Lithium-Ion Battery Raw Material Supply and Demand 2016 – 2025

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Presentation Outline
• The rechargeable battery market in 2016
• The Li-ion battery value chain
• Li-ion battery material market
• Forecasts & conclusions
THE BATTERY MARKET IS REALLY DYNAMIC

Lithium ion battery raw material supply & demand 2016 - 2025

June 19th, 2017
San Francisco, CA, USA

Source: AVICENNE ENERGY, 2017
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**

69 BILLION US$ in 2016 – Pack level¹

8% AVERAGE GROWTH PER YEAR (2006-2016)

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**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

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1. Other pack types: Pack level includes automotive (Hybrid cars, HEV, PHEV, EV), others (Medical: wheelchairs, medical carts, medical devices (surgical power tools, mobile instrumentation (x-ray, ultrasound, EKG/ECG), large oxygen concentrators).
THE WORLDWIDE BATTERY MARKET IN 2016: US $ 69 BILLION

June 19th, 2017
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1- Pack level: Pack including cells, cells assembly, BMS, connectors – Power electronics (DC DC converters, invertors…) not included

Source: AVICENNE ENERGY, 2017
LI-ION IN 2016 - MAIN APPLICATIONS

90,000 MWh - 23 B$ (1)
5,675 M small cells

CAGR 2006/2016
+23 % per year in Volume

(1) Cell level
Others: medical devices, power tools, gardening tools, e-bikes...
Source: AVICENNE Energy 2017
LI-ION IN 2016 - MAIN APPLICATIONS

+90 000 MWh - 23 B$ (1)
5 675 M small cells

CAGR 2006/2016
+23% per year in Volume
Cell: +17% per year in value
Pack: +18% per year in value

Source: AVICENNE Energy 2017
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

LIB Cost structure for TESLA & 40 Ah EV pouch cell NMC

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

CATHODE
211 000 T in 2016
Revenues: 4.75 B$
CAGR 06/16: +14%

ANODE
104 000 T
Revenues: 1.16 B$
CAGR 06/16: +13%

ELECTROLYTE
103 000 T
Revenues: 1.4 B$
CAGR 06/16: 19%

SEPARATOR
1 500 M m²
Revenues: 1.6 B$
CAGR 06/16: 15%

ANCILLARY
Revenues: 1.5 B$

CELL MANUFACTURERS
Revenues: 22.5 B$
Gross margin: <10%

PACK MANUFACTURERS
Revenues: 31 B$
Gross margin: <10%

Sources: AVICENNE ENERGY 2016
LIB CATHODE MATERIAL

Cathode raw materials market
- LiCoO2 (LCO)
- LiMn2O4 (LMO)
- LiMPO4\(^{(1)}\) (LFP)
- Li[\(\text{Ni}_{x}\text{Mn}_{y}\text{Co}_{z}\)]O2 - NMC
- Li[\(\text{Ni}_{x}\text{Co}_{y}\text{Al}_{z}\)]O2 – NCA

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

Source: SANYO, March 2011

Ni & Co price 2003-2015

Source: LME
CATHODE ACTIVE MATERIALS NEEDS

Cathode active materials for LIB in Tons, 2010-2016 (Demand)

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:+4%

LCO demand details

- **LCO: Tablets, Smartphones**
  - ELEC
  - Others
  - Industrials
  - E-bus
  - xEV China
  - xEV

LCO Offer in 2016

- **UMICORE** 15%
- NICHIA 8%
- ShanShan 10%
- Xiamen Tungsten (XTC) 7%
- Reshine 9%
- B&M 12%
- L&F 16%
- Pulead 12%
- Easpring 9%
- Others 2%

LCO Price forecasts

- Material: 2005 $19/kg, 2010 $29/kg, 2015 $19/kg, 2020 $21/kg, 2025 $21/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.

Assumption: 2016-2025 : Co price stable @ 28$/kg – Lithium carbonate stable @ 10 $/kg – Co price @ 56$/kg in June 2017 !

Sources: AVICENNE ENERGY 2017
NMC DEMAND: CAGR 2015-2025: +20%

**NMC demand details**

- **NMC: Electronics, EV, others**
  - Others
  - Industrials
  - E-bus
  - xEV China
  - xEV
  - Power Tools, E-bikes
  - Other Electronics
  - Portable PCs
  - Smart Phones, Tablets

**NMC Offer in 2016**

- **Tons**
  - 0
  - 50,000
  - 100,000
  - 150,000
  - 200,000
  - 250,000
  - 300,000
  - 350,000

**NMC Price forecasts**

- **$/kg**
  - 10
  - 20
  - 30
  - 40

**NMC evolution**

- **%**
  - 0%
  - 50%
  - 100%

**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. There market share may increase.

**Assumption:** 2016-2025: Co price stable @ 28$/kg – Lithium carbonate stable @ 10 $/kg – Ni stable @ 125$/kg / Co price @ 56$/kg in June 2017 !

**Sources:** AVICENNE ENERGY 2017
NCA DEMAND: CAGR 2015-2025: +16%

NCA demand details

NCA Offer in 2016

NCA Price forecasts

NCA summary of outlook

Assumption: 2016-2025 : Co price stable @ 28$/kg – Lithium hydroxide stable @ 12 $/kg – Ni stable @ 12$/kg BUT Co price @ 56$/kg in June 2017!

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 2016-2025:+8%

LFP demand details

LFP: Industrial, E-Bus

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

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

LFP Offer in 2016

- Internal: BYD, Hefei Guoxuan High Tech Power source (Gxgk), Huanyu Power Source Co., Ltd., LG, A123 (Wanxiang EV Co., Ltd), Hi Power - Others: Hunan Haorun Technology, Henan Tianke, Likai, Tiehu Energy and many others

LFP Price forecasts

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.

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.

Sources: AVICENNE ENERGY 2017
Lithium ion battery raw material supply & demand 2016 - 2025

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LMO DEMAND: CAGR 2015-2025: -12%

LMO demand details

LMO Offer in 2015

LMO Price forecasts

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

Sources: AVICENNE ENERGY 2017

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, ...).
**Cathode Active Material Forecasts 2000-2025**

Cathode active materials 2000-2025 - Tons

<table>
<thead>
<tr>
<th>Year</th>
<th>LCO</th>
<th>NMC</th>
<th>NCA</th>
<th>LMO</th>
<th>LFP</th>
</tr>
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<tbody>
<tr>
<td>2000</td>
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<td>2020</td>
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<td>2025</td>
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</tbody>
</table>

**Assumptions:**

- Portable devices: 2015-2025: +6% per year in volume
- HEV: 2.5 M HEV/year in 2020, 3.3 M HEV in 2025
- P-HEV: 0.4 M P-HEV/year in 2020, 0.7 M in 2025
- EV: 0.4 M EV/year in 2020 + 0.7 M in China, 0.7 M/year + 1 M in China in 2025, 100% LIB
- Industrial & stationary: 2015-2025: +16% per year

**Cathode active materials in 2016**

> 210 000 Tons

**Cathode active materials in 2025**

540 000 Tons

**Assumption:** Tesla keep NCA chemistry and have a relative success (+250 000 EV sold per year in 2025 – TESLA forecast 500 000)
ANODE ACTIVE MATERIALS
104 000 TONS IN 2016

LIB Anode Materials

Source: A. Jossen, IRES 2007

LIB Anode market, (Tons)

Source: AVICENNE ENERGY 2016
ANODE FOR LIB IN 2016
Natural graphite become a commodity

Carbon for LIB anodes by type (2016)

LEADERS:

- BTR
- HITACHI
- Nippon Carbon

NEW ENTRANTS ON THE FIELD:

- LEADERS:
  - Hard Carbon: 400 mAh/g
  - Soft Carbon: 250 mAh/g
  - Graphite: 325-375 mAh/g
  - Capacity (/g):
    - Hard Carbon: ++
    - Soft Carbon: 0
    - Graphite: +
  - Capacity (/cc):
    - Hard Carbon: ++
    - Soft Carbon: +
    - Graphite: 0
  - Power:
    - Hard Carbon: ++
    - Soft Carbon: 0
    - 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:
    - Hard Carbon: 25 -> 20 $/kg
    - Soft Carbon: 20 -> 15 $/kg
    - Graphite: 7-13 -> 6-10 $/kg
  - SUPPLIERS:
    - Hard Carbon: KUREHA
    - Soft Carbon: HITACHI
    - Graphite: HITACHI BTR...

Sources: AVICENNE ENERGY 2017

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Lithium ion battery raw material supply & demand 2016 - 2025
NATURAL GRAPHITE: CAGR 2015-2025: +4%

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
Lithium ion battery raw material supply & demand 2016 - 2025

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ARTIFICIAL GR.: CAGR 2015-2025: +15%

Artificial Graphite demand details

Artificial Graphite Offer in 2016

Artificial Graphite Price forecasts

Artificial Graphite summary of outlook

**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: +15%

Supplier, market share in 2016

Sources: AVICENNE ENERGY 2017
ELECTROLYTE SUPPLIERS/CUSTOMERS
103 000 TONS IN 2016

LIB electrolyte market, Tons, CAGR 2006/2016: +28%

LIB electrolyte supplier, market share in 2016

Sources: AVICENNE ENERGY 2017

Note: (1) GTHR: Zhangjiagang Guotai-Huarong
2025 LIB FORECASTS FOR PORTABLE ELECTRONIC DEVICES

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

CAGR 16-25: + 6%  

Source: AVICENNE ENERGY Analyses

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

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

Why x-EV?

Definition & segmentation

X-EV worldwide in 2016

- 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

CAGR 2016-2025: +17%
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)

Total Investment (M$) made for LIB manufacturing

BYD (2013 - 2015)
LiTec GmbH
Panasonic EV
SK Energy
Mitsubishi H.I.
NEC Tokin
AESC Japon
Hitachi Vehicle Energy
SATA
SATA US
BAK
Lihen
Nissan-Renault (Port)
Blue Energy
Toshiba
Nissan - Renault (UK)
LG Chem
Rusnano-Thunder Sky
Lithium Energy Japan
Hitachi Vehicle Energy
SB Limotive
GS YUASA
Dow Kokam
Nissan-Renault (Fr)
Ener1
Sanyo
A123
JCI
LG Chem
BYD
Sony
NISSAN Motor US
PANASONIC

2014 – 2017 TESLA, ATL, BYD Investments: 150 $ / kWh

Average 2012-2014 Investments: 250 $ / kWh

Source: AVICENNE ENERGY Analyses 2017
LITHIUM ION CELL PRODUCTION

Korean companies start to move in Malaysia
New production capacity in Europe and US

Source: AVICENNE 2017

* OTHERS: Malaysia mostly
(1) Government subsidies only
TIME TO MARKET FOR NEW MATERIALS IN LIB INDUSTRY

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.
### Time to Market for New Materials

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<td>LiMnPO4, 4v</td>
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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 BOLLORÉ, 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
LI-ION BATTERY COST
2015-2025
LIB cell average cost (40 Ah pouch)
(EV design ; NMC cathode)

LI-ION BATTERY PACK COST FOR EV

(1) Active materials only
Source: AVICENNE ENERGY 2016

* For Production > 100 000 packs/year
LIB PRICE FORECASTS

Source: *Rapidly falling costs of battery packs for electric vehicles*, Nature Climate Change, March 2015
TOTAL BATTERY DEMAND
2025 FORECASTS

Li-ion for EV, HEV & P-HEV Battery needs (MWh)
CAGR 2016-2025: +17%

Li-ion for EV, HEV & P-HEV Battery needs (M$)
CAGR 2016-2025: +12%
X-EV BATTERY MARKET
2000 – 2025 IN M$

Cell Level
CAGR 2016-2025: +12%

Pack Level
CAGR 2015-2025: +11%
From 90 GWh in 2016 to 300 GWh

CAGR 2016/2025
+15 % per year in Volume

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

- 50 000
- 100 000
- 150 000
- 200 000
- 250 000
- 300 000
- 350 000

2016: 90 GWh

Auto, E-bus China 30%
Industrial, ESS 13%
Electronic devices 40%
Others 6%

2025: 300 GWh

Auto, E-bus China 43%
Auto, E-bus Excl. China 21%
Industrial, ESS 7%
Electronic devices 18%
Others 11%

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
TAKEAWAYS

Battery Market 2015-2025
CAGR = +6% / Li-ion>+10%

- 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: 15 B$ market in 2016 - 28 B$ in 2020 & 38 B$ in 2025 with high numbers in China (2016: US$ 3,6 Billion for xEV and US$ 4,8 Billion for xE-Buses)
- 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
- Lithium battery for other application (ESS, stationary, industrial...) 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
THANK YOU

PHOTO

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