Lithium-Ion Battery Market Expansion Beyond Consumer and Automotive

Christophe PILLOT
Director, AVICENNE ENERGY

Presentation Outline
- The rechargeable battery market in 2013
- Lithium ion battery Battery beyond Consumer & Automotive in 2013
- Forecasts & conclusions
AVICENNE ENERGY: RENOWNED TO HAVE REALISTIC FORECASTS

HEV powered by Lithium ion battery forecasts from 2008 to 2013

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

AABC June 2007, AABC Asia, May 2014
THE BATTERY MARKET IS REALLY DYNAMIC

Source: AVICENNE ENERGY Analyses 2014
THE WORLDWIDE BATTERY MARKET
1990-2013

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

Source: AVICENNE ENERGY, 2014
THE WORLDWIDE BATTERY MARKET
1990-2013

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, 2014
THE WORLDWIDE BATTERY MARKET
1990-2020

54 BILLION US$ in 2013 – Pack level
5% AVERAGE GROWTH PER YEAR (1990-2013)

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
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, 2014
THE WORLDWIDE BATTERY MARKET
1990-2013

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, 2014
BATTERY FOR OTHER APPLICATION
US$ 18 BILLION\(^1\) MARKET

Battery market in 2013 (M$)

<table>
<thead>
<tr>
<th>Battery Market</th>
<th>M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Tools</td>
<td>1400</td>
</tr>
<tr>
<td>E-bikes</td>
<td>2290</td>
</tr>
<tr>
<td>Motive</td>
<td></td>
</tr>
<tr>
<td>Forklifts</td>
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<tr>
<td>Others</td>
<td>180</td>
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<tr>
<td>TOTAL MOTIVE</td>
<td>3750</td>
</tr>
<tr>
<td>Stationary</td>
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</tr>
<tr>
<td>Telecom back-up</td>
<td>2900</td>
</tr>
<tr>
<td>UPS</td>
<td>2400</td>
</tr>
<tr>
<td>Misc. Standby</td>
<td>315</td>
</tr>
<tr>
<td>ESS</td>
<td>450</td>
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<tr>
<td>Seismic (1)</td>
<td>210</td>
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<tr>
<td>Other Stationary</td>
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<tr>
<td>Total STATIONARY</td>
<td>7370</td>
</tr>
<tr>
<td>TOTAL INDUSTRIAL</td>
<td>11120</td>
</tr>
<tr>
<td>Medical Cart</td>
<td>150</td>
</tr>
<tr>
<td>Wheelchair</td>
<td>47</td>
</tr>
<tr>
<td>Medical Device (1)</td>
<td>1150</td>
</tr>
<tr>
<td>Marine</td>
<td>450</td>
</tr>
<tr>
<td>Others</td>
<td>1000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>17600</td>
</tr>
</tbody>
</table>

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

Source: AVICENNE ENERGY, 2014

(1) 500 M$ for Li-ion - Source: Zprime 2011
THE WORLDWIDE BATTERY MARKET IN 2013: US $ 54 BILLION

Battery market in 2013 (M$)

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

Source: AVICENNE ENERGY, 2014
# TOTAL POTENTIAL MARKET ANALYZED IN THE SURVEY (M$, PACK LEVEL\(^1\))

## Application details

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<td>E-bikes</td>
<td>2290</td>
</tr>
</tbody>
</table>

**Motive**

- Forklifts: 3570
- Others: 180
- TOTAL MOTIVE: 3750

**Stationary**

- Telecom back-up: 2900
- UPS: 2400
- Misc. Standby: 315
- ESS: 450
- Seismic (1): 210
- Other Stationary: 1090
- Total STATIONARY: 7370

**TOTAL INDUSTRIAL**: 11120

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</tbody>
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**TOTAL POTENTIAL MARKET ANALYZED IN THE SURVEY** (M$, PACK LEVEL\(^1\))

**US$ 18 Billion in 2013**

- E-Bikes: 12%
- Power Tools: 9%
- Forklift: 20%
- Other Motive: 6%
- Telecom: 17%
- UPS: 14%
- Other Stand-by: 3%
- ESS: 6%
- Seismic: 3%
- Other Stationary: 6%
- Medical Cart: 6%
- Wheelchair: 5%
- Medical devices: 3%
- Marine: 3%
- Other App (2): 3%

**Source**: AVICENNE ENERGY 2013

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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 TEMPLATE

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

Source: AVICENNE ENERGY Analyses
1- E-BIKES
LIB: FROM US$ 1,1 BILLION IN 2013 TO 2,7 IN 2020¹ – CAGR: +18%

Market 2013-2020 (US $, Million) – CAGR: 13%

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

LIB 2020 by Area
- US: 73%
- China: 14%
- Europe: 3%
- Others: 10%

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

Source: AVICENNE ENERGY Analyses

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

Battery 2013 by Area
- US: 10%
- Europe: 3%
- China: 10%
- Others: 77%
2- POWER TOOLS
LIB: FROM US$ 0.8 BILLION IN 2012 TO 1.2 IN 2020¹ – CAGR: +7%

Market 2013-2020 (US $, Million) – CAGR:+3%

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

<table>
<thead>
<tr>
<th>Battery 2013 by Area</th>
<th>LIB 2020 by Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;75% of the power tools are made in China</td>
<td>Power tools will be made in China</td>
</tr>
<tr>
<td>But, battery pack could be made on the end-user area (Ex: Bosch – Axeon Poland)</td>
<td>Local demand in Europe, US, next to the end user to increase flexibility &amp; Just in Time mfg.</td>
</tr>
</tbody>
</table>

Battery needs
- Important characteristic:
  1- Higher power & capacity
  2- Fast recharge
- 2012 ASP NiCd: 350 $/kWh
- 2012 ASP LIB: 550 $/kWh
- Average Capacity: 60 Wh

LIB needs
- Most valuable improvements
  1- Price decrease
  2- Fast charge
  3- High rate discharge
- Form factor: Cylindrical
- No standardization

Source: AVICENNE ENERGY Analyses

Note: 1- Pack level
3- MOTIVE INDUSTRIAL: FORKLIFTS
LIB: FROM US$ 60 MILLION IN 2013 TO 375 IN 2020 – CAGR: >40%

Market 2013-2020 (US $, Million) – CAGR:7%

Main drivers
- Where economies are healthy, they reflect strong motive power production
- Europe & US got high E-forklift ratio compare 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 compare 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
- 7% US
- 51% Europe
- 42% Others

LIB Penetration
- Important characteristic
  1-high charge/discharge rates and capacity
  2-high life time, range,
- Average Capacity: 22 kWh

LIB market (M$)
- Most valuable improvements
  1- Price
  2- Convince customers on “total cost of ownership”
- Form factor: large format prismatic – size standardization

Source: AVICENNE ENERGY Analyses
Note: : 1- Pack level 2- Including all kind of Material handling equipment
4- STATIONARY: TELECOM MARKET
LIB: FROM US$ 0,2 BILLION IN 2013 TO 1,1 IN 2020¹ – CAGR: >50%

Market 2013-2020 (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

Customers

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

Competitors

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

Battery needs

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

LIB needs

- 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

AABC 2015
January 26-29
Mainz, Germany
Market 2013-2020 (US $, Million) – CAGR: +4%
THE BATTERY MARKET FOR ENERGY STORAGE SYSTEM (ESS)

ESS segmentation

ESS by power rating

PHS: Pumped Hydroelectric Storage
CAES: Compressed air energy storage

6- ESS (LARGE SYSTEMS²)
LIB: FROM US$ 0,2 BILLION IN 2013 TO 0,7 IN 2020¹ – CAGR: +30%

Battery Market 2013-2020 (US $, Million) – CAGR: +25%

Main drivers
- Integration of Renewable energy
- Poor electricity network
- Gas Turbine Replacement

Purpose:
- Frequency Regulation
- Peak Shifting
- Load Leveling

Main Limiters
- Not a mature market
- Business model?
- Regulation?
- Battery capital cost (leasing could be a good solution)

Battery 2012 by Area
- CHINA: 45%
- US: 22%
- JAPAN: 11%
- EUROPE: 6%
- OTHERS: 6%

Battery 2012 by type
- > 100 kWh: 1%
- 10-100 kWh: 88%
- < 10 kWh: 11%

Competition
- All big LIB suppliers: Panasonic, Samsung, LG, ...
- A123,
- Johnson Controls
- Yuasa
- SAFT
- Tesla
- Altairnano
- ...

Customers
- Large Electricity providers
- New comers with renewable energy
- Often support by local government

Battery needs
- Most important performances characteristic
  1- Life time
  2- Power capabilities
  3- Cost
- Average Capacity: from 10 kWh to MWh

LIB needs
- Most valuable improvements
  1- cost of ownership
  2- Customized development

Source: AVICENNE ENERGY Analyses

ASP 2012: 900 $/kWh
2020: 500 $/kWh

ASP 2012: 500 $/kWh
2020: 450 $/kWh

Note: 1- Pack level – 2- > 10 kWh systems
Lithium-Ion Battery Market: Expansion Beyond Consumer and Automotive

AABC 2015
January 26-29
Mainz, Germany

7- ESS (SMALL SYSTEMS)²
LIB: FROM US$ 40 MILLION IN 2013 TO 170 IN 2020¹ – CAGR>30%

Battery Market 2013-2020 (US $, Million) – CAGR: +27%

Main drivers
- Residential back-up
- PV Integration
- « Net Zero Energy Home »
- Electricity cost
- Government subsidiaries

Main Limiters
- Not a mature market
- Business model?
- Regulation?
- Battery capital cost (leasing could be a good solution)

Main countries
- Germany
- France
- US
- Japan

Battery 2012 by type
- > 100 kWh: 1%
- 10-100 kWh: 88%
- < 10 kWh: 11%

Competitors
- All big LIB suppliers: Panasonic, Samsung, LG, ...
- A123, Johnson Controls
- Yuasa
- SAFT
- Tesla
- Altairnano
- ...

Customers
- Large Electricity suppliers
- Private companies: (Ex: Solarcities, One Energy Corp., SunRun’s)
- PV residential solution providers: Panasonic, Kyocera, Sharp, SMA ...

Battery needs
- Most important performances characteristic
  1- Energy density
  2- Life time
  3- Power capabilities
  Average Capacity: < 10 kWh

LIB needs
- Most valuable improvements
  1- Cost of ownership
  2- Life time
  3- Charge acceptance
- Customized development
- Standardization?

Source: AVICENNE ENERGY Analyses

Note: 1- Pack level – 2- < 10 kWh systems for home or office
3- Battery pack only, not including the management system, power electronics, installation, ...
The total price of a 7 kWh system from SAFT is 10 k€ (1800 $/kWh)
THE BATTERY MARKET FOR ESS IN 2013-2020

AVICENNE ENERGY estimates the ESS market in 2013 < 500 M$

ESS market in MWh worldwide

ESS market in M$ worldwide

On Sept 2011 NGK-manufactured NaS batteries plant caught fire. Following the incident, NGK temporarily suspended production.
2013 OTHER APPLICATION MARKET
US$ MILLION

US $ 18 Billion in 2013

E-bikes  Power Tools  Forklifts  Other Motive  Telecom Market  UPS  Other Stand-by ESS (>10 kWh)  ESS (<10 kWh)  Seismic  Other stationary  MEDICAL-CART  Wheelchairs  Other medical devices  Marine  Other applications

MOTIVE  STATIONNARY  MEDICAL

Others  Li-ion  Ni based  Lead Acid

21%  4%  4%  71%
Lithium-Ion Battery Market: Expansion Beyond Consumer and Automotive

AABC 2015
January 26-29
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2020 OTHER APPLICATION MARKET US$ MILLION

US $ 28 Billion in 2020 – CAGR 2013/2020: +8%
“OTHER APPLICATIONS”
10 B$ POTENTIAL MARKET

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

Portable: from 28 to 83 GWh
Automotive: from 6 to 50 GWh
« Others »: from 5 to 30 GWh

Li-ion cell market (B$)

2013 - 2025

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...

Source: AVICENNE ENERGY Analysis 2014
SAFETY ISSUES

Li-ion is 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**

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.
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>
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</tr>
<tr>
<td>xEV ?</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<table>
<thead>
<tr>
<th>Anode</th>
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<th>Li Metal</th>
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<tr>
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<tr>
<td>xEV ?</td>
<td>YES</td>
<td>YES</td>
<td>No (1)</td>
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<table>
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<tr>
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</thead>
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<tr>
<td>SAFETY</td>
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<table>
<thead>
<tr>
<th>Separator</th>
<th>PE, PP membrane</th>
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- **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

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

Battery Market 2013-2025

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 for the grid will represent less than 5% of the total battery market

RECHARGEABLE BATTERY MARKET WORLDWIDE 2000-2025

<table>
<thead>
<tr>
<th>Year</th>
<th>Others</th>
<th>LIB</th>
<th>NiMH</th>
<th>NiCd</th>
<th>Lead Acid</th>
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<tbody>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
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</table>

LIB: CAGR > +10% in the next 15 years

Lead acid (+4%) NiCd (-5%) LIB for 3C (+3%) LIB for xEV (+16%) Others (+16%)

Others: Automatic handling equipment, forklifts, back-up, UPS, Telecom, medical devices, Residential ESS, Grid ESS, ...