>3000</td>
<td>195</td>
</tr>
</tbody>
</table>

Portable PC sold per Year (Million)

<table>
<thead>
<tr>
<th>Year</th>
<th>Li-ion</th>
<th>Tablets</th>
<th>Portable PCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
<td>195 M</td>
<td>165 M</td>
</tr>
<tr>
<td>2016</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
</tbody>
</table>

Tons of cathode active materials

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>6900</td>
</tr>
<tr>
<td>2016</td>
<td>178000</td>
</tr>
</tbody>
</table>

Li-ion 18650 cell price ($/Wh)

<table>
<thead>
<tr>
<th>Year</th>
<th>$/Wh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>2.6</td>
</tr>
<tr>
<td>2016</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Source: AVICENNE ENERGY, 2017

The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA
THE WORLDWIDE BATTERY MARKET
1990-2016

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

Source: AVICENNE ENERGY, 2017
THE WORLDWIDE BATTERY MARKET 1990-2016

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, 2017
THE WORLDWIDE BATTERY MARKET
1990-2016

65 BILLION US$ in 2016 – Pack level¹
5% AVERAGE GROWTH PER YEAR (2000-2016)

SLI: Start light and ignition batteries for cars, truck, moto, boat etc...
PORTABLE: consumer electronics (cellular, portable PCs, tablets, Camera, ...), data collection & handy terminals,
POWER Tools: power tools but also gardening tools

1- Pack: cell, cell assembly, BMS, connectors — Power electronics (DC-DC converters, invertors...) not included

Source: AVICENNE ENERGY, 2017
THE WORLDWIDE BATTERY MARKET IN 2016: US $ 65 BILLION

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

Source: AVICENNE ENERGY, 2017
WORLDWIDE BATTERY SALES BY CHEMISTRY, UNITS, 1995-2015

The worldwide rechargeable battery market, Million cells, 1995-2016

Which cell are we talking about?

Source: AVICENNE ENERGY, 2017
The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA

WORLDWIDE BATTERY SALES BY CHEMISTRY, MWH, 1995-2016

The worldwide rechargeable battery market, in volume, MWh, 1995-2016

Source: AVICENNE ENERGY, 2017
WORLDWIDE BATTERY SALES BY CHEMISTRY, M$, 1995-2016

The worldwide rechargeable battery market, in value, M$, 1995-2016 (1)

2006 – 2016 CAGR): +13%
NiCd: -6% per year
NiMH: +2% per year
Li-ion: +16% per year

Source: AVICENNE ENERGY, 2017

(1) Cell level

2016: AVICENNE Estimation
EACH BATTERY TECHNOLOGY HAS ITS SPECIFIC ABSOLUTE ADVANTAGES

<table>
<thead>
<tr>
<th>Advantage of...</th>
<th>Lead Acid</th>
<th>Nickel Cadmium NiCd</th>
<th>Nickel Metal Hydride NiMH</th>
<th>Lithium-Ion</th>
<th>Conventional</th>
<th>Laminate</th>
</tr>
</thead>
<tbody>
<tr>
<td>...On</td>
<td>energy density</td>
<td>Gravimetric energy density</td>
<td>Gravimetric energy density</td>
<td>energy density</td>
<td>Gravimetric energy density</td>
<td>Gravimetric energy density</td>
</tr>
<tr>
<td></td>
<td>Operating temperature</td>
<td>Volumetric energy density</td>
<td>Volumetric energy density</td>
<td>Operating temperature</td>
<td>Volumetric energy density</td>
<td>Volumetric energy density</td>
</tr>
<tr>
<td></td>
<td>Self discharge rate</td>
<td>Voltage output</td>
<td>Voltage output</td>
<td>Self discharge rate</td>
<td>Voltage output</td>
<td>Self discharge rate</td>
</tr>
<tr>
<td></td>
<td>Reliability (progressive extinction)</td>
<td>Self discharge rate</td>
<td>Self discharge rate</td>
<td>Design characteristics</td>
<td>Design characteristics</td>
<td>Design characteristics</td>
</tr>
</tbody>
</table>

- **Lead Acid**
  - Energy density
  - Operating temperature
  - Self discharge rate
  - Reliability (progressive extinction)

- **Nickel Cadmium NiCd**
  - Higher cyclability
  - Voltage output
  - Price

- **Nickel Metal Hydride NiMH**
  - Higher cyclability
  - Voltage output
  - Price

- **Lithium-Ion**
  - Conventional
    - Higher cyclability
    - Price
    - Safety
    - Recyclability
    - Operating temperature range
    - Higher cyclability
    - Price
    - Safety
    - Discharge rate
    - Recyclability

  - Laminate
    - Higher cyclability
    - Price
    - Recyclability
    - Operating temperature range
    - Higher cyclability
    - Price

- **Absolute advantages**
  - Higher cyclability
  - Price

**Source:** AVICENNE ENERGY, 2017
JAPANESE, CHINESE & KOREAN MARKET SHARE

Japanese market share (value) decreasing: from 84% of the market in 2000 to < 30% in 2016

Battery(1) market by country

LIB market by country

(1) Excluding lead acid batteries
Source: AVICENNE ENERGY, 2017
The worldwide NiCd battery market Company market share in 2016 in volume – 830 M cells

**In volume**

<table>
<thead>
<tr>
<th>Companies</th>
<th>Million cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANYO-PANASONIC</td>
<td>320</td>
</tr>
<tr>
<td>SAFT</td>
<td>50</td>
</tr>
<tr>
<td>GOLD PEAK</td>
<td>40</td>
</tr>
<tr>
<td>BYD</td>
<td>300</td>
</tr>
<tr>
<td>OTHERS</td>
<td>120</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>830</strong></td>
</tr>
</tbody>
</table>

**In value**

Source: AVICENNE ENERGY, 2017

Fumio Ohtsubo (Panasonic) & Seiichiro Sano (Sanyo) January 8th, 2012

NICD BATTERY: MARKET SHARE IN 2016 IN VOLUME WORLDWIDE
NICD IN 2016
MAIN APPLICATION: POWER TOOLS

830 M cells – 2250 MWh
526 M$\textsuperscript{1}

NiCd by application worldwide, % in value, 2015

Security lighting 11%
Others 18%
Power Tools 71%

CAGR 2006/2016
-3% per year in volume
-6% per year in value

- All the applications are decreasing
- Competition with NiMH & Li-ion
- New application (?)
  - Energy storage

Note:
\textsuperscript{1} Portable applications, power tools and emergency lighting only: industrial application as well as energy storage are excluded

Source: AVICENNE ENERGY, 2017

ABB Inc., Fairbanks, Alaska, 27 MW/15 minutes

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Source: AVICENNE ENERGY, 2017

ABB Inc., Fairbanks, Alaska, 27 MW/15 minutes
NIMH BATTERY: MARKET SHARE IN 2016 WORLDWIDE

The worldwide NiMH battery market
Company market share in 2016 in volume – 1020 M cells

The worldwide NiMH battery market
Company market share in 2016 in value – 1150 M$

Note:
1 PEVE: Primearth EV Energy (PEVE) The company was known as Panasonic EV Energy Co until 2 June 2010. The company was formed in 1996 as a joint venture between Toyota and Panasonic, with Panasonic holding 60% of the capital. Panasonic sold 40.5% of the company to Toyota. PEVE is the supplier of the NiMH battery packs for Toyota’s hybrids, as well as for Honda (Civic hybrid and first generation Insight) hybrids. The company also provides the NiMH prismatic battery modules for the General Motors
2 Japan’s Sanyo Electric Co sold part of its battery operations to FDK Corp a Fujitsu Ltd unit, for 6.4 billion yen ($70 million) to satisfy antitrust regulators ahead of its planned takeover by Panasonic Corp at the end of 2009.

Source: AVICENNE ENERGY, 2016
NIMH IN 2016
MAIN APPLICATION: HYBRID VEHICLES

1 020 M cells – 2 700 MWh
1.15 B$(1)

CAGR 2006/2016
+2% per year in Volume
+2% per year in value

NiMH battery market worldwide in value
% for HEV application

NiMH battery by applications, worldwide, % in value, 2016

(1) Cell based market – 1,45 B$ at the pack level
Source: AVICENNE ENERGY, 2016
LI-ION BATTERY: MARKET SHARE IN 2015/2016 WORLDWIDE

The worldwide Li-ion battery market
Company market share in 2016 in volume
(small cells only) 5675 M cells

The worldwide Li-ion battery market
Company market share in 2015 in value
– 18,4 B$ (Estimated at B$ 20,6 in 2016)

Others for Small cells: Chinese suppliers like First new Energy, Zhuoneng, Tenpower, DLG... For Auto market: CALB, Microvast, Guoxuan, Optimum Nano, Wanxiang, and many others

(1) Cell level. LIB battery pack market: > 20 B$ in 2015 and 24,4 B$ estimated for 2016
Source: AVICENNE ENERGY Analyses 2016
MAJOR LI-ION MANUFACTURERS YEARLY PRODUCTION 2001-2016

Samsung SDI & LG Chem are growing very fast

Panasonic acquired Sanyo in Dec 2009

Source: AVICENNE ENERGY Analyses 2016
Cylindrical LIB market Company market share in 2016 in volume: 2330 Million cells (+6%)

Key success factor

- Production speed (-> cost)
- Performances
- Customer (Portable PCs) access

### Production Speed: 18650 – 2.8Ah cells

<table>
<thead>
<tr>
<th>Company</th>
<th>PANASONIC</th>
<th>SDI</th>
<th>LG</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ah / min</td>
<td>200 ppm²</td>
<td>220 ppm</td>
<td>300 ppm</td>
<td>200 ppm</td>
</tr>
</tbody>
</table>
| Source: Interviews with LG, SAMSUNG, SANYO-PANASONIC, AVICENNE Energy Analyses 2016

Assumptions: TESLA sold 35 kEV in 2014, 55 kEV in 2015 and 100 kEV in 2016
PRISMATIC LI-ION BATTERY (SMALL CELLS)

Prismatic LIB market Company market share in 2016 in volume: 980 Million cells (-8%)

Source: AVICENNE ENERGY Analyses 2016
LI-LAMINATE BATTERY (SMALL CELLS)

Laminate battery market Company market share in 2016 in volume: 2 350 Million cells (+7%)

Pouch cells (M) by Mfg. SONY, ATL and SAMSUNG are leading this market

Source: AVICENNE ENERGY Analyses 2016
The rechargeable battery market 2016-2025

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LI-ION IN 2016 - MAIN APPLICATIONS

+78 000 MWh - 20 600 M$ (1)
5 675 M small cells

CAGR 2006/2016
+22 % per year in Volume

source: AVICENNE Energy 2016
LI-ION IN 2016 - MAIN APPLICATIONS

CAGR 2006/2016
+22% per year in Volume
Cell: +15.5% per year in value
Pack: +16% per year in value

+78 000 MWh - 20 600 M$ (1)
5 675 M small cells

Li-ion cells
M$, Worldwide, 2005-2016

Li-ion Packs
M$, Worldwide, 2000-2016

Others: medical devices, power tools, gardening tools, e-bikes...

Source: AVICENNE Energy 2016
The rechargeable battery market 2016-2025

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CELLULAR PHONES MARKET
> 2 000 M LIB CELLS IN 2015

+2000 M cell phones sold in 2015 (+4% CAGR)

Source: AVICENNE Energy 2016
CELLULAR PHONES/LIB SUPPLIERS RELATIONSHIPS

2015 Cellular Phone makers / battery suppliers relation

<table>
<thead>
<tr>
<th>Company</th>
<th>Panasonic</th>
<th>Sony</th>
<th>SDI</th>
<th>LGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>XIAOMI</td>
<td>20%</td>
<td>60%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>ZTE</td>
<td>30%</td>
<td>30%</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>APPLE</td>
<td>40%</td>
<td>40%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>LG Chem</td>
<td>50%</td>
<td>30%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Samsung</td>
<td>60%</td>
<td>25%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Nokia</td>
<td>70%</td>
<td>20%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Smartphones ie laminate LIB increasing

<table>
<thead>
<tr>
<th>Smartphones</th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPod</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iPhone</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>IPad</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mac</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>15</td>
<td>250</td>
<td>150</td>
<td>525</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>

APPLE needs in 2015

<table>
<thead>
<tr>
<th>Product</th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPod</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>iPhone</td>
<td>100</td>
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<td></td>
</tr>
<tr>
<td>IPad</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mac</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: AVICENNE Energy 2016
PORTABLE PC MARKET
960 M LIB CELLS IN 2015

165 M portable PCs sold - 2014/2015: -5%

Market outlook 2015

- Uncertain macro & weakness in both consumer & commercial growth
- No sign for end-customer demand recovery
- Decrease due to cannibalization by tablets
- Small overall decrease only thanks to Emerging market growth

Increase of Ultra-thin Portable PCs

Note: Excluding Tablets & convertible or hybrid portable PC + tablets
Source: AVICENNE Energy 2016
TABLET MARKET
> 500 M CELLS IN 2015

Tables sold (Million) - Apple leadership

Market Outlook 2015
- Decrease in 2015 (-10%), and 2016 (-6%)
- Market driven by
  - mature market (77%)
  - consumer market (90%)
- Apple (27%), Samsung (17%), Asus (5%), Acer, Lenovo, Amazon are the key competitors
- Increasing part of convertible (Tablets+PC): 16.6 M in 2015 (8% of the market)

ASP tablets drop From $636 in Q4 2010 to < 300 $ in Q4 2015

Source: Gartner, IDC, Display search
Others 2015: Asus 8 M, Lenovo 11 M, Amazon 5.2 M...

Source: AVICENNE Energy 2016
The rechargeable battery market 2016-2025

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POWER TOOL MARKET
LIB DEMAND IS GROWING

Power tools market is growing

Power tools makers market share (2015)

Others: Jingding (3.6 M), Panasonic (0.5 M), Hitachi (2.4 M), Hilti (2M)...

Power tools maker battery choice

Source: AVICENNE Energy 2016
LIB BATTERY SHORT TERM TRENDS

18650 battery capacity*

Cellular phones battery capacity

Cylindrical/Prismatic/Laminates

Source: AVICENNE Energy 2016

Li-ion cylindrical: “Tesla impact”: 180 M cells in 2013, 300M in 2014, 430 M in 2015 and 600 M cells in 2016 (Avicenne Assumptions)
BATTERY PRICE IS DECREASING

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

Evolution of Cobalt price and cell price

Source: UMICORE, march 2011

Cylindrical Production capacity 09/11: from 150 to 250 M cells/month

Average LIB cell price ($/Wh)

18650 oversupply ratio is decreasing thanks to TESLA

Source: AVICENNE Energy 2016
LIB: THE BIGGEST PART OF THE COST IS RAW MATERIALS

RAW MATERIALS ACCOUNT FOR 50 TO 70% OF LIB CELLS BUSINESS
RAW MATERIAL COST IMPACT DRASTICALLY ON THE BATTERY MAKERS PROFIT

Note: Average mix of cylindrical, prismatic & laminate cells
Sources: AVICENNE ENERGY 2017
LI-ION VALUE CHAIN – MARKET DEMAND

CATHODE
184 000 T in 2016
Revenues: 4 B$
CAGR 06/16: +22%

ANODE
>88 000 T
Revenues: 0,9 B$
CAGR 06/16: +12%

ELECTROLYTE
>86 000 T
Revenues: 1,1 B$
CAGR 06/16: 19%

SEPARATOR
1 300 M m²
Revenues: 1,3 B$
CAGR 06/16: 18%

ANCILLARY
Revenues: 1,3 B$

CELL MANUFACTURERS
Revenues: 20,6 B$
Gross margin: <10%

PACK MANUFACTURERS
Revenues: >24,4 B$
Gross margin: <10%

Sources: AVICENNE ENERGY 2016
LIB CATHODE MATERIAL

Cathode raw materials market
- LiCoO2 (LCO)
- LiMn2O4 (LMO)
- LiMPO4\(^{(1)}\) (LFP)
- Li\([\text{NixMnyCoz}]\)O2 - NMC
- Li\([\text{NixCoyAlz}]\)O2 – NCA

\(^{(1)}\) M= Fe or Mn

Ni & Co price 2003-2015

Source: Mitsubishi, Batteries 2012 – Nice
Source: SANYO, March 2011
Source: LME
CATHODE ACTIVE MATERIALS NEEDS

Rationales

- In 2016, LCO is used in pouch cells for electronic devices: smartphones, tablets, ultra thin portable PCs
- NMC is used in other electronic devices & xEV
- NCA is used by 18650 Panasonic cells in Tesla cars and as a blend with LMO in other xEV
- LMO is mostly used as a blend with NMC in xEV
- LFP is used in xEV, e-buses in China and for industrial applications
LCO DEMAND: CAGR 2015-2025:+5%

LCO demand details

<table>
<thead>
<tr>
<th>Material</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>xEV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Tools, E-bikes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Electronics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable PCs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart Phones, Tablets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LCO Offer in 2015

- PULEAD: 15%
- Internal: 2%
- Nichia: 9%
- Shan Shan: 2%
- Others: 9%
- China: 8%
- L&F: 15%
- Reshine: 15%
- Easpring: 6%
- B&M: 10%

LCO Price forecasts

<table>
<thead>
<tr>
<th>Year</th>
<th>Material $/kg</th>
<th>Others $/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>2015</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>2020</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>2025</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Assumption: 2016-2025 : Co price stable @ 28$/kg – Lithium carbonate stable @ 10 $/kg

LCO summary of outlook

- Demand: LCO was used in most of the pouch cell lithium ion batteries for electronic devices like smartphones & tablets.
- Most OEM (Samsung, Apple, etc.) confirm that LCO will be the first choice for the future.
- Then, for portable PCs, penetration of LCO will increase thanks to thinner high end portable PC using pouch cells.
- LCO will not be used in large format cells where NMC is preferred.
- Price: if the metal price are stable from 2016 to 2025, small cost decrease thanks to scale economy.
- Suppliers: Umicore, L&F, and main Chinese (Pulead, ShanShan, Reshine) will keep the lead. Not sure that Nichia will stay at the top.

Sources: AVICENNENERGY 2017
NMC DEMAND: CAGR 2015-2025: +15%

NMC demand details

NMC Offer in 2015

NMC Price forecasts

NMC evolution

Assumption: 2016-2025 : Co price stable @ 28$/kg – Lithium carbonate stable @ 10 $/kg - – Ni stable @ 125$/kg

NMC summary of outlook

Demand: Except xEV in China, NMC is driven by xEV: Nissan will switch from NCA-LMO to NMC for example. Then, Toyota, Mitsubishi, Honda all choose NMC. From 2012 to 2016 the clear trend was to switch from LMO-NMC 75/25 to LMO-NMC 25/75. LG, Panasonic and Samsung agreed that NMC will be the 1st choice for xEV first in Japan, US and Europe, and then, in 2020 in China. Price will decrease thanks to process manufacturing improvement. Suppliers: Umicore, L&F, and main Chinese (ShanShan) will keep the lead. LG and Samsung will outsource more (internal part will decrease). As new entrant, BASF try to be on this market since 2011. Their market share may increase.
NCA demand details

- Others
- Industrials
- E-bus
- xEV China
- xEV
- Power Tools, E-bikes
- Other Electronics
- Portable PCs
- Smart Phones, Tablets

NCA Offer in 2015

- Sumitomo: 58%
- Nihon Kagaku: 13%
- Ecopro: 5%
- Toda Kogyo: 16%
- Others: 8%

NCA Price forecasts

Assumption: 2016-2025: Co price stable @ 28$/kg – Lithium carbonate stable @ 10 $/kg - Ni stable @ 125$/kg

NCA summary of outlook

Demand: NCA are also used in electronic devices, in prismatic and cylindrical cells. Main NCA users in electronic devices are Panasonic, Sony and Samsung. They will keep using NCA but LCO will stay the first choice. Panasonic and Samsung confirm that they supply more and more power tools mfg with NCA (from 15% in 2015 to 25% in 2025). Other NCA usage is of course for the TESLA. We do not think TESLA will switch for another technology in the next years.

Price decrease thanks to better mfg. process

Supplier: Sumitomo will keep the lead thanks to Panasonic / Tesla. Toda Kogyo market share will probably increase thanks to BASF partnership.

Sources: AVICENNE ENERGY 2017
LFP DEMAND: CAGR 2015-2025+: +8%

LFP demand details

LFP Offer in 2015

LFP Price forecasts

LFP summary of outlook

LFP demand is driven by xEV, E-Bus in China, e-bikes and Stationary application. Chinese industrial agreed that E-bikes, e-bus and stationary app will use LFP for the next 10 years. The cost and the life time are the main criteria and Energy density is not so important. Then, Chinese xEV mfg. (BYD, Kandi, Zotye, Baic, Chery...) told us that they will switch from LFP to NMC.

Price: Process manufacturing cost will decrease. Pulead forecast price @ 11-12$/kg in 2025.

Suppliers: Pulead will probably increase market share thanks to new contract with BYD and others Chinese battery mfg.

Assumption: 2016-2025 : Lithium carbonate stable @ 10 $/kg

Sources: AVICENNE ENERGY 2017
LMO DEMAND: CAGR 2015-2025: +10%

LMO demand details

LMO Offer in 2015

LMO Price forecasts

LMO summary of outlook

Demand: LMO is almost never the first choice for Lithium ion cathode. But, LMO is low cost and bring stability to the cathode. LMO is used in power tools and will be used, blended with NMC. So, for the future, LMO demand will be mostly driven by NMC/LMO blended cathode used in EV worldwide, EV in China to replace LFP (2020) and later E-bus in China (2025).

Price: LMO price decreased a lot from 2010 to 2015. We think we almost achieve the lowest possible level.

Suppliers: Most of the supply will stay in China (ShanShan, Qyanyun, ...).

Assumption: Lithium carbonate price 2016 – 2025 stable @ 10 $/kg

Sources: AVICENNE ENERGY 2017
CATHODE ACTIVE MATERIAL FORECASTS 2000-2025

Cathode active materials
2000-2025 - Tons

Cathode active materials in 2016
> 180 000 Tons

Cathode active materials in 2025
400 000 Tons

ASSUMPTIONS:

- Portable devices: 2015-2025: +6% 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 + 0.5 M in China in 2020, 0.6 M in 2025 + 1 M in China, 100% LIB
- EV: 0.6 M EV/year in 2020 + 1 M in China, 1M/year + 1.5 M in China in 2025, 100% LIB
- Industrial & stationary: 2015-2025: +16% per year

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

- LCO
- NMC
- NCA
- LMO
- LFP
- China (%)

ASSUMPTIONS:

- Portable devices: 2015-2025: +6% 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 + 0.5 M in China in 2020, 0.6 M in 2025 + 1 M in China, 100% LIB
- EV: 0.6 M EV/year in 2020 + 1 M in China, 1M/year + 1.5 M in China in 2025, 100% LIB
- Industrial & stationary: 2015-2025: +16% per year

Assumption: Tesla keep NCA chemistry and have a relative success
(200 000 EV sold per year in 2025 – TESLA forecast 500 000)
ANODE ACTIVE MATERIALS
> 88 000 TONS IN 2016

LIB Anode Materials

Source: A. Jossen, IRES 2007

Source: Hitachi Chemical

LIB Anode market, (Tons)

Source: Sanyo, March 2013

Sources: AVICENNE ENERGY 2016
ANODE FOR LIB IN 2016

Natural graphite become a commodity

**Carbon for LIB anodes by type (2016)**

- Artificial Graphite: 43%
- Amorphous: 7%
- Natural Graphite: 46%
- Si or Sn Type: 2%
- LTO Type: 2%
- Natural or petroleum coke: 7-13% > 6-10 $/kg
- Petroleum coke: 20-15 $/kg
- Petroleum Pitch, Resin, cellulose, wood, coconuts...

### NEW ENTRANTS ON THE FIELD:

- **LEADERS:**
  - Hard Carbon: Hitachi
  - Soft Carbon: Kureha
  - Graphite: Hitachi BTR...

### Natural graphite become a commodity

- **Sources:** AVICENNE ENERGY 2017

### Capacity (g)

- Hard Carbon: 400 mAh/g
- Soft Carbon: 250 mAh/g
- Graphite: 325-375 mAh/g

### Capacity (cc)

- Hard Carbon: ++
- Soft Carbon: 0
- Graphite: +

### Power

- Hard Carbon: ++
- Soft Carbon: +
- Graphite: 0

### Stability

- Hard Carbon: ++
- Soft Carbon: +
- Graphite: 0

### Cyclability

- Hard Carbon: ++
- Soft Carbon: +
- Graphite: 0

### Precursors

- Hard Carbon: Petroleum Pitch, Resin, cellulose, wood, coconuts...
- Soft Carbon: Petroleum coke
- Graphite: Natural or petroleum coke

### COST 2015->2020

- Hard Carbon: 25 -> 20 $/kg
- Soft Carbon: 20->15 $/kg
- Graphite: 7-13->6-10 $/kg

### SUPPLIERS

- Kureha
- Hitachi
- Hitachi BTR...

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**The rechargeable battery market 2016-2025**

March 20th, 2017
Fort Lauderdale, FL, USA

**Contact**

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**Sources:** AVICENNE ENERGY 2017
NATURAL GRAPHITE: CAGR 2015-2025: +3%

Natural Graphite demand details

NG Offer in 2016

NG Price forecasts

NG summary of outlook

Demand: small growth because new app. Need artificial Gr. This demand may change if the price decrease is more important for NG compare to AG. Price: The price will decrease fast because the supply is huge. Already over supply in China (Capacity: BTR 30 000 Tons, Zichen: 10 000 Tons, Shinzom: 10 000 Tons, Sinuo: 8 000 Tons, Qingdao: 8 000 Tons, Jianxi Zhentuo: 7000 Tons, Kimwan: 5 000 Tons…). Then, a lot of new projects in China and Canada: Focus Graphite > 40000 Tons/year (2020*), Northern Graphite > 20 000 Tons/year (after 2018*) Syrah Resources Ltd. > 80 000 Tons (2020*)

Suppliers: BTR and new Chinese (Zichen thanks to ATL, - Shinzom thanks to BYD, CATL – Sinuo etc…). New entrant like Focus Graphite, Northern Graphite, or Syrah Resources Ltd. May change the market share in the future

* Subject to financing

Sources: AVICENNE ENERGY 2017
**ARTIFICIAL GR.: CAGR 2015-2025: +15%**

### Artificial Graphite demand details

- **2005**: 10,000 Tons
- **2010**: 20,000 Tons
- **2015**: 40,000 Tons
- **2020**: 80,000 Tons
- **2025**: 140,000 Tons

### Artificial Graphite Offer in 2016

- **HITACHI**: 31%
- **Shanshan**: 38%
- **Mitsubishi**: 9%
- **JFE**: 11%
- **Showa Denko**: 6%
- **Others**: 6%

**CHINA**: 45%

**OTHERS**: 55%

**Typical Product**
- $D_{50} = 20 \mu m$
- BET: 0.5 m²/g
- 1-5% irreversible cap.

### Artificial Graphite Price forecasts

- **2010**: $25/kg
- **2015**: $15/kg
- **2020**: $10/kg
- **2025**: $5/kg

### Artificial Graphite summary of outlook

- **Demand**: The demand will increase fast thanks to xEV market. Long life time requirement involve high level of purity and high consistancy, difficult to achieve with Natural Graphite.
- **Price**: will decrease fast thanks to better process efficiency, new process
- **Supply**: Thanks to the best quality, Hitachi will keep the lead but Chinese main suppliers market share will increase (ShanShan mostly).
- **Production Capacity**: Hitachi: 15 000 Tons, ShanShan: 15 000 Tons project in Lingang Park (Shanghai) to add 20 000 Tons/year, Mitsubishi: 7 000 Tons, JFE: 7000 Tons, Showa Denko: 3000 Tons

**Sources**: AVICENNE ENERGY 2017
LIB SEPARATOR MARKET 2016

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.

LIB separator market, M$ - CAGR 2006/2016: +13%

Supplier, market share in 2016

Others: Shanghai Energy, Newmi, JGP, TDK, In house (BYD), Mingzhu, Tianfeng, Yiteng, BNE…

Sources: AVICENNE ENERGY 2017
THE RECHARGEABLE BATTERY MARKET 2016-2025

LIB electrolyte market, Tons, CAGR 2006/2016: +26%

LIB electrolyte supplier, market share in 2016

Sources: AVICENNE ENERGY 2017

Note: (1) GTHR: Zhangjiagang Guotai-Huarong
BATTERY MARKET FORECASTS 2016-2025

Applications covered

- Portable PCs, net-book, Ultra-book
- Cellular Phones, Smart-phones
- Tablets
- Camcorders
- Cordless Tools, Gardening tools
- Digital Camera
- Games, MP3
- Cordless Phones
- Shavers, Toothbrush,
- RC Cars
- E-bikes
- Power tools
- Security lighting
- Vehicles: HEV, P-HEV, EV
- Industrial motive (forklift)
- Industrial stationary (UPS, Telecom)
- Medical
- Energy Storage (Small / large)

Parameters analysis

- Main segment trends
- Power need trends (volume, weight, capacity, running time)
- Penetration rate for each Chemistry, each form factor,
- 2016 -2025 Forecasts
- OEM strategies and positions
- Main drivers & limiters
PORTABLE ELECTRONIC DEVICES FORECASTS 2010-2025

Cellular phones demand (M Units) CAGR 2010-2025: +4%

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

LIB cells demand 2010-2025
Polymer penetration: 20% -> 75%

LIB cells for cellular phones trends
- Laminates ratio increase
- Increase of Thickness
- Increase of >1400 mAh capacity

Source: AVICENNE ENERGY Analyses
PORTABLE ELECTRONIC DEVICES FORECASTS 2010-2025

Portable PCs demand (M Units) 2016-2025 – Almost stable

- Mature market stable or decreasing
- Growth driven by Emerging market
- Ultrabook is increasing
- ASP decreasing (<499$ Portable PCs increase from 25% in 2010 to 40% in 2015)

LIB cells for portable PCs trends
- Thinner cells
- Pouch cells penetration increasing from 7% in 2010 to 40% 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
X-EV MARKET

- Why x-EV?
- Definition & segmentation
- X-EV worldwide in 2015
  - By country
  - By car makers
  - By battery chemistry
- X-EV forecasts
  - AVICENNE ENERGY & other analyst forecasts
  - Battery chemistry forecasts
  - Battery cost forecasts
- X-EV battery forecasts
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%
HEV, P-HEV & EV
DEFINITION & SEGMENTATION

EV & HEV MARKET

EV
25 kWh

HEV
0.6-2 kWh batteries

P HEV
10 kWh batteries

MICRO HEV
MILD HEV
MEDIUM HEV
FULL HEV

CITROEN C2, C3
BMW 3Series
Fiat 500
Hyundai i10
Hyundai i30
Kia
Smart for2
Toyota Yaris
Toyota Auris
VW Passat
.....

GM Saturn Vue
GM MALIBU
HONDA ACCORD

HONDA CIVIC
INSIGHT
MERCEDES S400

TOYOTA PRIUS
TOYOTA CAMRY
FORD ESCAPE
FORD FUSION
MILAN
GM YUKON
GM TAHOE
NISSAN ALTIMA

DEFINITION & SEGMENTATION

Note: Micro HEV are not in the HEV statistics & HEV forecast

Fuel saving Vs. Cost

EV
P-HEV
HEV

0 $  5 000 $  10 000 $  15 000 $
HEV WORLDWIDE IN 2016
1,8 M HEV
HEV sold per year, M units, worldwide, 2000 - 2016

Penetration of hybrids in the global sales, 2000-2016

Gazoline price impact on HEV market in the US

Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
Micro hybrid not included
HEV WORLDWIDE IN 2016
BY CAR SUPPLIER

Total HEV Vehicles
1,8 Million HEV in 2016

TOYOTA 70%
HONDA 15%
HYUNDAI 3%
KIA 3%
VW 1%
OTHERS 4%
FORD 4%
NISSAN 3%

HEV sold per year, M units per car manufacturers, 2000-2016

Others: GM, Porsche, Mercedes, Mazda, Audi, Subaru etc...

Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
Micro hybrid not included
HEV WORLDWIDE IN 2016
BY CAR SUPPLIER

TOP 2: TOYOTA, HONDA

OTHERS: FORD, VW, HYUNDAI, …

Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
Micro hybrid not included
HEV WORLDWIDE IN 2016 BY COUNTRY

Total HEV Vehicles
1,84 M in 2016

- **JAPAN**: 54%
- **USA**: 19%
- **EUROPE**: 18%
- **OTHERS**: 9%

HEV sold per year, M units per country, 2004-2016

- **USA**
- **EUROPE**
- **JAPAN**
- **OTHERS**

Source: AVICENNE ENERGY Analyses 2015

Micro hybrid not included
PHEV SOLD WORLDWIDE

World excl. China growth +14%
Chinese Growth +26%

China is leading the P-HEV market thanks to high incentives

Source: AVICENNE ENERGY Analysis, 2017
The rechargeable battery market 2016-2025

World excl. China growth +15%
Chinese Growth +68%

China is leading the EV market thanks to high incentives

Source: AVICENNE ENERGY Analysis, 2017
NEV* DEVELOPMENT IN CHINA

362 100 PHEV & EV sold in China in 2016

PHEV & EV evolution

*NEV=PHEV+EV (New Energy Vehicles)
XEV BUSES MARKET IN CHINA

The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA

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The rechargeable battery market 2016-2025

xEV buses market in China:
132 000 xEV Buses sold in 2016

Rationales

The Chinese government is working on addressing environmental issues. Central and local governments are engaged in subsidy policies to promote EV/PHV/FCV as new energy vehicles. The amount of subsidy for EV/FCV with low environmental impact is set high. As the subsidy policy is announced to be carried out until 2020, it is predicted that this market will be on an expansion trend centering on EV. However, due to the occurrence of the case of receiving subsidies illegally in 2015, the government has begun to strictly control the production of new energy vehicles after 2016.
The new energy bus market in China is mainly made up of EV with a large amount of subsidy from the government, and there are many cases where older makers also produce PHV.

As a result of the illegal receipt of subsidy occurred in 2015, publication of the company name and administrative guidance (penalty) from the government were carried out. Consequently, several makers including King Long have significantly reduced their market share in 2016, and old makers such as Yutong and Zhong Tong are expanding their market shares.
The largest share of the value (40%) comes from cell components.

Cell manufacturers & OEM alliance may be the winning model but comes with high risk if the wrong cell manufacturer is selected.

Tiers 1 - cell manufacturers alliance: most of them disappear (eg. Saft-Johnson Controls, Bosch-Samsung, Enerdel-Delphi...)

Tiers 1 - OEM alliance on Battery are not successful.

Panasonic and LG Chem, cell manufacturers develop raw material in-house and make the pack integration for OEM.

On a different scale, Toyota, BYD or BOLLORE are fully integrate.

Source: AVICENNE ENERGY 2016
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)

TESLA Plant, Nevada, Feb 2015

Source: AVICENNE ENERGY Analyses 2017
The research and development in this industry is very long and time consuming.

Time to market to commercialize a new material is long. Remember that the first Li-ion battery was launched by Sony in 1991 with LCO cathode, graphite, LiPF$_6$ electrolyte & polyolefin membrane. It was 20 years ago.

LTO was invented by Matsushita in 1993 (22 years ago)

Lithium iron phosphate was invented in 1995 (20 years ago).

So, it takes between 10 & 20 years to commercialize a new material in the battery industry.
BATTERY TECHNOLOGY ROADMAP

Batteries take a long time to develop; to reach the automotive market, another 4 to 5 years are needed.

Source: Avicenne Energy analysis
The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA

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Source: AVICENNE ENERGY 2016
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. 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”).
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**
Boing 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 Boing.

Source: AVICENNE ENERGY 2016
LIB BUSINESS
RECALLS SLASH BATTERY PROFIT

➢ More & more incidents & accidents
➢ All the battery makers and the OEM are concerned
➢ Recall cost impact drastically the battery business and the profitability

Source: AVICENNE ENERGY 2016
SAFETY IS A SINE-QUA-NON SELECTION CRITERIA FOR BATTERY TECHNOLOGIES

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

### Cathode

<table>
<thead>
<tr>
<th>Technology</th>
<th>LCO</th>
<th>NMC</th>
<th>LMO</th>
<th>LFP</th>
<th>High V</th>
<th>Sulfur</th>
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</thead>
<tbody>
<tr>
<td>xEV?</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

### Anode

<table>
<thead>
<tr>
<th>Technology</th>
<th>Graphite</th>
<th>Hard Carbon</th>
<th>Soft Carbon</th>
<th>LTD</th>
<th>SUC</th>
<th>Li Molot</th>
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</thead>
<tbody>
<tr>
<td>SAFETY</td>
<td>YES</td>
<td>YES</td>
<td></td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>xEV?</td>
<td>YES</td>
<td>YES</td>
<td></td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

### Electrolyte

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

### Packaging

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

### Thermal

- Thermal management improve both the safety and the life time

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<table>
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<th>CONTACT</th>
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<td><a href="mailto:c.pillot@avicenne.com">c.pillot@avicenne.com</a></td>
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</tbody>
</table>

The lithium ion technologies that win will win partly on their safety argument, possibly sacrificing some energy density.

*Source: AVICENNE ENERGY 2016*
LIB BATTERY COST

The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA

Costs analysis

- Raw material cost (Co, Mn, Ni, Al, Cu, ...)
- Anode, cathode, Electrolyte, separator, binders, Cu & Al foil, etc... cost structure:
  - CAPEX,
  - labor cost,
  - R&D
  - Marketing, Adm, Overhead, margin)
- Raw material needs / mAh
- Electrode process Yield
- Assembly Process Yield
- Cell manufacturing cost
- Module manufacturing cost
- Pack assembly cost
- ...

Battery price in 2016
$/kWh

Source: AVICENNE ENERGY 2016
LI-ION BATTERY COST
2015-2025
LIB cell average cost (40 Ah pouch)
(EV design; NMC cathode)

LI-ION BATTERY PACK COST FOR EV

* For Production > 100,000 packs/year

Source: AVICENNE ENERGY 2016

(1) Active materials only
LIB PRICE FORECASTS

Source: *Rapidly falling costs of battery packs for electric vehicles*, Nature Climate Change, March 2015
HEV FORECASTS 2000-2020

HEV MARKET: <2 M units in 2016 – 2,5 M in 2020 – 3,3 M in 2025

Micro hybrid not included

Source: AVICENNE ENERGY Analyses 2016
EV, P-HEV, EV 2025 FORECASTS

Thanks to very high incentives, China change the game

2016 forecasts: HEV, P-HEV & EV market forecasts up to 2025
TOTAL BATTERY DEMAND
2025 FORECASTS

Li-ion for EV, HEV & P-HEV Battery needs (MWh)
CAGR 2016-2025: +14%

Li-ion for EV, HEV & P-HEV Battery needs (M$)
CAGR 2016-2025: +8%
X-EV BATTERY MARKET
2000 – 2025 IN M$

Cell Level
CAGR 2016-2025: +8%

Pack Level
CAGR 2015-2025: +8%

The rechargeable battery market 2016-2025

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35 MILLION MICRO-HYBRIDS CAR IN 2020

Micro-hybrids car market 2010-2020

Advantages of micro-hybrid compare to HEV

- Powered by Advanced lead acid batteries
- 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></th>
<th>Micro-hybrid</th>
<th>Full HEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>Advanced lead acid</td>
<td>NiMH or LIB</td>
</tr>
<tr>
<td>Cost ($)</td>
<td>300</td>
<td>3000</td>
</tr>
<tr>
<td>Fuel saving</td>
<td>5%</td>
<td>20%</td>
</tr>
<tr>
<td>Million Vehicle sold per year in 2020</td>
<td>&gt; 35</td>
<td>2,5</td>
</tr>
</tbody>
</table>
The rechargeable battery market 2016-2025

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HEV, P-HEV AND EV REALITY OF THE MARKET WILL BOOST MICRO HYBRID AND ADVANCED LEAD ACID BATTERIES

<table>
<thead>
<tr>
<th>Year</th>
<th>STANDARD CAR</th>
<th>MICRO HYBRIDS</th>
<th>MILD HEV</th>
<th>FULL HEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>88.5%</td>
<td>10%</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>2015</td>
<td>STANDARD Lead acid Batteries</td>
<td>Advanced Lead acid</td>
<td>NiMH</td>
<td>Li-ion batteries</td>
</tr>
<tr>
<td>2020</td>
<td>STANDARD CAR 44%</td>
<td>MICRO HYBRID 50%</td>
<td>FULL HEV 2,5%</td>
<td>EV P-HEV 1,5%</td>
</tr>
</tbody>
</table>

AFTER
- ULTRA BATTERY
- Li-ion
- Li-Air, Li-S, Fuel Cells
THE WORLDWIDE BATTERY MARKET
1990-2015

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Li-ion</th>
<th>NiMH</th>
<th>NiCD</th>
<th>Lead Acid</th>
<th>Others (Flow battery, NAS, …)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

Source: AVICENNE ENERGY, 2016

Lead Acid Batteries 2016
+360 GWh for > US $ 33 Billion

<table>
<thead>
<tr>
<th>Segment</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLI</td>
<td>62%</td>
</tr>
<tr>
<td>Industry, ESS</td>
<td>32%</td>
</tr>
<tr>
<td>Others medical, e-bikes</td>
<td>6%</td>
</tr>
</tbody>
</table>

Industrial Batteries
55 GWh for US $ 11 Billion

<table>
<thead>
<tr>
<th>Segment</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecom</td>
<td>26%</td>
</tr>
<tr>
<td>UPS</td>
<td>22%</td>
</tr>
<tr>
<td>Motive</td>
<td>23%</td>
</tr>
<tr>
<td>Other Stationary, ESS</td>
<td>29%</td>
</tr>
<tr>
<td>Others (Flow battery, NAS, …)</td>
<td>26%</td>
</tr>
</tbody>
</table>
THE WORLDWIDE BATTERY MARKET IN 2016: US $ 65 BILLION

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

Source: AVICENNE ENERGY, 2017
TOTAL POTENTIAL MARKET (M$, PACK LEVEL\(^1\))

Application details

US$ 22,8 Billion in 2016 (1)

<table>
<thead>
<tr>
<th>Application</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Bikes</td>
<td>13%</td>
</tr>
<tr>
<td>Power Tools</td>
<td>9%</td>
</tr>
<tr>
<td>Forklift</td>
<td>13%</td>
</tr>
<tr>
<td>Telecom</td>
<td>14%</td>
</tr>
<tr>
<td>UPS</td>
<td>12%</td>
</tr>
<tr>
<td>ESS</td>
<td>13%</td>
</tr>
<tr>
<td>Seismic</td>
<td>1%</td>
</tr>
<tr>
<td>Marine</td>
<td>2%</td>
</tr>
<tr>
<td>Other Motive</td>
<td>1%</td>
</tr>
<tr>
<td>Medical devices</td>
<td>1%</td>
</tr>
<tr>
<td>Marine</td>
<td>2%</td>
</tr>
<tr>
<td>Others</td>
<td>14%</td>
</tr>
</tbody>
</table>

Source: AVICENNE ENERGY 2016

1- Pack level: Pack including cells, cells assembly, BMS, connectors – Power electronics (DC DC converters, invertors...) not included
2- Other App: Military, aerospace, Oil & Gas, Railways, Aviation, Utility metering,...
MARKET SEGMENT SYNTHESIS

MODEL MARKET
LIB: FROM US$ XX MILLION IN 2012 TO YY IN 2020 – CAGR: +ZZ%

Lib market in value 2012/2025 - CAGR

Battery market in value 2012/2025 - CAGR

ASP in 2012 & 2020

LIB market in value 2012/2025 - CAGR

LIB main drivers & limiters

LIB market by Area

Battery market by Area

LIB Penetration in % of total device

LIB market in M$

Source: AVICENNE ENERGY Analyses
1 - E-BIKES
LIB: FROM US$ 1,8 BILLION IN 2016 TO 3,2 IN 2020¹ – CAGR: +16%

Market 2016-2020 (US $, Million) – CAGR: 11%

Main drivers
- E-bike in China: Banning of gasoline powered motorcycles in China boost e-bikes: “Necessary”
- In US, Europe and Japan, “Green image”, sport, leisure, transportation: “Environment & Health”
- LIB penetration in China from 6 to 14%

Main Limiters
- In Japan, US and Europe, E-bikes are already equipped by Li-ion
- In China the only parameter to choose a battery is the cost
- Chinese E-bike ASP: 320 $/kWh: very difficult to penetrate this market

Competitors
- BMZ (Germany)
- AXEON² (UK)
- HITECH (Taiwan)
- Phylion (China)

Customers
- Bosch
- Panasonic
- Bion-X
- TranX-Z

Battery needs
- Performances characteristic
  1- Cycle life
  2- Energy density
  3- Low cost
- Average Capacity: 300 Wh

LIB needs
- Most valuable improvements
  1- Price decrease
  2- Cycle life
  3- Fast charge
- Form factor: from cylindrical to Laminate
- No standardization

Note: 1- Pack level – 2- A Johnson Matthey affiliate

Source: AVICENNE ENERGY Analyses
2- POWER TOOLS
LIB: FROM US$ 1.4 BILLION IN 2016 TO 1.9 B IN 2020\(^1\) – CAGR:+8%

Market 2016-2020 (US $, Million) – CAGR:+5%

<table>
<thead>
<tr>
<th>Year</th>
<th>Li-ion</th>
<th>NiCd</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>2013</td>
<td>2000</td>
<td>1000</td>
</tr>
<tr>
<td>2014</td>
<td>3000</td>
<td>1500</td>
</tr>
<tr>
<td>2015</td>
<td>4000</td>
<td>2000</td>
</tr>
<tr>
<td>2016</td>
<td>5000</td>
<td>2500</td>
</tr>
<tr>
<td>2017</td>
<td>6000</td>
<td>3000</td>
</tr>
<tr>
<td>2018</td>
<td>7000</td>
<td>3500</td>
</tr>
<tr>
<td>2019</td>
<td>8000</td>
<td>4000</td>
</tr>
<tr>
<td>2020</td>
<td>9000</td>
<td>4500</td>
</tr>
</tbody>
</table>

**LIB Main drivers**
- Higher voltage
- NiCd substitution
- NiCd regulation
- Cordless power tools & gardening tools market increase (+4% per year)
- Higher energy density, less weight

**LIB main Limiters**
- LIB average sales price
- Reliability
- High rate discharge
- Fast charge
- Life time

**Competitors**
- Cell/Pack Mfg.: TOP3: Samsung, Panasonic, Sony (> 75%)
- Pack makers: AXEON (Bosch),

**Customers**
- Bosch
- B&D
- TTI
- Makita
- Jingding
- Hilti
- ...

**Important characteristic:**
- Price decrease
- Fast charge
- Form factor: Cylindrical
- No standardization

**Note:** 1- Pack level

Source: AVICENNE ENERGY Analyses

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The rechargeable battery market 2016-2025

March 20\(^{th}\), 2017
Fort Lauderdale, FL, USA
3- MOTIVE INDUSTRIAL: FORKLIFTS

LIB: FROM US$ 160 MILLION IN 2016 TO 275 IN 2020 – CAGR: 15%

Market 2016-2020 (US $, Million) – CAGR:7%

Main drivers
- Where economies are healthy, they reflect strong motive power production
- Europe & US get high E-forklift ratio compared to Asia
- LIB higher life time (* 3 to 5)
- Multiple shift operation where battery change is required (time consuming)

Main Limiters
- Low penetration of E-forklift in Asia
- High LIB capital price (x 5 compared to lead acid)
- Safety concerns in two of the lift truck types, sit-down rider and high reach, the counterbalance for the lift truck is supplied mainly by a lead acid battery

Battery 2012 by Area
- Europe – largest producer of motive power batteries – has higher percentage of electric vs. gas trucks (75%) than in N. America (64%) – China: High % of Gas/propane trucks (> 80%)

LIB 2020 by Area
- US: 51%
- Europe: 42%
- Asia: 7%

LIB 2020: 365 $/kWh
- Lead Acid 2020: 144 $/kWh

Battery needs
- Important characteristic
  1. high charge/discharge rates and capacity
  2. high life time, range,

Average Capacity: 22 kWh

LIB needs
- Most valuable improvements
  1. Price
  2. Convince customers on “total cost of ownership”
- Form factor: large format prismatic – size standardization

Customers
- For lead acid, After market represent 60% of the market: lot of different customers (industrials)
- For LIB, OEM Forklift: TOYOTA, Kion, Jungheinrich, NACCO, Crown, Mitsubishi Caterpillar

Competitors
- Lead Acid & LIB: Enersys (35%), Exide (10%), East Penn (10%), Hoppecke (10%), Crown (10%)
- LIB systems: BMZ, Lithium Balance, …

Source: AVICENNE ENERGY Analyses
Note: 1- Pack level 2- Including all kind of Material handling equipment

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The rechargeable battery market 2016-2025

4- STATIONARY: TELECOM MARKET
LIB: FROM US$ 0.5 BILLION IN 2016 TO 1.1 IN 2020¹ – CAGR > 20%

Market 2016-2020 (US $, Million) – CAGR: +7%

Main drivers
- LIB developed for new equipment
- Increased Bandwidth requirements
- Wireless Market driving growth
- Strong Network Growth in China, India, E. Europe & S. America
- 2G > 3G > 4G … need new equipment’s
- LIB: Specially in Hot climate

Main Limiters
- Lead Acid Vs. Li-ion…
- Lead Acid capital cost 5 times cheaper
- Total cost of ownership could be compare with Lead Acid

Battery 2012 by Area
- China: 44%
- Europe: 30%
- US: 14%
- India: 6%

Battery 2020 by Area
- China: 39%
- Europe: 25%
- US: 19%
- India: 9%
- Others: 9%

LIB Penetration
2012: 0%
2018: 10%
2020: 20%

LIB market (M$)
2012: $2000
2018: $4000
2020: $6000

ASP
2012: $200/kWh
2020: $185/kWh

Competitors
- Lead Acid & LIB: Enersys (35%), Exide (10%), and local suppliers in each countries
- LIB systems: “large companies” : SAFT, others?

Customers
- Not so many customers; big telecom carriers in each countries

Most important performances characteristic
- 1- Hot T°C performances
- 2- Customized for the new Equipment network
- Average Capacity: 5-10 kWh modules (100 Ah)

Most valuable improvements
- 1- Capital costs
- 2- Safety Proof
- 3- Reliability
- Customized battery developed for new equipment

Source: AVICENNE ENERGY Analyses

Note: : 1- Pack level

Customers
- Not so many customers; big telecom carriers in each countries

LIB needs

Note: : 1- Pack level
5- STATIONARY: UPS MARKET
LIB: FROM US$ 0.27 BILLION IN 2016 TO 0.55 IN 2020¹ – CAGR: 19%

Market 2013-2020 (US $, Million) – CAGR: +4%

Main drivers

- UPS Drivers:
  - New Data Storage Centers
  - Mobile Society

- LIB drivers:
  - Less volume, less place
  - > Life time
  - LIB is more needed where data are sensitive
  - Li-ion battery could also help to save electricity during peak time

Main Limiters

- Safety could be an important issue here

Competitors

- Lead Acid & LIB: Enersys (35%), Exide (10%), and local suppliers in each countries
- LIB systems: local companies providing > services

Customers

- Few leaders/many products: Emerson/Liebert, Schneider/APC, Eaton Powerware, Gamatron, Riello

Battery 2012 by Area

- China
- Europe
- US
- India

Battery 2020 by Area

- China
- Europe
- US
- India
- Others

LIB Penetration

LIB market (M$)

- ASP 2012: 600 $/kWh
- ASP 2020: 400 $/kWh

- ASP 2012: 200 $/kWh
- ASP 2020: 170 $/kWh

- Average Capacity: 3-5 kWh modules

Most important performances characteristic
- 1- Back-up at high current
- 2- weight, volume
- 3- life time

Most valuable improvements
- 1- Convince on Safety
- 2- Capital Cost
- 3- Reliability

Note: UPS: Uninterruptible Power Supply
APC: American Power Conversion

Source: AVICENNE ENERGY Analyses

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The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA
### ESS SEGMENTATION

**Services provided by Energy Storage System (ESS)**

#### On grid services

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Regulation**        | - Reconcile momentary differences caused by fluctuations in generation and/or loads  
                          - Frequency regulation  
                          - Voltage support  
                          - Load following/ramping support  
                          - Power quality                                                                 |
| **Arbitrage**         | - Store energy when the price of electricity is low and releases it on the grid when prices are high |
| **Black start**       | - Provide an active reserve of power and energy to (re)start power generator                                                               |
| **Investment deferral** | - Enable deferral of utility investments by using relatively small amounts of storage  
                                - Congestion relief  
                                - Avoid infrastructure investment |
| **Grid independent power supply** | - Provide electricity power supply in an area not connected to the grid  
                                           - Rural community  
                                           - Based stations powered by Solar energy |
| **Back-up and reserves** | - Provide emergency power when utility power is not available  
                                   - UPS (Uninterruptible power supply)  
                                   - Power continuity  
                                   - Reserves to face lose of one generator |

#### Off grid services

Source: AVICENNE ENERGY 2016
# ESS SEGMENTATION

## Stationary Energy Storage - Potential segmentation

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Arbitrage</th>
<th>Black start</th>
<th>Back-up</th>
<th>Invest. deferral</th>
<th>Grid independent power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hourly/ daily peak</td>
<td>Weekly peaks</td>
<td>Seasonal peak</td>
<td>UPS</td>
<td>Power continuity</td>
</tr>
<tr>
<td>Conventional &amp; regular RE</td>
<td>1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PV integration</td>
<td>2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Wind integration</td>
<td>3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transmission &amp; Distribution</td>
<td>11</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

### End-users

- Residential | 13 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
- Commercial | ✓ | 15 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
- Industrial | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# Existing markets  # Emerging markets

Source: AVICENNE ENERGY 2016
ESS REQUIREMENTS

On structuring parameters: discharge time and average power, segments highlight different patterns

Source: AVICENNE Energy, 2016
ENERGY STORAGE SOLUTIONS

Mapped on discharge time and power, technologies will appear suitable for certain segments only.

System power and discharge time of energy storage technologies

Source: AVICENNE Energy, 2016
ESS MARKET & FORECASTS

From 36 GWh to 65 GWh in 2025
CAGR: +6%

ESS excl Telecom & UPS
CAGR: +13 to 15%

Source: AVICENNE Energy, 2016

(1) If LIB cost is < 150$/kWh, the market could be much more important
The rechargeable battery market 2016-2025

March 20th, 2017
Fort Lauderdale, FL, USA

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LI-ION BATTERY MARKET FORECASTS

From 78 GWh in 2016 to 210 GWh

CAGR 2016/2025
+13 % per year in Volume

Li-ion Battery sales,
MWh, Worldwide, 2000-2015

2016: 78 GWh
Auto, E-bus Excl. China 13%
China 30%
Electronic devices 40%
Industrial, ESS 6%
Others 11%

2025: 210 GWh
Auto, E-bus Excl. China 15%
China 35%
Electronic devices 26%
Others 16%

Others: medical devices, power tools, gardening tools, e-bikes...

Source: AVICENNE Energy 2016
LI-ION BATTERY MARKET FORECASTS

CAGR 2016/2025 +13 % per year in Volume
Cell: +7% per year in value
Pack: +8% per year in value

Source: AVICENNE Energy 2016

Others: medical devices, power tools, gardening tools, e-bikes...
**TAKEAWAYS**

**Battery Market 2010-2025**

CAGR = +5% / Li-ion>+8%

- Li-ion battery is driven today by Automotive & Industrial applications
- In 2012, most of the car makers (except Toyota) switch to Li-ion for HEV
- P-HEV, EV and E-buses will be powered by Li-ion:
- EV expectations attract large Chemical companies
- New materials are needed to meet Automotive standards
- HEV will account for less than 3% of the auto sales in 2020
- P-HEV & EV < 2% by 2020
- Micro-hybrid will achieve >50% in 2020/25
- Lead acid battery will be the first market in 2025 in volume, but Li-ion market will be higher than Lead acid from 2020.
- 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 > 10% in the next 15 years
- ESS will reach 10 Billion $ market at the pack level in the next 5 years
- ESS market could be much more important if the price of LIB at the system level is under 150 $/kWh

---

**RECHARGEABLE BATTERY MARKET WORLDWIDE 2000-2025**

![Battery Market Graph](image-url)
THANK YOU

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