Li-ion batteries & material market trends: Past & Future

Christophe PILLOT
Director, AVICENNE ENERGY
AVICENNE PROFILE

Information for Growth - Powering your company’s market strategy with in-depth research

- Creation: 1992
- Headquarter: Paris
- Liaison Office: Japan, USA
- AVICENNE Energy Director: Christophe Pillot
- 4 consultants in Paris

The Rechargeable Battery Market and Main Trends 2011-2020

International Congress on Automotive Li Ion Batteries 2012 23 – 25 April 2012

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METHODOLOGY: EXTENSIVE FIELD RESEARCH TO RETRIEVE & CROSS CHECK INFORMATION

Top management contacts network
> 17 000 contacts

Conferences & Exhibitions

In Depth analysis Of applications

Cross Check Analysis

- Battery Makers
- Battery Users, OEM
- Substitution technologies: SuperCap, Fuel cells
- Raw materials suppliers
- Safety
- Environment & recycling

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### MORE THAN 170 REFERENCES

**WORLDWIDE**

- A123
- Air Liquide
- Air Product
- Alcatel
- Amperex (ATL)
- Aros Securities
- ARC
- Atofina - Arkema
- AT Kearney
- Axeon
- Bain
- Battery R&D Association of Korea
- B&D
- BHP Billiton
- Brand Licencing Parners (BLP)
- Bourns
- Bosch
- BYD
- Cap X
- Catella
- Carbone Lorraine
- Carlyle
- CDN Cobalt
- CEA/LITEN
- Celgard
- Chemetall
- CIAPS
- CIBA
- CNRS
- Cogema
- CRU Group
- CSC Challenge Strategy Change
- DELTA
- DGA
- Dialog Semiconductor
- Dow Chemical
- Dupont
- Duracell
- EDF
- Electro Energy
- Ener 1
- Energizer
- ETC AB
- Facom
- Falcon Bridge
- Fairchild semiconductor
- Fameart
- FIST
- Floridienne de Chimie
- FMC Lithium
- Fortu Power Cell
- France Telecom
- Fulton Innovation
- GAIA
- GIL Import Batteries Ltd.
- GS Melctocet
- HC Starck (Bayer)
- HILTI
- Hitachi Maxell
- Hollingsworth & Vose Cie
- Honeywell
- HPL (High Power Lithium)
- Hutchinson
- IER
- IGL Export.
- International Component
- Inco
- Intersil
- ITRI
- ITS
- Johnson Controls
- JBC
- Kodak
- Kruger
- Lazard
- Leclanché
- Legrand
- LG Chemical
- Lion cells
- Little Fuse
- Lilipucian
- Lynas Corp
- Matsushita
- Microsoft
- MTI Micro Fuel Cells
- Mindbranch
- Moltech
- Molycorp
- Motorola
- NCCP - Russia
- Nitech
- NKKPC – Brett Nelson
- Norilsk Nickel
- Novaled
- NTK Powerdex
- OMG Inc
- Panasonic
- Philips
- Photon
- PK & Wise
- PRAYON
- Prismark
- PSA
- Rayovac
- Recharge
- Renault
- Rhodia
- Saft
- Samsung SDI
- Sanik
- Schroder Venture
- Scotent Entreprise
- Shenzhen High Power Technology
- Schott AG
- SKC
- SVE - Dassault
- Solvay
- Sony
- Stibat
- Starck
- Toda Kogyo
- TOTAL
- Total Wireless Solution
- Toyota
- Tyco
- Umicore
- Uniros
- Varta
- Warburgpincus
- World Industrial Information Center
- WR Grace & Cie
- Zebra
- ZPower
AVICENNE ENERGY: RENOWNED TO HAVE REALISTIC FORECASTS

HEV powered by Lithium ion battery forecasts from 2008 to 2011

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

OUTLINE

- THE RECHARGEABLE BATTERY MARKET IN 2011
- ELECTRIC VEHICLE SEGMENTATION
- HEV, P-HEV & EV MARKET BY COMPETITOR AND BY AREA
- FORECASTS BY 2025
- IMPACT ON THE BATTERY BUSINESS
THE BATTERY MARKET IS REALLY DYNAMIC

**Cellular Phones sold per Year (Million)**

- Li-ion
- NiMH

**Portable PC sold per Year (Million)**

- Li-ion
- NiMH

**Tons of Li-ion Cathode per year**

**Li-ion 18650 cell price ($/Wh)**
THE WORLDWIDE BATTERY MARKET
1990-2010

30 BILLION US$
3-4% AVERAGE GROWTH PER YEAR (1990-2010)
The worldwide rechargeable battery market, in volume, MWh, 1995-2011

- NiCd: 0% per year
- NiMH: +3% per year
- Li-ion: +27% per year

2001-2011 (CAGR)
LI-ION IN 2011

MAIN APPLICATIONS: CELLULAR, NOTEBOOK

4 125 M cells – 28 000 MWh
9 300 M$

CAGR 2006/2011
+21% per year in Volume
+12% per year in value

Li-ion Battery sales, MWh, Worldwide, 2000-2011

Li-ion Battery sales, MWh, Worldwide, 2000-2011

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WHY X-EV?

The Rechargeable Battery Market and Main Trends 2011-2020

Petroleum consumption worldwide 1960-2030

Price of the WTI barrel of oil, US $

CO2 density in the atmosphere increase

Petroleum consumption worldwide 1960-2030

Price of the WTI barrel of oil, US $

CO2 density in the atmosphere increase

Source: Energy Information Administration, US Government

Source: IPCC, Intergovernmental Panel on Climate Change, Climate Change 2007, Synthesis Report p38
HEV, P-HEV & EV
DEFINITION & SEGMENTATION

INFORMATION FOR GROWTH
www.avicenne.com

The Rechargeable Battery Market and Main Trends 2011-2020

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Note: Micro HEV are not in the HEV statistics & HEV forecast
HEV WORLDWIDE IN 2011
LESS THAN 0.9M HEV SOLD

HEV sold per year, M units, worldwide, 2000 - 2011

Penetration of hybrids in the global sales, 2000-2011

Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
HEV WORLDWIDE IN 2011
BY CAR SUPPLIER

Total HEV Vehicles
Less than 0.9 M in 2011

HEV sold per year, M units per car manufacturers, 2000-2010

Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
HEV WORLDWIDE IN 2011
BY COUNTRY

Total HEV Vehicles
Less than 0.9 M in 2011

USA 31%
JAPAN 48%
EUROPE 14%
OTHERS 7%

HEV sold per year, M units per country, 2004-2011
RAW MATERIALS IS DRIVING THE BATTERY BUSINESS

RAW MATERIALS ACCOUNT FOR 50 TO 80% OF LIB BUSINESS
RAW MATERIAL COST IMPACT DRASTICALLY ON THE BATTERY MAKERS PROFIT

Production cost for Japanese, Chinese & Korean makers for prismatic cells in 2011

- Operating profit
- Depreciation
- SGA
- R&D
- Labor
- Material

Co price ($/kg)

Profit level (% of revenues)

Co Price

Profit level (% of the revenues)

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The Rechargeable Battery Market and Main Trends 2011-2020

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LIB BUSINESS RECALL 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

<table>
<thead>
<tr>
<th>Battery Makers</th>
<th>OEM</th>
<th>Battery recall</th>
<th>Date</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matsushita</td>
<td>Nokia</td>
<td>46 M cells</td>
<td>08/07</td>
<td>170 MUS$</td>
</tr>
<tr>
<td>Sanyo</td>
<td>Mitsubishi</td>
<td>1.3 M cells</td>
<td>12/06</td>
<td>35 MUS$</td>
</tr>
<tr>
<td>Sony</td>
<td>Dell, Apple, Toshiba, Lenovo,...</td>
<td>10 M Packs 65 M cells</td>
<td>2006</td>
<td>430 MUS$</td>
</tr>
<tr>
<td>Sony</td>
<td>HP, Toshiba, Dell</td>
<td>0.44 M</td>
<td>2009</td>
<td></td>
</tr>
</tbody>
</table>

RECALL SLASH BATTERY PROFIT

Operating profit/Revenue

- Sanyo
- MBI
- BYD
- SGS
- NEC
- Sony
- Maxell
- LGC
- SDI
- Average
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LI-ION VALUE CHAIN

CATHODE SUPPLIERS
63 000 T in 2011
Revenues: 1,8 B$
CAGR 06/11: +13%

ANODE SUPPLIERS
32 000 T
Revenues: 0,6 B$
CAGR 06/11: 11%

ELECTROLYTE SUPPLIERS
21 000 T
Revenues: 0,4 B$
CAGR 06/11: 17%

SEPARATOR SUPPLIERS
440 M m²
Revenues: 0,8 B$
CAGR 06/11: 15%

ANCILLARY
Revenues: 0,6 B$

CELL MANUFACTURERS
Revenues: 9 B$
Gross margin: <10%

PACK MANUFACTURE RS
Revenues: 11 B$
Gross margin: <10%

-> Cell makers & raw material suppliers relationship
-> Raw material new entrants
-> Entry barriers for raw materials suppliers
-> Raw material impact on battery efficiency
-> Raw material cost and main trends
CATHODE ACTIVE MATERIALS NEEDS BY CHEMISTRY

Cathode active materials for LIB in Tons, 2000-2011

Cathode active materials for LIB, % of volume, 2011
ANODE FOR LIB IN 2011

Natural graphite is more & more used

Note:
MCMB: Mesocarbon Microbeads
LIB SEPARATOR MARKET 2011

LIB separator market, M$, CAGR 2001/2011: +19%

LIB Separator supplier, market share in 2011

Others: TDK/Nitto Denko, Foshan Jinhui Hi-Tech, Shenzhen Senior Technology Material, Xinxiang Green next Energy, Dupont,...
ELECTROLYTE SUPPLIERS/CUSTOMERS
21 200 TONS IN 2011

LIB electrolyte market, Tons, CAGR 2001/2011: +19%

LIB electrolyte supplier, market share in 2011

- Mitsubishi 24%
- PANAX-ETEC 21%
- Zhangjiagang Guotai-Huarong 19%
- Others 18%
- Ube 11%
- In-House 4%
- Tomiyama 3%

Cellular Portable PC Tablets
Power tools Auto Others
LI-ION RAW MATERIALS ROADMAP


CATHODE
- LCO
- LCO
- LMO
- LFP

ANODE
- Graphite
- Hard Carbon
- Soft Carbon
- C/Alloy Composite
- Li Metal
- Li$_4$Ti$_5$O$_12$
- Non Si Alloys
- Si Alloys

ELECTROLYTE
- LiPF$_6$ + Org. solvents
- LiPF$_6$ free electrolyte
- Gel-polymer electrolyte
- 5v electrolyte

SEPARATOR
- Polyolefin
- Polyolefin+ ceramic coating
- Cellulose
- Non-woven

Source: Avicenne Compilation, Kai-Christian Möller, Fraunhofer ISC

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LONG TERM HEV FORECAST FROM 3 TO 8 M HEV IN 2020

AVICENNE ENERGY FORECASTS ARE REALISTIC COMPARE TO OTHER ANALYSTS

Source: AVICENNE ENERGY Compilation, February 2012
WHICH BATTERY TECHNOLOGY FOR HEV?

NiMH is improving and powering more than 95% of HEV car sold in 2011

<table>
<thead>
<tr>
<th></th>
<th>PRIUS II</th>
<th>PRIUS III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>6.5 Ah</td>
<td>6.5 Ah</td>
</tr>
<tr>
<td>Cells</td>
<td>228 (38 * 6)</td>
<td>168 (28 * 6)</td>
</tr>
<tr>
<td>Voltage</td>
<td>273.6 v</td>
<td>201.6 v</td>
</tr>
<tr>
<td>Specific power</td>
<td>1000 W/kg</td>
<td>1300 W/kg</td>
</tr>
<tr>
<td>Specific energy</td>
<td>46 Wh/kg</td>
<td>46 Wh/kg</td>
</tr>
<tr>
<td>Total power/HEV</td>
<td>36 kW</td>
<td>37.8 kW</td>
</tr>
<tr>
<td>Total energy/HEV</td>
<td>1778 Wh</td>
<td>1310 Wh</td>
</tr>
</tbody>
</table>

NiMH Capacity is increasing

![Graph showing NiMH Capacity increase](image)

Example of AA NiMH

![Graph showing NiMH Capacity](image)

NiMH Cost per kWh is decreasing

![Graph showing NiMH Cost decrease](image)

Source: TOYOTA

Source: Sanyo – AVICENNE ENERGY Compilation

Source: AVICENNE ENERGY
NIMH BATTERIES FOR HEV IN 2010/2011

Thanks to TOYOTA, Primearth EV Energy (PEVE), got more than 75% of the HEV battery market and a large know-how

<table>
<thead>
<tr>
<th>Car Maker</th>
<th>PEVE</th>
<th>SANYO-Panasonic</th>
<th>COBASYS (SB Limotive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOYOTA</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEXUS</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HONDA</td>
<td>■</td>
<td></td>
<td></td>
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<tr>
<td>FORD</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISSAN</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM</td>
<td>■</td>
<td>■</td>
<td></td>
</tr>
<tr>
<td>BMW</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAIMLER</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHRYSLER</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VW</td>
<td>■</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMW</td>
<td>■</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NiMH battery & Car makers relationships 2011

Sanyo’s battery used by Ford
LI-ION PENETRATION IN VARIOUS DEVICES: AVICENNE & OTHER ANALYSTS FORECAST

Li-ion penetration in electronic devices & HEV

HEV powered by LIB forecasts from 2008 to 2011


(1) AVICENNE HEV Forecasts, march 09, Relevant scenario
(2) AVICENNE HEV Forecasts, march 09, Li-ion Optimistic scenario
(3) IIT, TAKESHTA, March 08, THE 25th INTERNATIONAL BATTERY SEMINAR & EXHIBIT, Slide 8 & March 2009, 26th Battery Seminar,
(4) AAB, Menahem ANDERMAN, Ph.D, Tampa, Florida, May 2009
LI-ION BATTERY DEVELOPMENTS FOR HEV, P-HEV & EV

Li-ion is THE solution for the future

*BUT, SAFETY, LIFE TIME & COST issues*

*Lot of technical solutions (NMC, NCA, LFP, LCO...)*

*Lot of EXPENSIVE Developments (cell mfg, cooling systems, pack assembly...)*

So,

*Lot of JV, partnerships etc...*

LIB >NiMH but

SAFETY & COST ISSUES

<table>
<thead>
<tr>
<th></th>
<th>PRIUS III NiMH</th>
<th>PRIUS x - Li-ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volts</td>
<td>201.6</td>
<td>201.6</td>
</tr>
<tr>
<td>Cells</td>
<td>168 (28*6)</td>
<td>56</td>
</tr>
<tr>
<td>Capacity</td>
<td>6.5 Ah</td>
<td>3.8 Ah</td>
</tr>
<tr>
<td>Energy</td>
<td>1310 Wh</td>
<td>766 Wh</td>
</tr>
<tr>
<td>Weight</td>
<td>38 kg</td>
<td>25 kg</td>
</tr>
<tr>
<td>°C Range</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cyclability</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

JOINT VENTURE & STRONG PARTNERSHIP

<table>
<thead>
<tr>
<th></th>
<th>TOYOTA</th>
<th>NISSAN</th>
<th>HONDA</th>
<th>MITSUBISHI</th>
<th>DAIMLER</th>
<th>BYD AUTO</th>
<th>BOSCH</th>
<th>SAIC</th>
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<tbody>
<tr>
<td>PANASONIC</td>
<td>PEVE</td>
<td>AESC</td>
<td>JVS</td>
<td>LEJ (EV)</td>
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<td>NEC</td>
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<tr>
<td>GSY</td>
<td></td>
<td></td>
<td>JVS</td>
<td>LEJ (EV)</td>
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<tr>
<td>BYD</td>
<td></td>
<td></td>
<td>JVS</td>
<td>HEV, EV</td>
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<td></td>
<td></td>
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<tr>
<td>Evonik</td>
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<td>Li-Tec,</td>
<td>Deutsche Accu</td>
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<td></td>
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<tr>
<td>A123</td>
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</tbody>
</table>
LIB MANUFACTURING INVESTMENTS
2009-2015

10-12 B$ WORLDWIDE
>50 GWh in 2015

Total Investment (M$) made for LIB manufacturing

**Average Investments:** 250 $ / kWh

- LITec GmbH
- Panasonic EV
- SK Energy
- Mitsubishi H.I.
- NEC Tokin (Electrodes)
- AESC Japon
- Hitachi Vehicle Energy
- SAFT
- SAFT US
- BAK
- Lishen
- Nissan-Renault (Port)
- Blue Energy
- Toshiba
- Nissan - Renault (UK)
- LG Chem - Compact...
- Rusnano-Thunder Sky
- Lithium Energy Japan
- Hitachi Vehicle Energy
- SB Limotive
- GS YUASA
- Dow Kokam (KD ABG MI)
- Nissan-Renault (Fr)
- Ener1
- Sanyo
- A123
- JCI
- LG Chem
- BYD
- Sony
- NISSAN Motor US
- PANASONIC

A123 Michigan Plant - Photo courtesy of A123 Systems

Liotech Plant, Novosibirsk – 1.5 GWh production capacity
LIB BATTERY COST

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 2011

$/kWh

LIB 18650 cell  LIB EV Cell  LIB pack for EV  LIB HEV cell  LIB pack for HEV
EV FORECASTS
2011-2020

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

EV impact on the LIB & raw material market is HUGE

IIT, March 2011 Fort Lauderdale
IIT, March 2010 Fort Lauderdale
Deutsche Bank, Electric Cars: Plugged In 2 – Nov 2009
Roland BERGER, Oct 2011, Batteries 2011 Cannes
AAB, AABC Europe, Mainz, June 2011
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TOTAL BATTERY DEMAND 2011-2020

EV, HEV & P-HEV Battery needs (M Wh) 2005 – 2020

Total battery demand (MWh) 2000 – 2025
## RECHARGEABLE BATTERY MARKET
### 2000 – 2025 (CELLS LEVEL)

### Rechargeable battery market, M$ for x-EV 2000-2025

<table>
<thead>
<tr>
<th>Year</th>
<th>M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>200</td>
</tr>
<tr>
<td>2005</td>
<td>500</td>
</tr>
<tr>
<td>2010</td>
<td>1500</td>
</tr>
<tr>
<td>2015</td>
<td>4500</td>
</tr>
<tr>
<td>2020</td>
<td>9000</td>
</tr>
</tbody>
</table>

### Rechargeable battery market, M$, 2000-2025

<table>
<thead>
<tr>
<th>Year</th>
<th>M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>500</td>
</tr>
<tr>
<td>2005</td>
<td>1000</td>
</tr>
<tr>
<td>2010</td>
<td>2500</td>
</tr>
<tr>
<td>2015</td>
<td>5000</td>
</tr>
<tr>
<td>2020</td>
<td>10000</td>
</tr>
<tr>
<td>2025</td>
<td>30000</td>
</tr>
</tbody>
</table>

**Legend:**
- NiCd
- NiMH for HEV
- LIB for HEV
- LIB for P-HEV
- LIB for EV
- NiMH except Auto
- LIB Cyl
- LIB Pr
- LIB Pol
- LIB Auto

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TAKEAWAYS

Battery Market 2010-2020
CAGR = +7%

- Li-ion battery is driven today by Portable PCs & electronic devices
- For automotive, the battery technology is today the NiMH
- LIB begin really to compete in 2012
- P-HEV & EV will be powered by Li-ion:
  5 B$ market in 2015 & 9 B$ in 2020
- 1 M EV represent roughly 25 000 MWh, or 60 000 tones of cathode materials!
- EV expectations attract now large Chemical companies
- New materials are needed to meet Automotive standards
- In 2020, Energy storage will represent less than 5% of the total battery market

Note: Excluding Energy Storage batteries
Thank you

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