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ENERGY

INFORMATION FOR GROWTH

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Séminaire sur les métaux de la
transition énergétique

Paris, France

3 Février 2017

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Evolution du marché mondial des batteries rechargeables

Impact sur la demande en Nickel, Cobalt et Lithium

Christophe PILLOT

Director, AVICENNE ENERGY

Presentation Outline

- The rechargeable battery market in 2016
- The NiCd, NiMH & Li-ion battery value chain
- Li-ion battery material market: cathode & anode – Impact on Metals demand
- Forecasts & conclusions

Evolution du marché
mondial des batteries
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Impact sur la demande en
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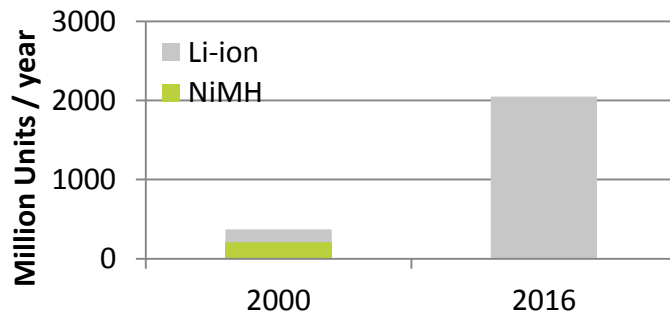
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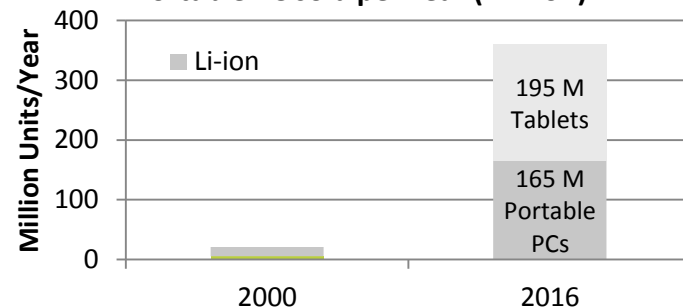
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THE BATTERY MARKET IS REALLY DYNAMIC

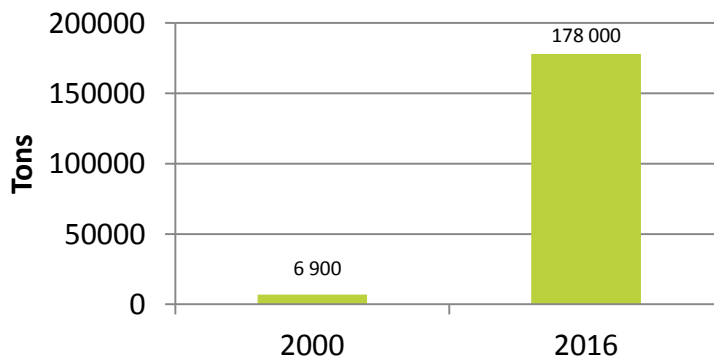
Cellular Phones sold per Year (Million)



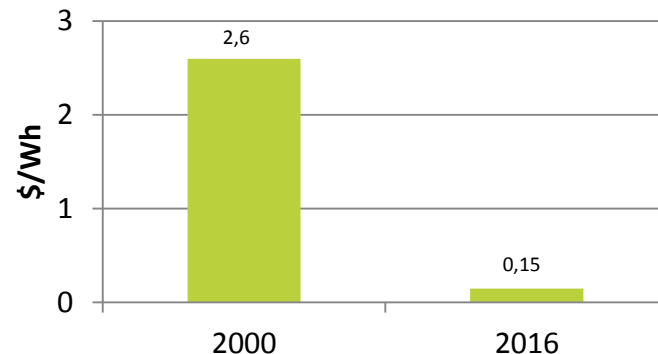
Portable PC sold per Year (Million)



Tons of cathode active materials



Li-ion 18650 cell price (\$/Wh)



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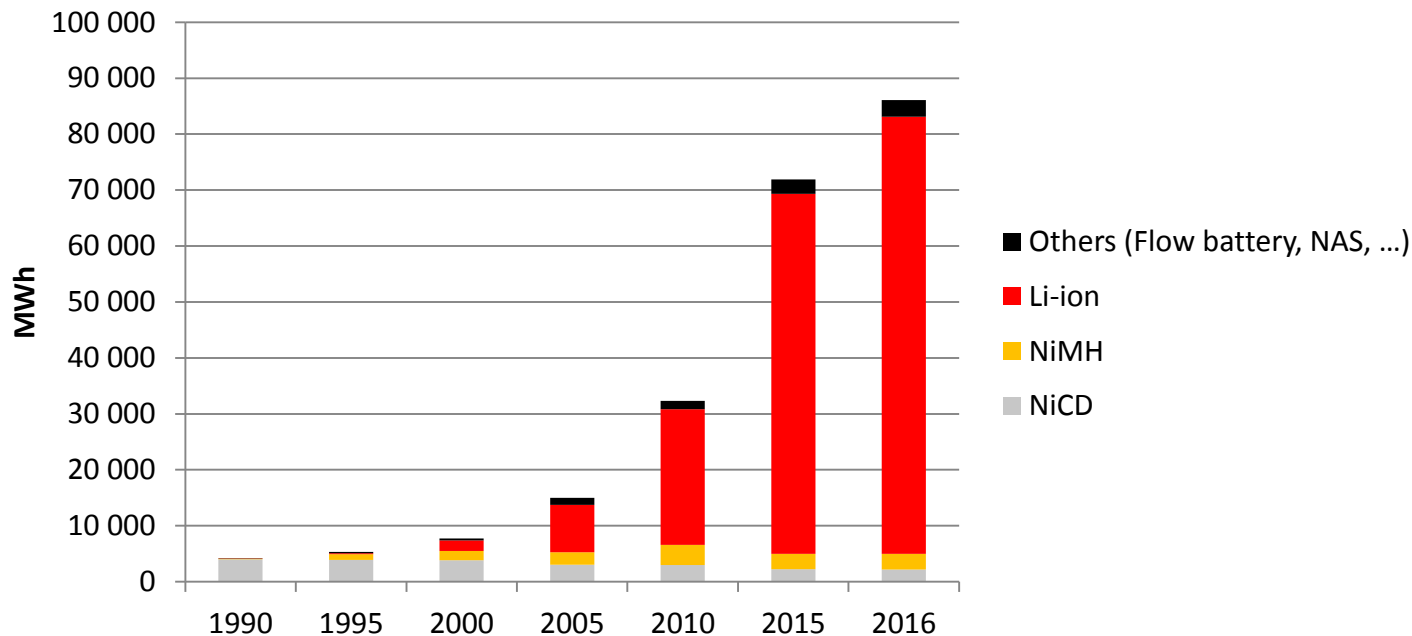
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THE WORLDWIDE BATTERY MARKET 1990-2016

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



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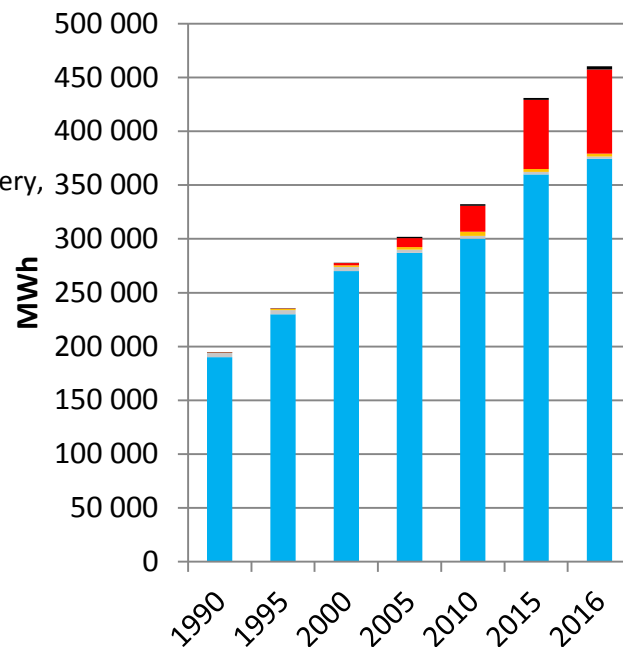
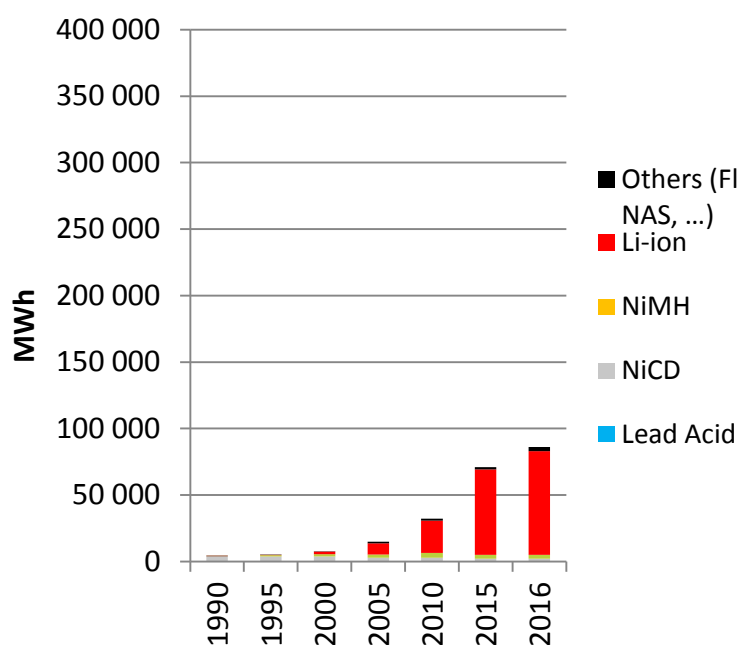
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THE WORLDWIDE BATTERY MARKET 1990-2016

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



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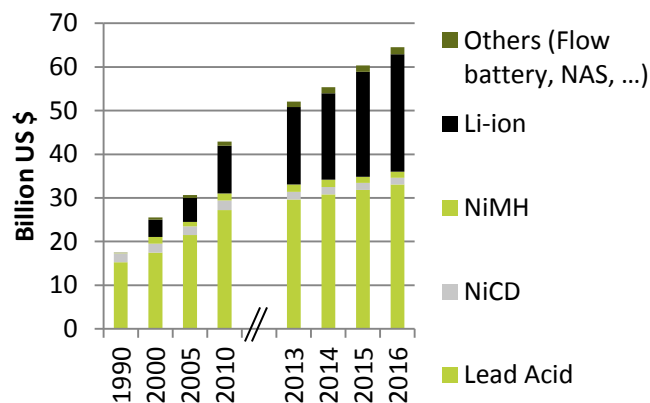
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THE WORLDWIDE BATTERY MARKET 1990-2016

65 BILLION US\$ in 2016 – Pack level¹

5% AVERAGE GROWTH PER YEAR (2000-2016)



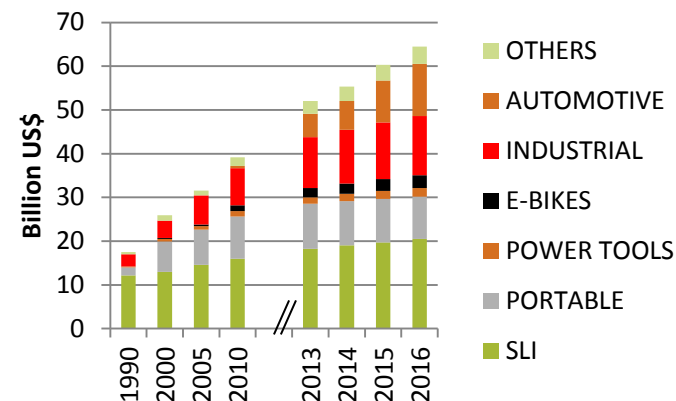
SLI: Start light and ignition batteries for cars, truck, moto, boat etc...

PORTABLE: consumer electronics (cellular, portable PCs, tablests, 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



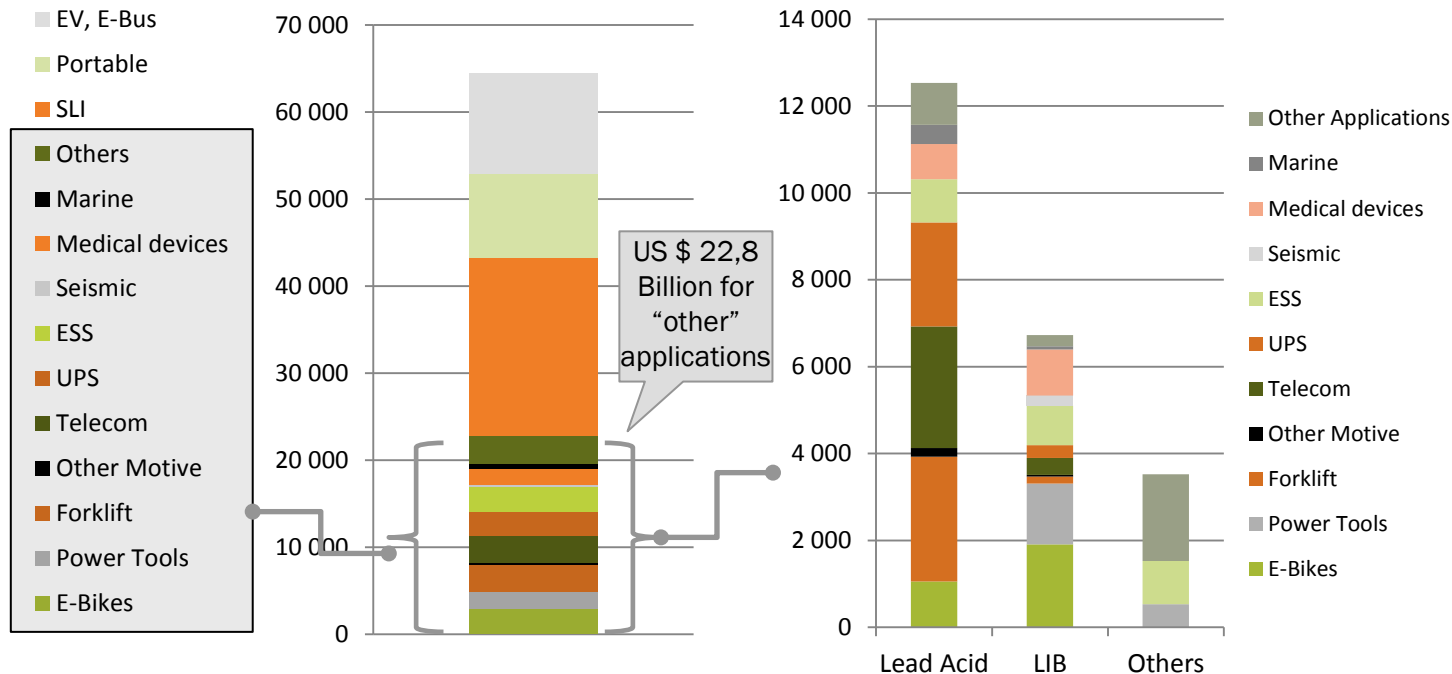
INDUSTRIAL

- 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

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

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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

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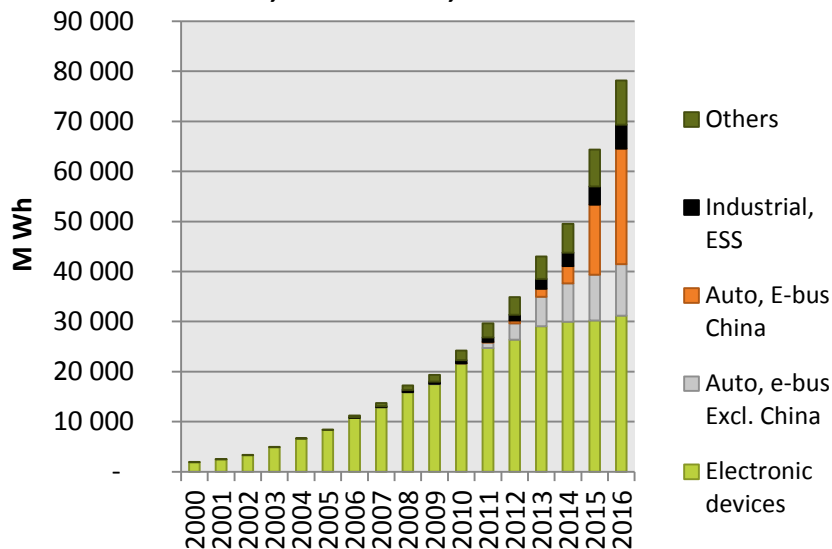
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**Li-ion Battery sales,
MWh, Worldwide, 2000-2015**

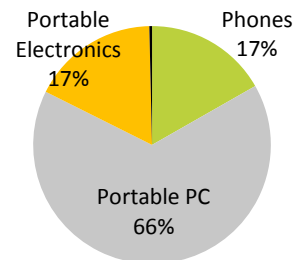


(1) Cell level

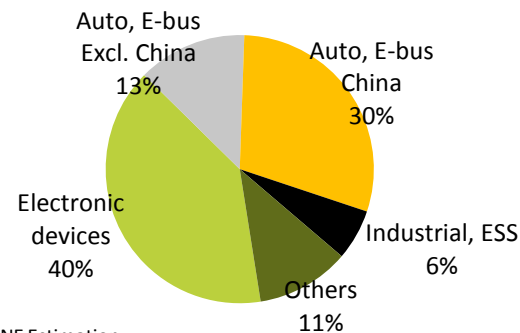
Others: medical devices, power tools, gardening tools, e-bikes...

Source: AVICENNE Energy 2017

2000: < 2GWh



2016: 78 GWh



2016: AVICENNE Estimation

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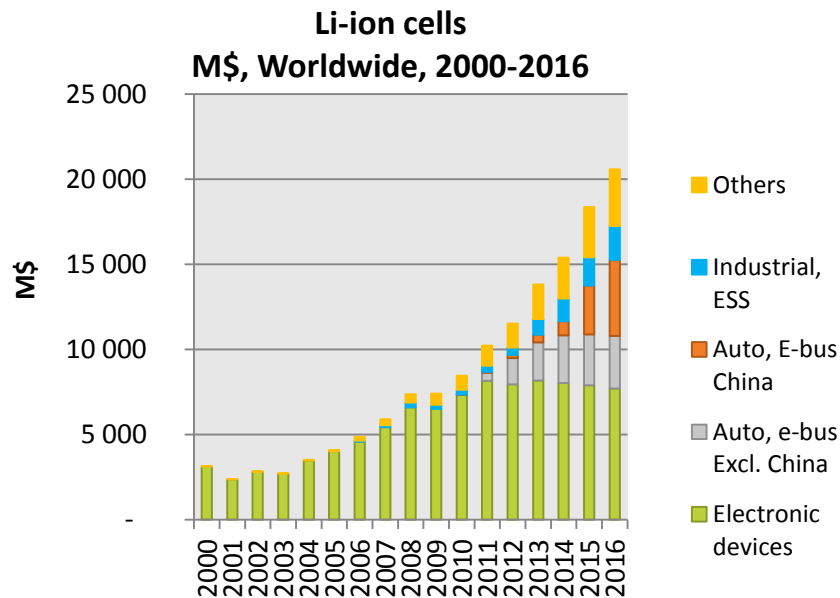
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LI-ION IN 2016 - MAIN APPLICATIONS

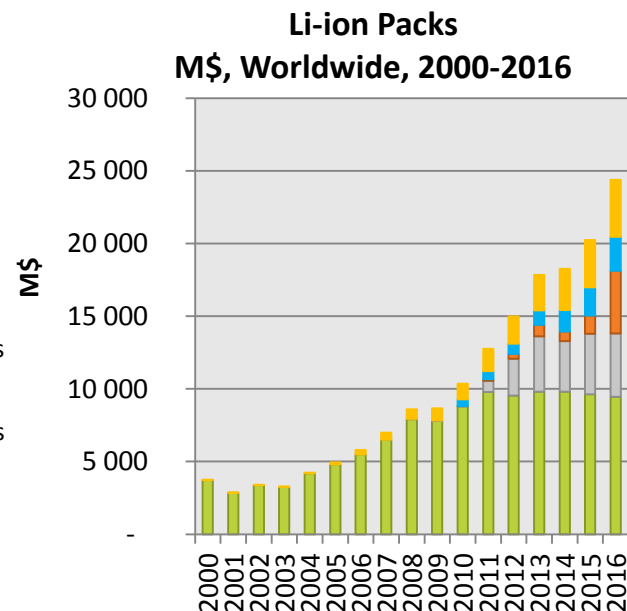
+78 000 MWh - 20 600 M\$ (1)
 5 675 M small cells

CAGR 2006/2016
 +22 % per year in Volume
 Cell: +15,5% per year in value
 Pack: +16% per year in value



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

Source: AVICENNE Energy 2017

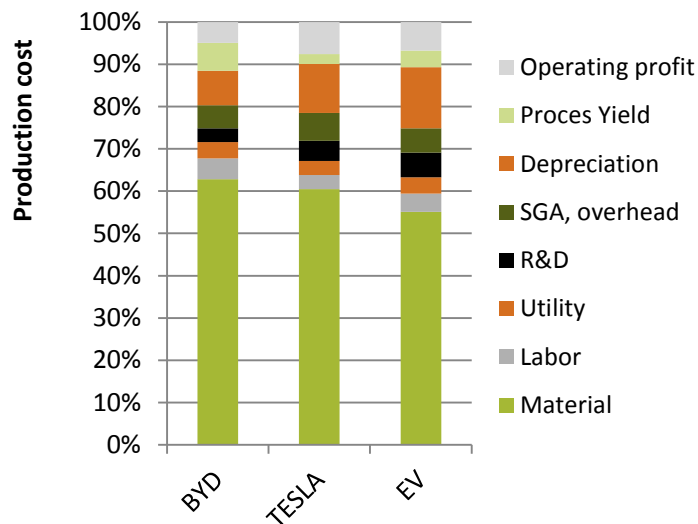


LIB: THE BIGGEST PART OF THE COST IS RAW MATERIALS

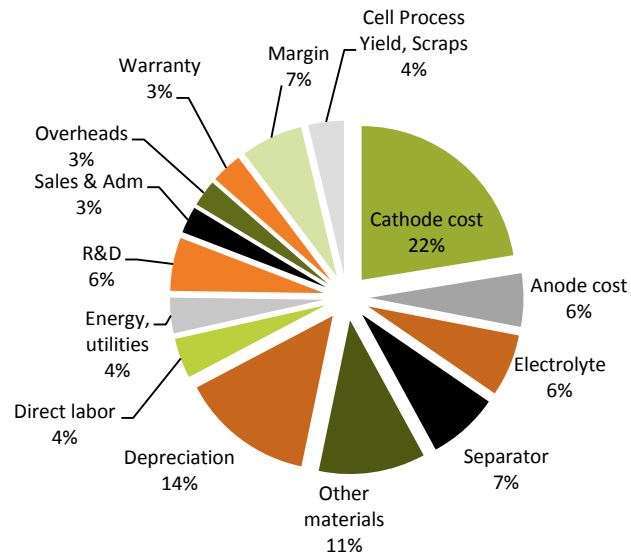
RAW MATERIALS ACCOUNT FOR 50 TO 70% OF LIB CELLS BUSINESS

RAW MATERIAL COST IMPACT DRASTICALLY ON THE BATTERY MAKERS PROFIT

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



Average cost structure of Li-ion cell in 2016



Note: Average mix of cylindrical, prismatic & laminate cells
Sources: AVICENNE ENERGY 2017

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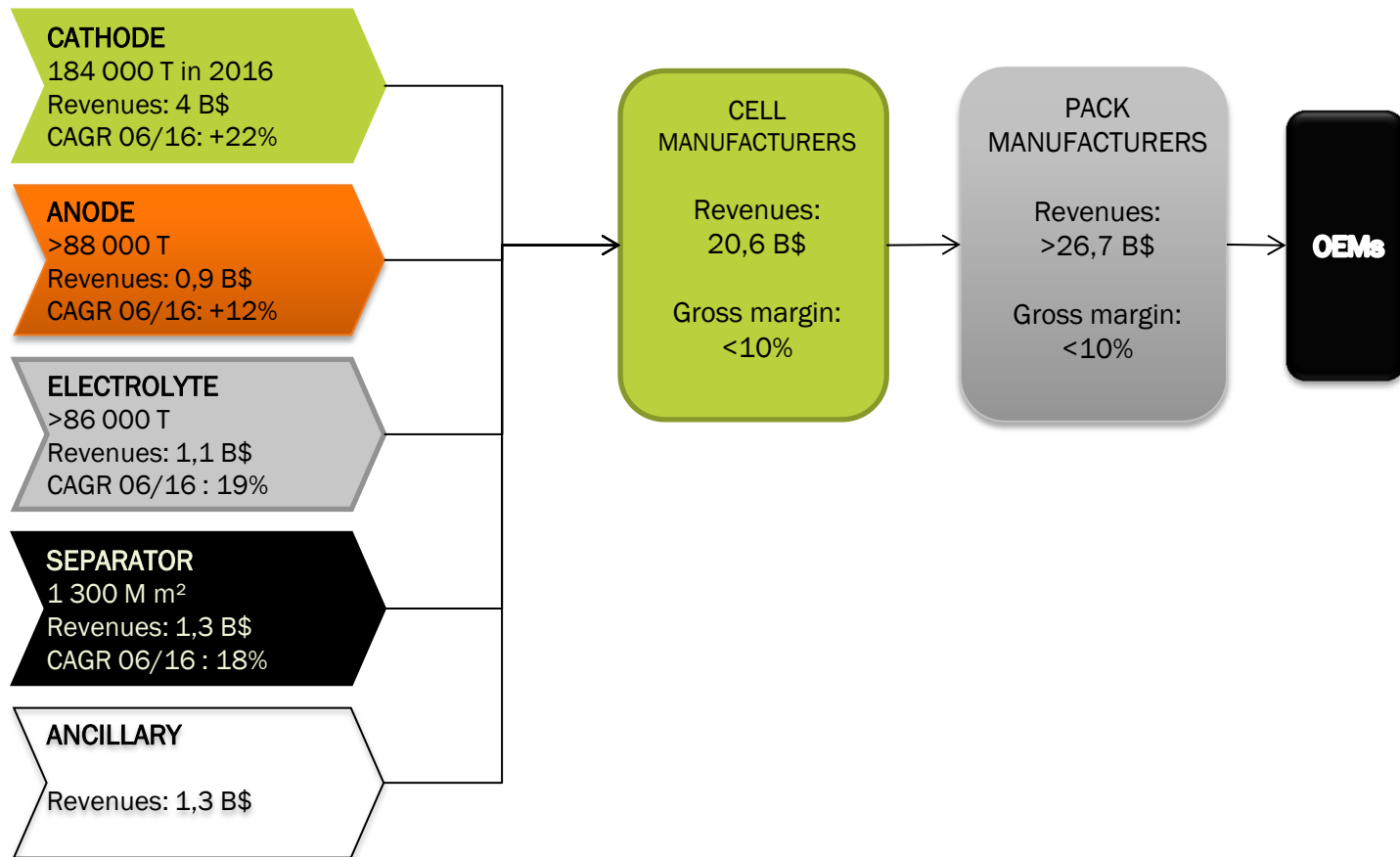
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LI-ION VALUE CHAIN – MARKET DEMAND

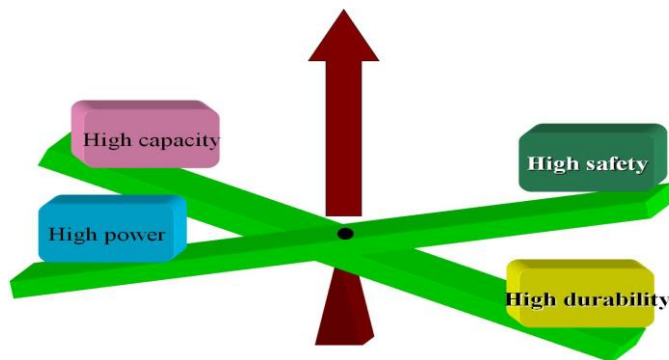


LIB CATHODE MATERIAL

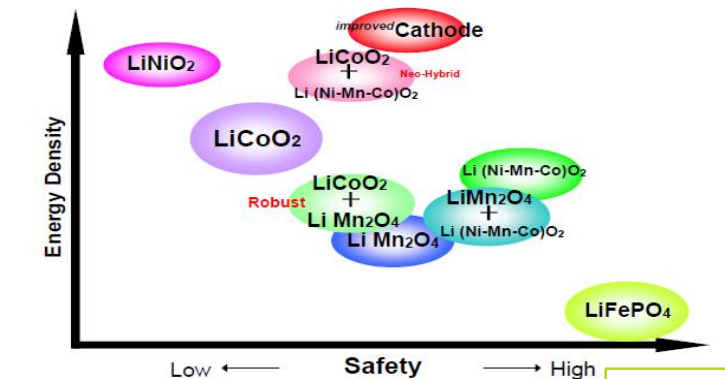
⌚ Cathode raw materials market

- ⌚ LiCoO₂ (LCO)
- ⌚ LiMn₂O₄ (LMO)
- ⌚ LiMPO₄⁽¹⁾ (LFP)
- ⌚ Li[NixMnyCoz]O₂ - NMC
- ⌚ Li[NixCoyAlz]O₂ - NCA

(1) M= Fe or Mn

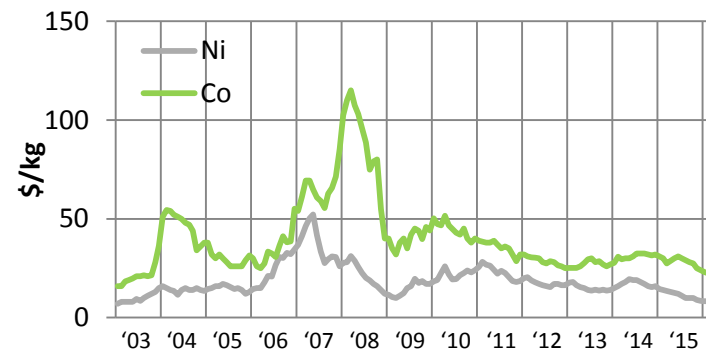


Source: Mitsubishi, Batteries 2012 – Nice



Source: SANYO, March 2011

Ni & Co price 2003-2015



Source: LME

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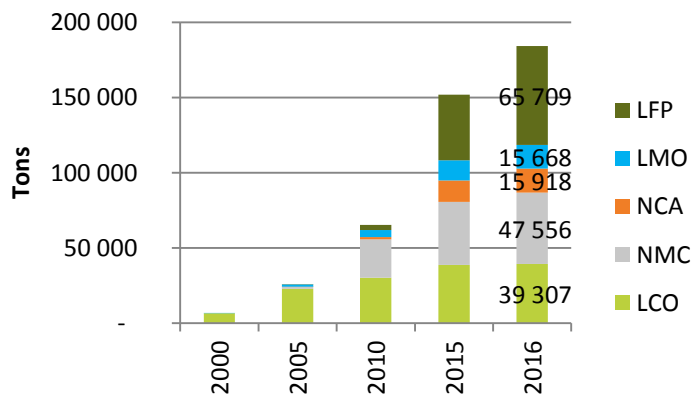
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CATHODE ACTIVE MATERIALS NEEDS

Cathode active materials for LIB in Tons, 2000-2016 (Demand)



LEADERS:



NEW ENTRANTS ON THE FIELD:

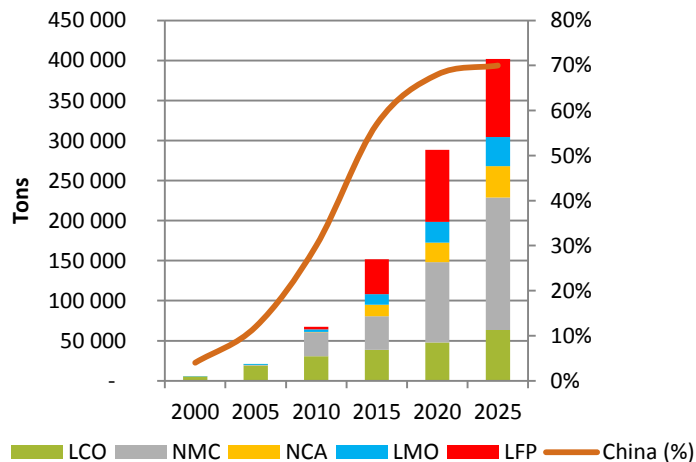


Rationales

- 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

CATHODE ACTIVE MATERIAL FORECASTS 2000-2025

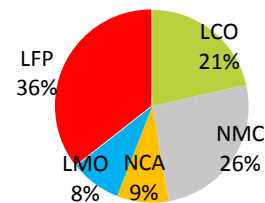
Cathode active materials 2000-2025 - Tons



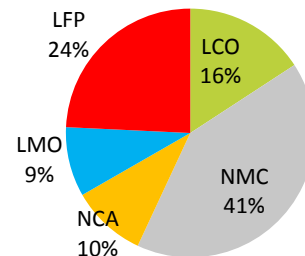
ASSUMPTIONS:

- 🕒 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 + 1M in China, 100% LIB
- 🕒 EV: 0,6 M EV/year in 2020 + 1M in China, 1M/year + 1,5 M in China in 2025, 100% LIB
- 🕒 Industrial & stationary: 2015-2025: +16% per year

Cathode active materials in 2016 > 180 000 Tons



Cathode active materials in 2025 400 000 Tons



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

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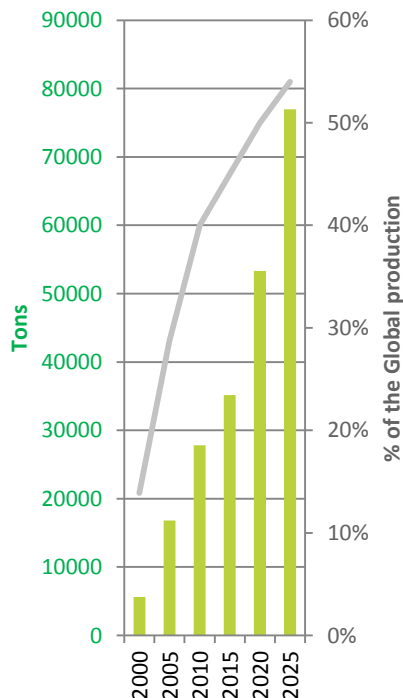
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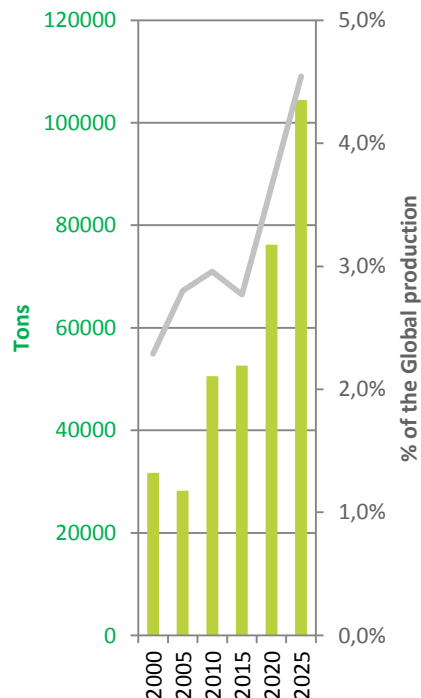
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METAL NEEDS FOR RECHARGEABLE BATTERY WILL INCREASE RAPIDLY

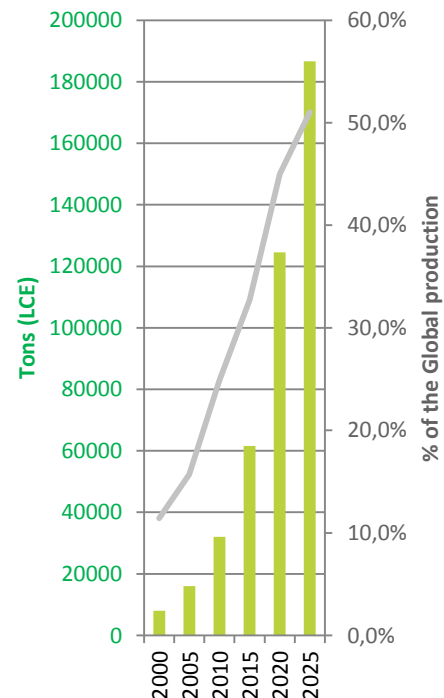
Cobalt



Nickel



Lithium



Sources: AVICENNE ENERGY 2017

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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

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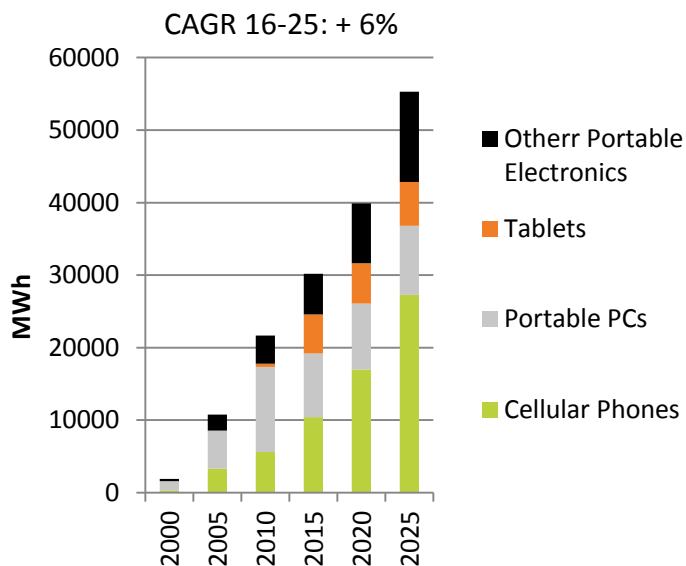
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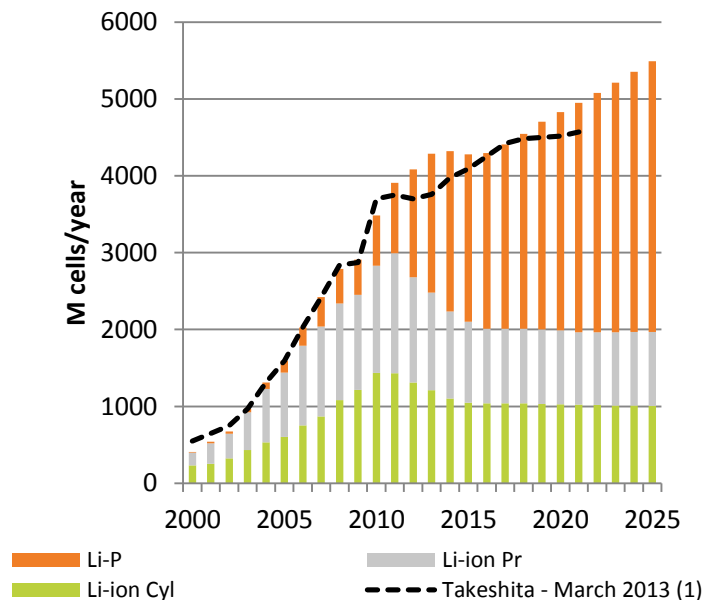
2025 LIB FORECASTS FOR PORTABLE ELECTRONIC DEVICES

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



Source: AVICENNE ENERGY Analyses 2017

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



(1) Source: Tateshita, Battery Japan 2013 BJ-3 conference Slide p 4

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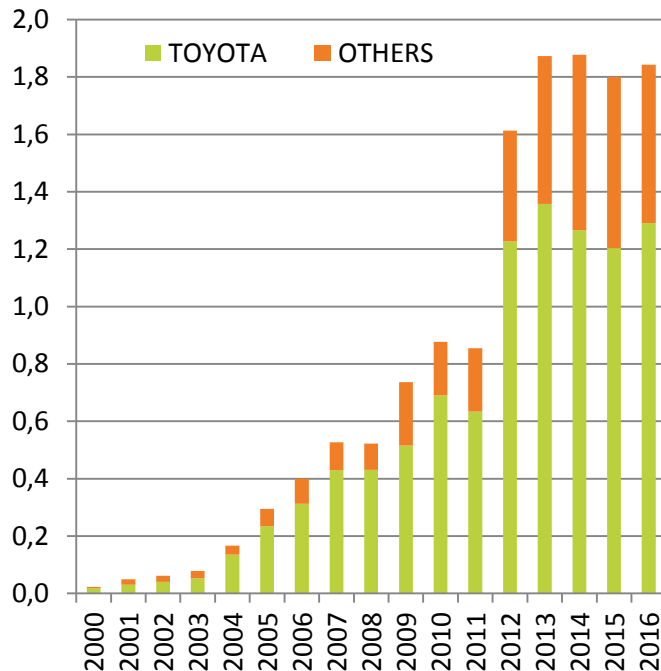
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HEV WORLDWIDE IN 2016

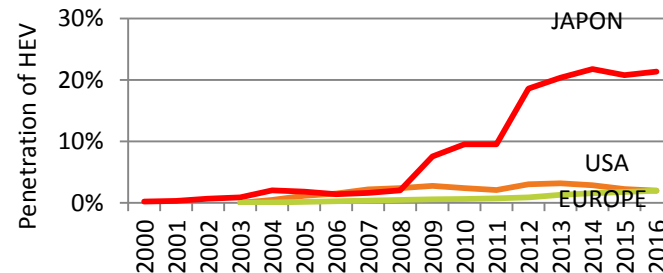
1,8 M HEV

HEV sold per year, M units, worldwide,
2000 - 2016

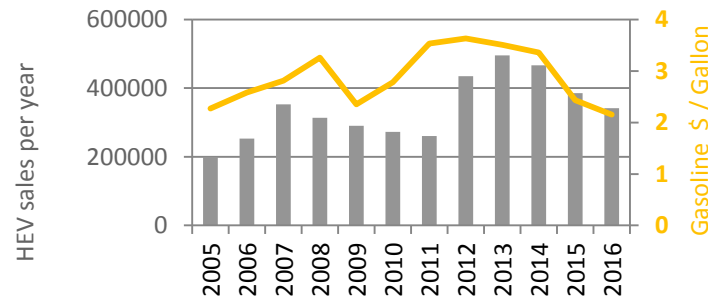


Growth 2014-2015: +2%
 From 1,8 M to 1,84 M HEV

Penetration of hybrids in the global sales,
2000-2016



Gazoline price impact on HEV market in
the US



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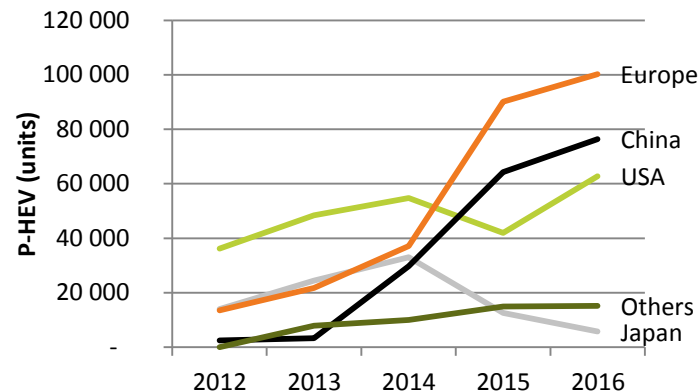
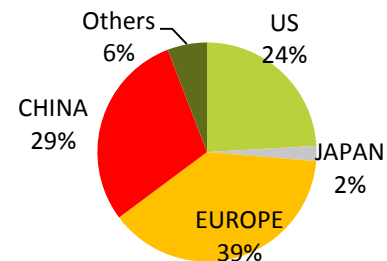
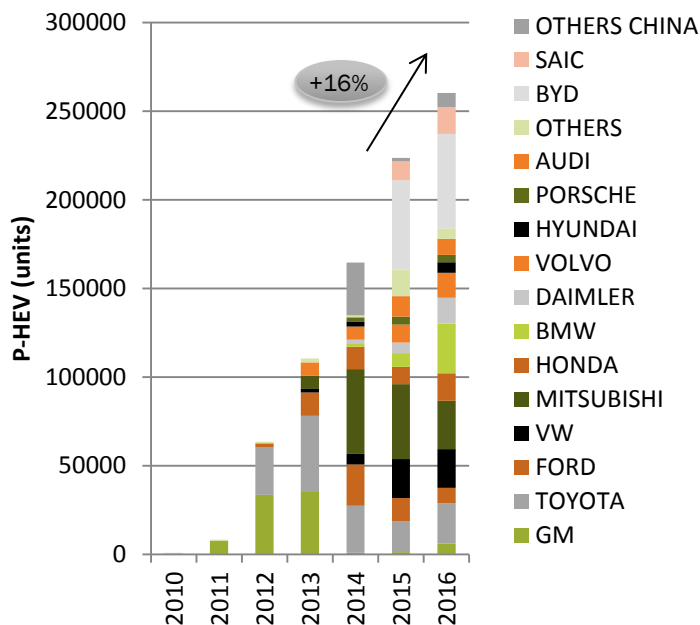
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PHEV SOLD WORLDWIDE

World excl. China growth +14%
Chinese Growth + 21%

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

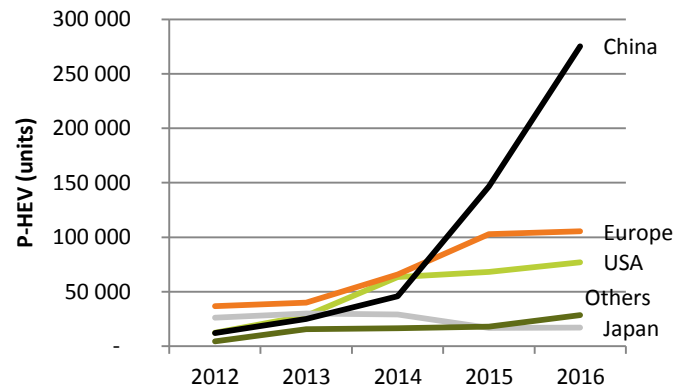
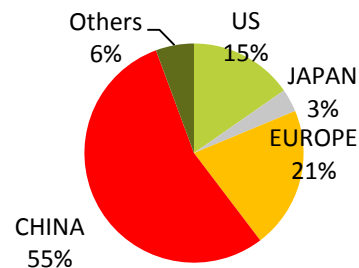
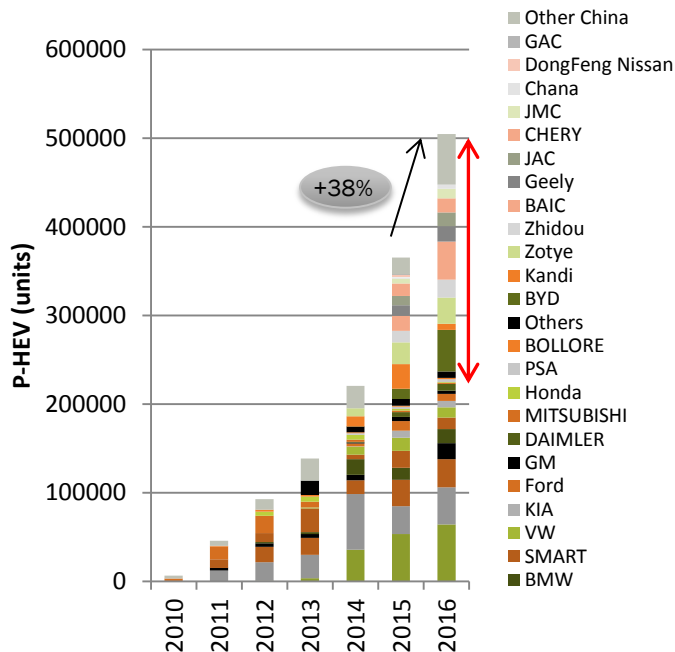


Source: AVICENNE ENERGY Analysis, 2017

EV SOLD WORLDWIDE

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

China is leading the EV market thanks to high incentives



Source: AVICENNE ENERGY Analysis, 2017

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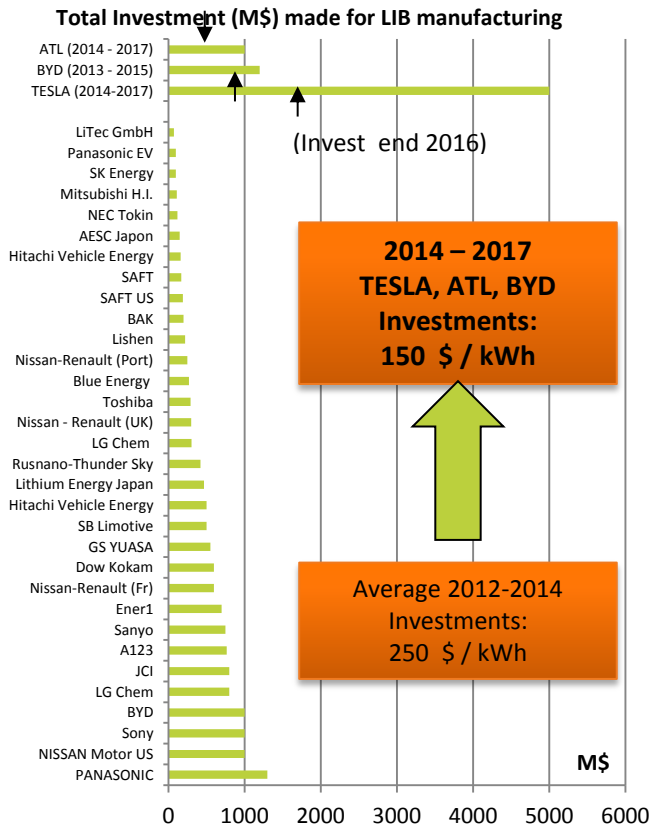
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LIB MANUFACTURING INVESTMENTS 2009-2015

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



TESLA GIGA FACTORY, Dec 2016

Source: AVICENNE ENERGY Analyses 2017

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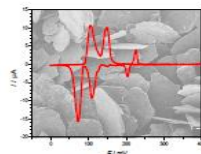
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TIME TO MARKET FOR NEW MATERIALS IN LIB INDUSTRY



1970ies



1980ies



1991



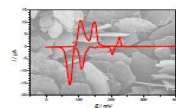
2004



2010

- ⌚ 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



1970ies



1980ies



1991



2004



2010

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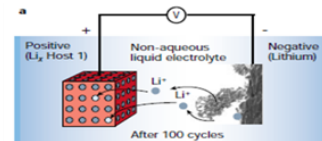
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	2000	2005	2010	2015	2020	2025	2030
CATHODE	LCO		NMC/NCA LMO LFP	LiNiMnO ₂ High voltage	5v spinel LiNiPO ₄ , 5v LiCoPO ₄ , 5v LiMnPO ₄ , 4v	Sulfur	Air
ANODE	Graphite Hard Carbon		Soft Carbon Li ₄ Ti ₅ O ₁₂	C/Alloy Composite	Non Si Alloys	Li Metal Si Alloys	
ELECTROLYTE	LiPF ₆ + Org. solvents		LiPF ₆ free electrolyte	Gel-polymer electrolyte	5v electrolyte		
SEPARATORS	Polyolefin		Polyolefin+ ceramic coating	Cellulose Non-woven		Polymer membrane	Solid Electrolyte

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 their profit-to-date
Automotive	With new cathode chemistry, most of the automotive today on the markets experienced safety concerns: (1) BYD Taxi in China with a lithium iron phosphate cathode (2) GM Volt in the US with a LG Chemical battery using LMO cathodes (as a result of a crashed tested Chevrolet Volt caught three weeks after the testing !) (3) PRIUS P-HEV in the US (converted from HEV Prius by a local engineering company without any authorisation by Toyota)
Aircraft	Boeing 787: The fire that burned near the tail of a parked Boeing 787 in Boston was caused by an overheating Lithium ion battery pack. The battery fire could have been hot enough to melt the carbon-fiber reinforced plastic that makes up the plane's shell. <u>CONSEQUENCES</u> : All the 787 worldwide are grounded. Considerable losses for Boeing.



Safety is a sine-qua-non selection criteria for batteries. The lithium ion technologies that win will win partly on their safety argument, possibly sacrificing some energy density.

Source: AVICENNE ENERGY 2016

Evolution du marché
 mondial des batteries
 rechargeables

 Impact sur la demande en
 Nickel, Cobalt et Lithium

 Séminaire sur les métaux de
 la transition énergétique

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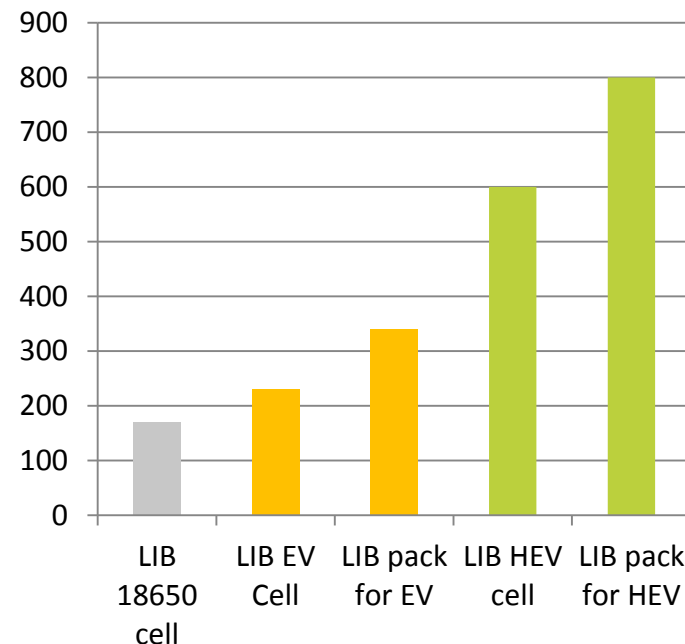
LIB BATTERY COST

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
- 🕒 ...

Source: AVICENNE ENERGY 2017

Battery price in 2016 \$/kWh



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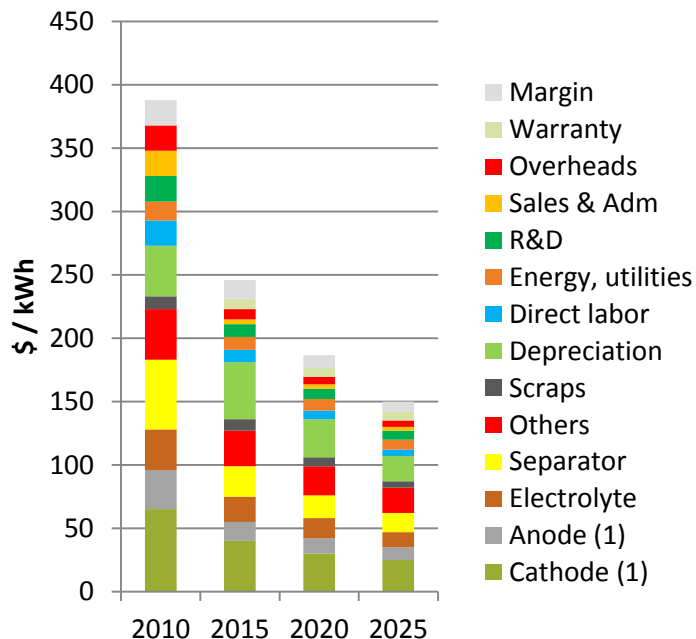
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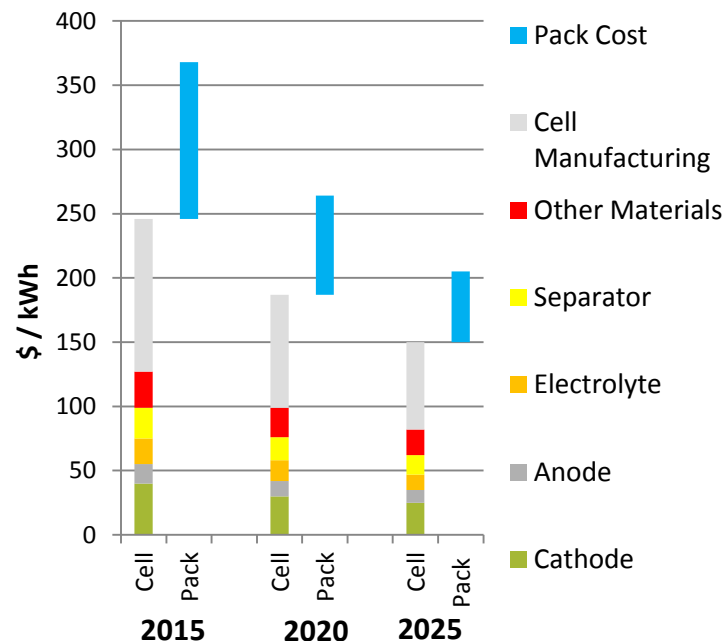
LI-ION BATTERY COST 2015-2025

LIB cell average cost (40 Ah pouch)
(EV design ; NMC cathode)



(1) Active materials only
Source: AVICENNE ENERGY 2017

LI-ION BATTERY PACK COST FOR
EV



* For Production > 100 000 packs/year

HEV FORECASTS 2000-2020

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

Evolution du marché
mondial des batteries
rechargeables

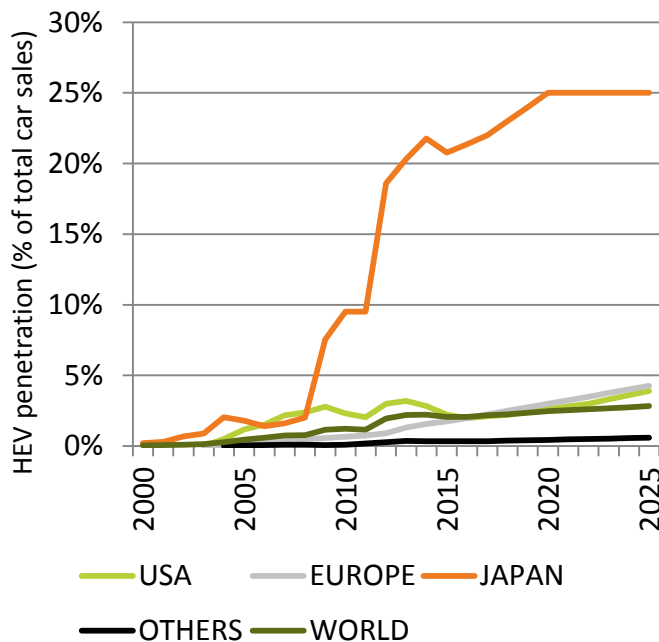
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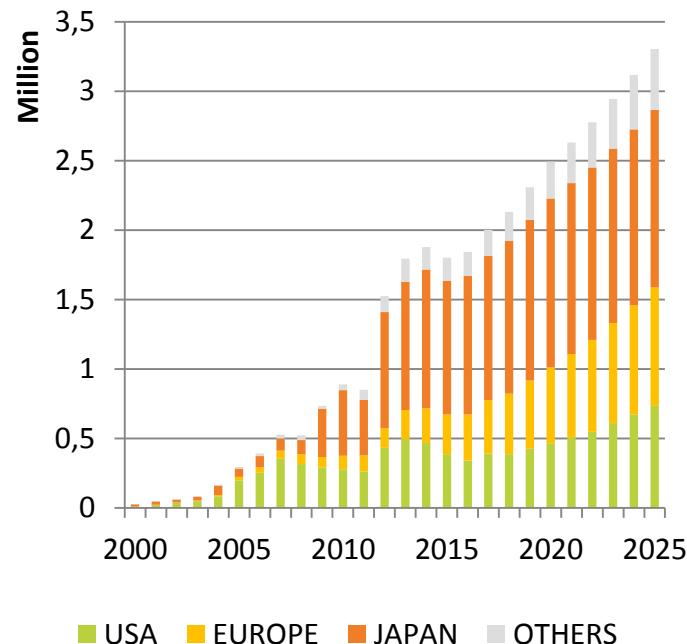
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Micro hybrid not included



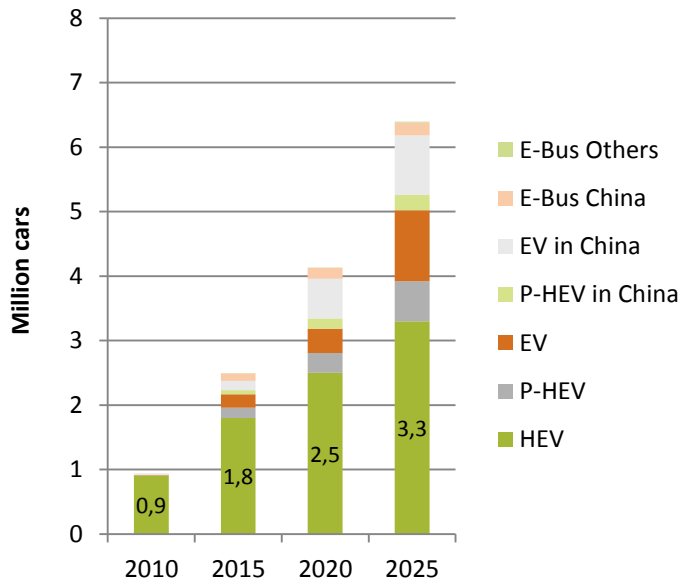
Source: AVICENNE ENERGY Analyses 2017

EV, P-HEV, EV 2025 FORECASTS

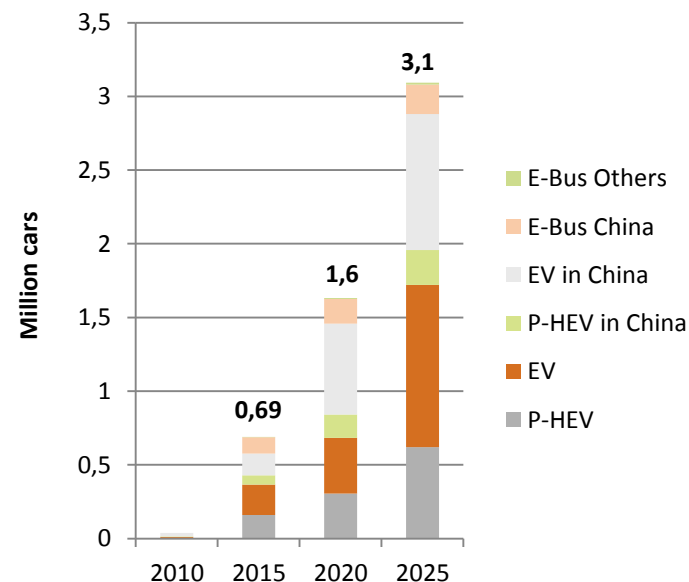
Thanks to very high incentives, China change the game

2016 forecasts: HEV, P-HEV & EV market forecasts up to 2025

HEV, PHEV, EV & E-Bus



PHEV, EV & E-Bus



Source: AVICENNE ENERGY Analyses 2017

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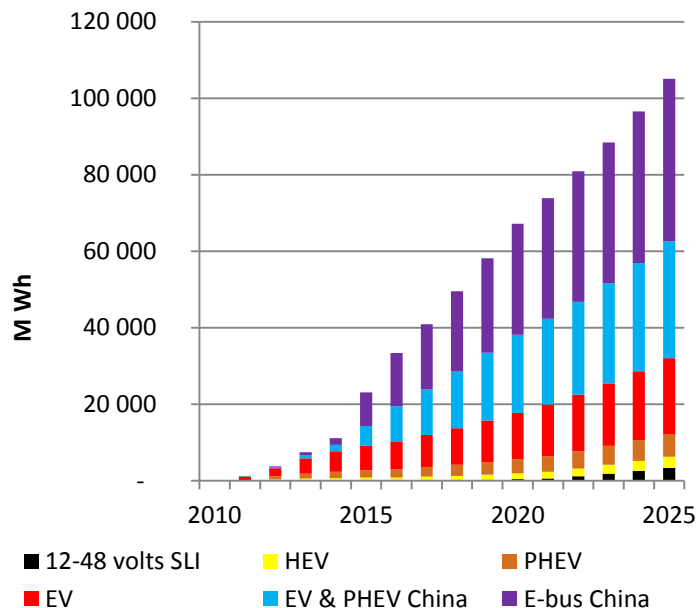
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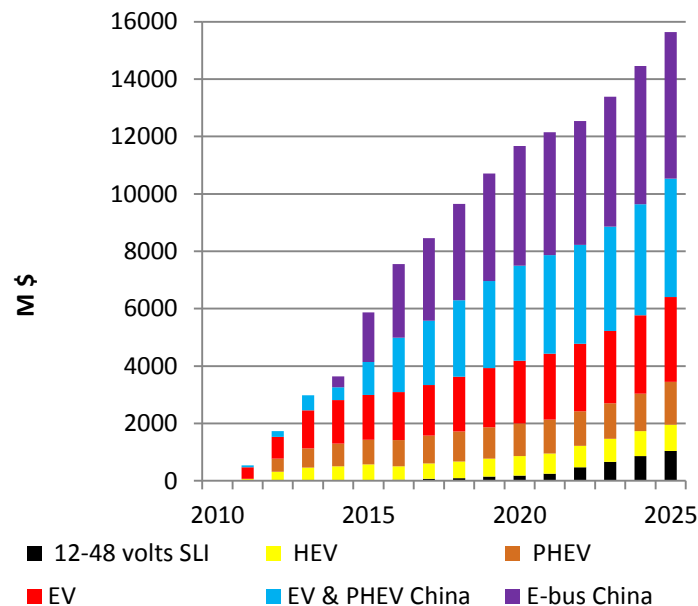
TOTAL BATTERY DEMAND FOR XEV 2025 FORECASTS

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



Source: AVICENNE ENERGY Analyses 2017

Li-ion for E-Buses, EV, HEV & P-HEV
Battery needs (M\$)
CAGR 2016-2025: +8%



LI-ION BATTERY MARKET FORECASTS

From 78 GWh in 2016 to
210 GWh

CAGR 2016/2025
+13 % per year in Volume

Evolution du marché
mondial des batteries
rechargeables

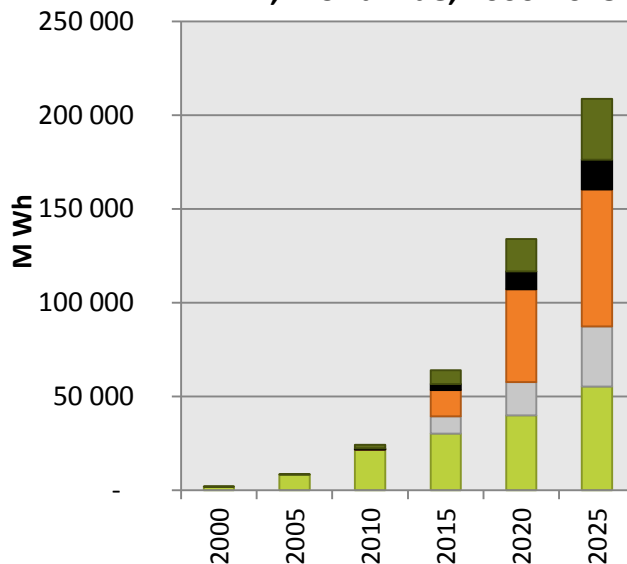
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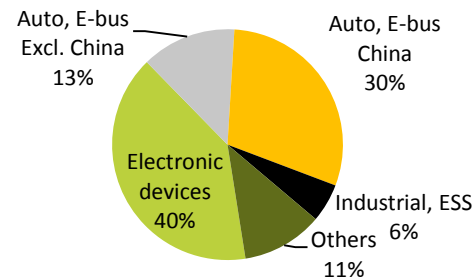
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**Li-ion Battery sales,
MWh, Worldwide, 2000-2015**

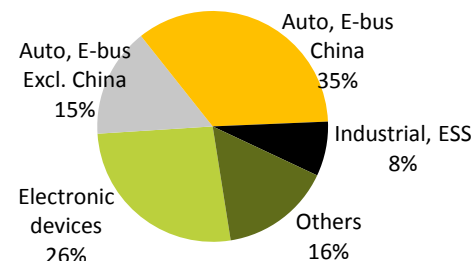


CAGR 15/25	
Others	16%
Industrial, ESS	17%
Auto, E-bus China	18%
Auto, e-bus Excl. China	13%
Electronic devices	6%

2016: 78 GWh



2025: 210 GWh



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

Evolution du marché
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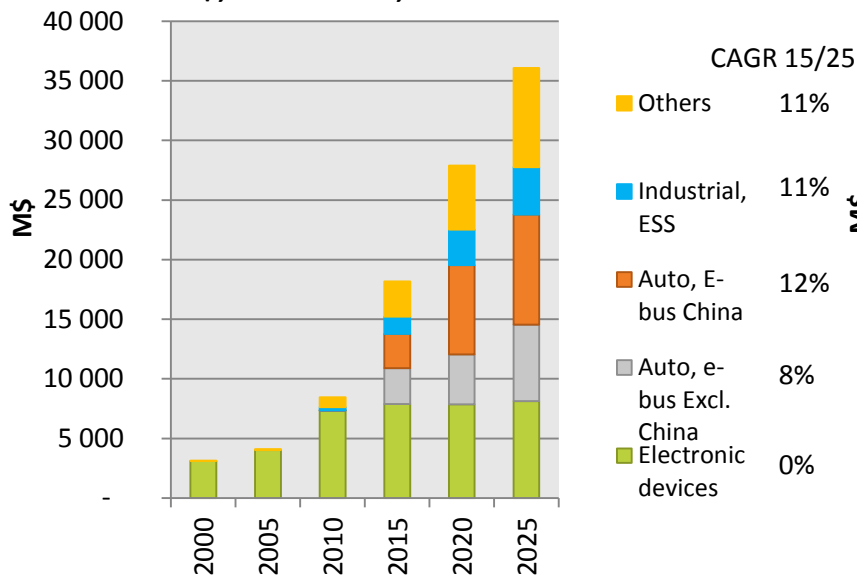
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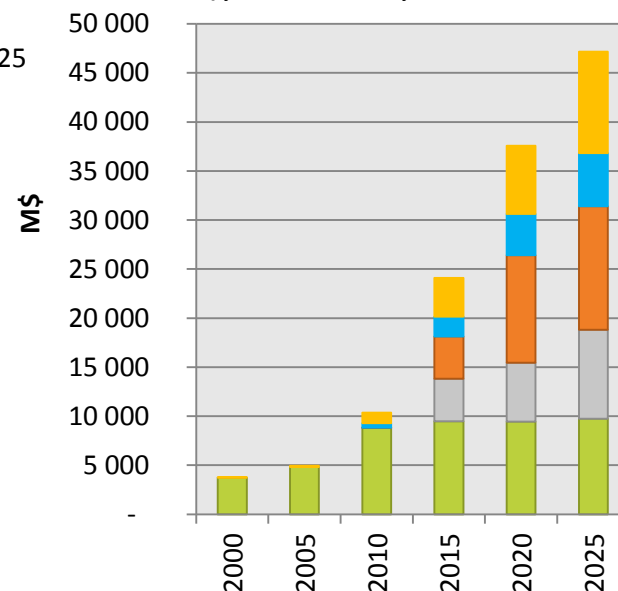
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Li-ion cells
M\$, Worldwide, 2000-2025



Others: medical devices, power tools, gardening tools, e-bikes...
Source: AVICENNE Energy 2016

Li-ion Packs
M\$, Worldwide, 2000-2025



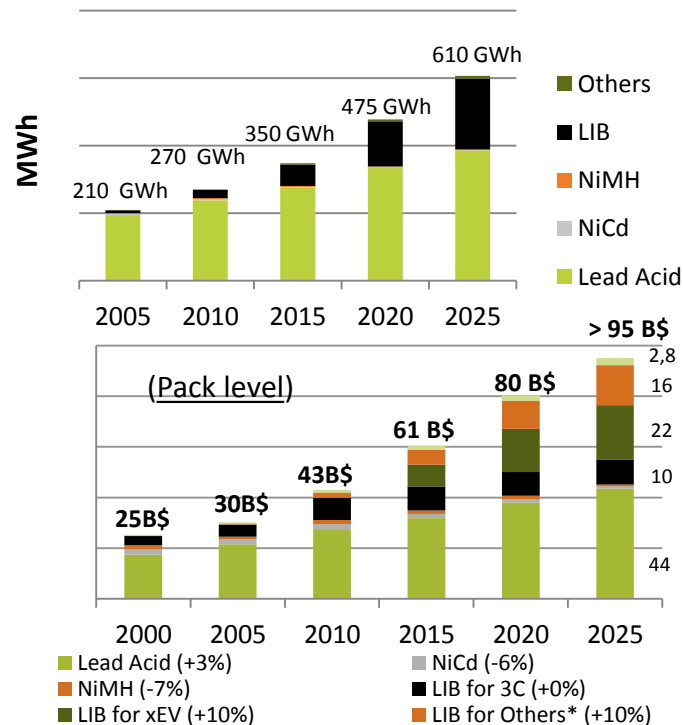
TAKEAWAYS

Battery Market 2010-2025

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

- Li-ion battery is driven today 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:
11 B\$ market in 2016 - 17 B\$ in 2020 & 22 B\$ in 2025 with high numbers in China (2016: US\$ 2,8 Billion for xEV and US\$ 3,7 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
- 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



(CAGR 2016-2025)

Others: Automatic handling equipment, forklifts, back-up, UPS, Telecom, medical devices, Residential ESS, Grid ESS, ... 31

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THANK YOU



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