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September 23-25, 2015
Montreux, Switzerland

CONTACT

Christophe PILLOT
c.pillot@avicenne.com
+33(0)1 4778 4600

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2015



September 23 – 25, 2015
Montreux, Switzerland

Future trends in the rechargeable battery market

Christophe PILLOT

Director, AVICENNE ENERGY

Presentation Outline

- The rechargeable battery market in 2014
- The Li-ion battery value chain
- Li-ion battery material market 2014 - 2025
- Forecasts & conclusions



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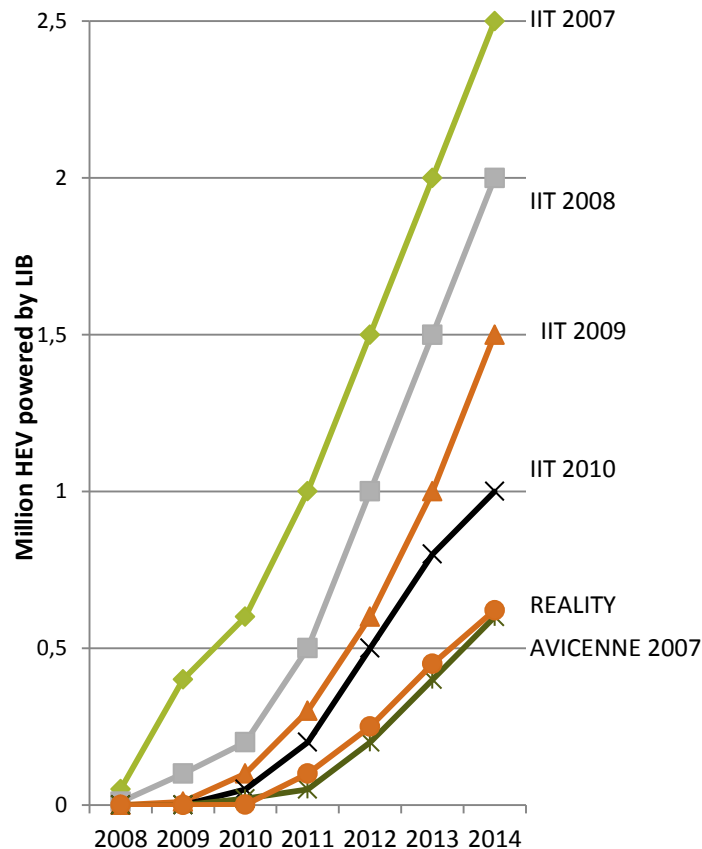
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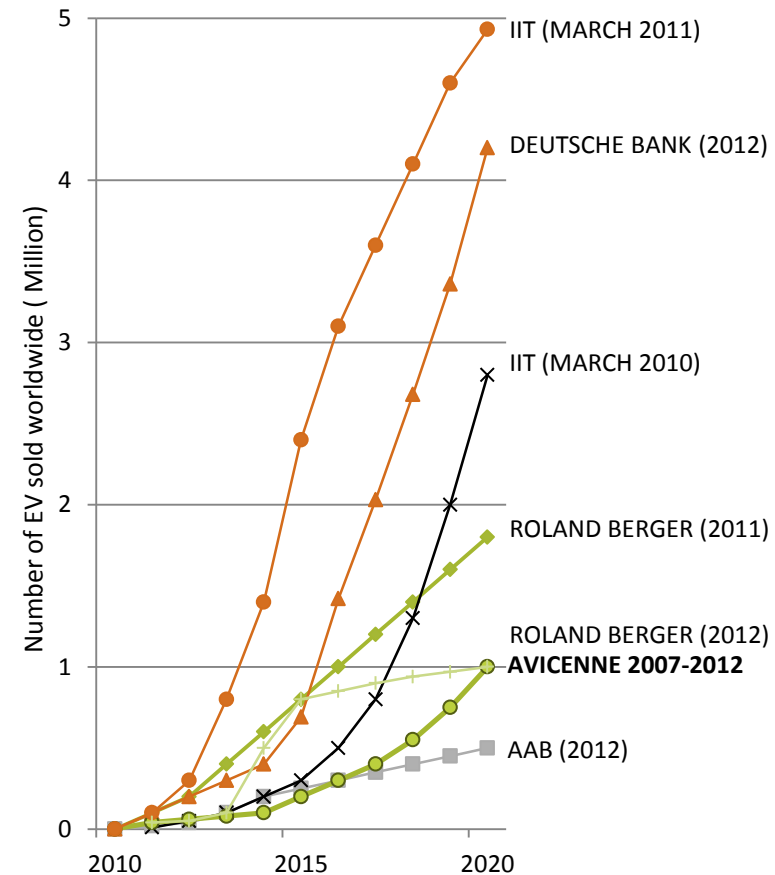
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+ 33 1 47 78 46 00
c.pillot@avicenne.com

AVICENNE ENERGY: RENOWNED TO HAVE REALISTIC FORECASTS

HEV powered by Lithium ion battery
forecasts from 2008 to 2014



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



Source : International Battery Conference, Fort Lauderdale 2007, 2008, 2009, 2010 & 2011

Future trends in the
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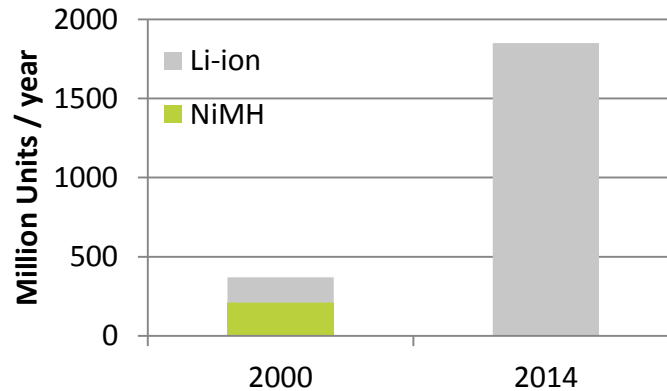
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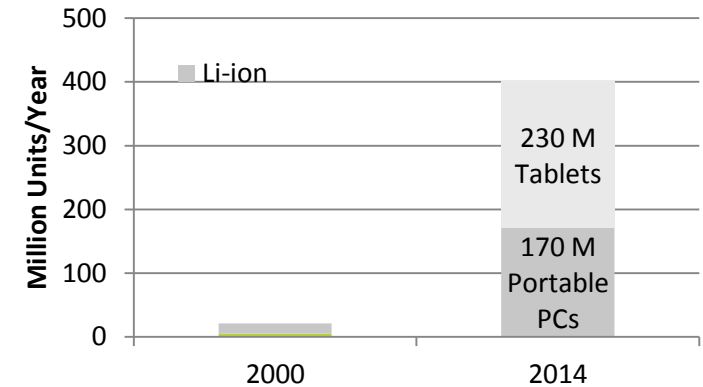
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+ 33 1 47 78 46 00
c.pillot@avicenne.com

THE BATTERY MARKET IS REALLY DYNAMIC

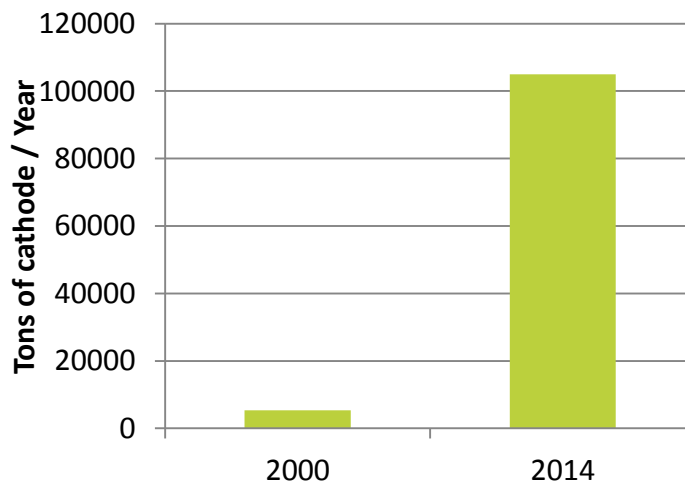
Cellular Phones sold per Year (Million)



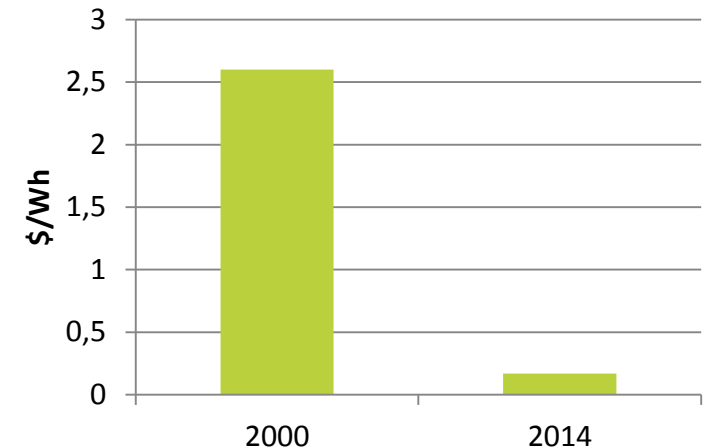
Portable PC sold per Year (Million)



Tons of Li-ion Cathode per year



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



Source: AVICENNE ENERGY Analyses 2015

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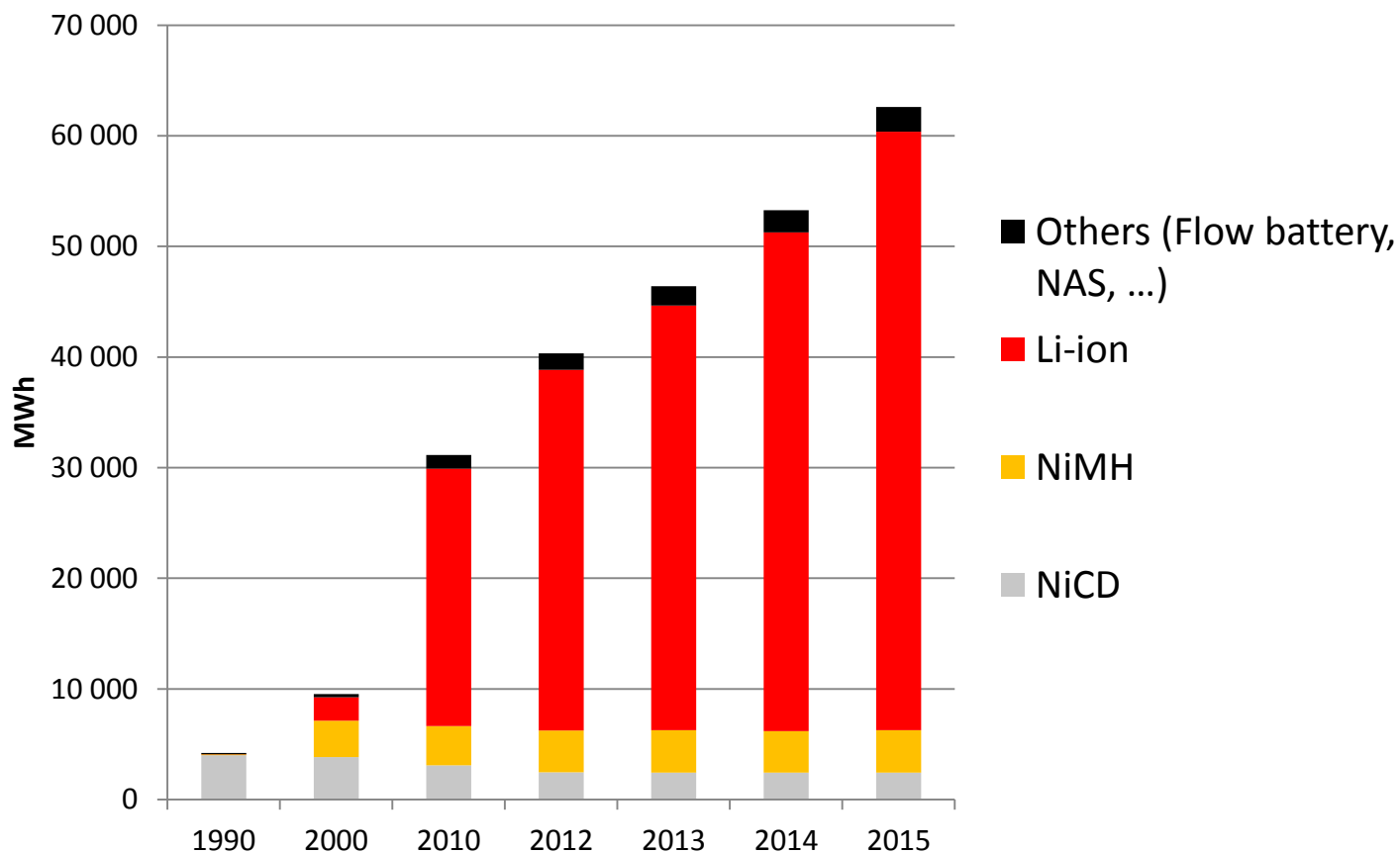
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 + 33 1 47 78 46 00
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THE WORLDWIDE BATTERY MARKET 1990-2015

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



Source: AVICENNE ENERGY, 2015

2015: Estimations



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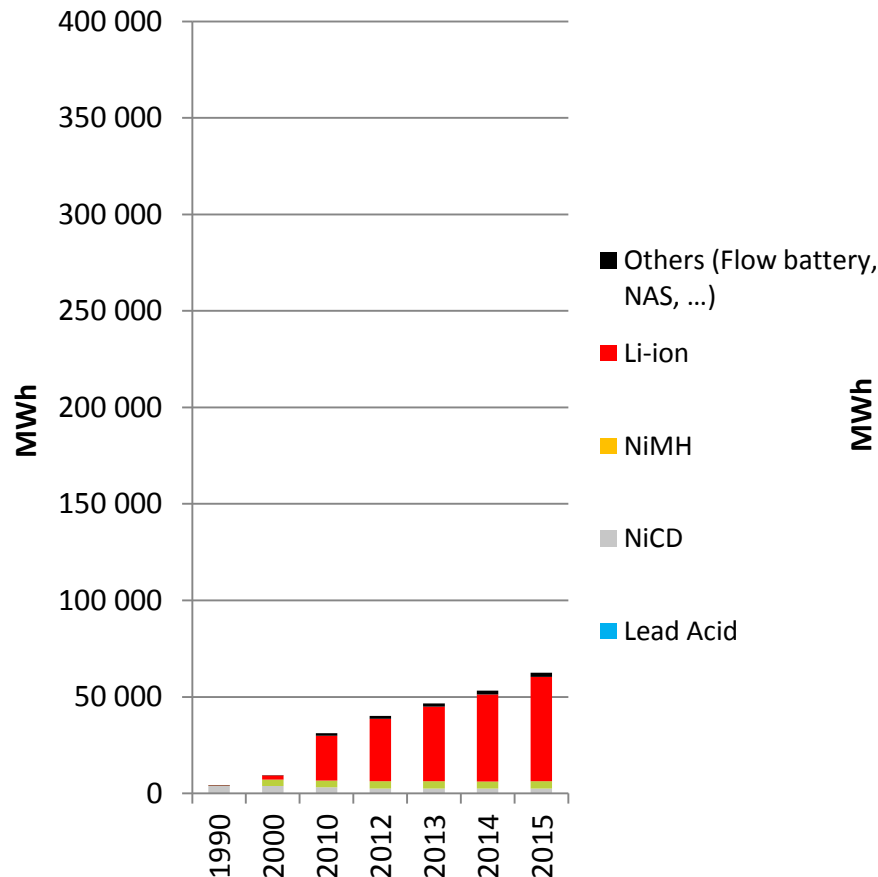
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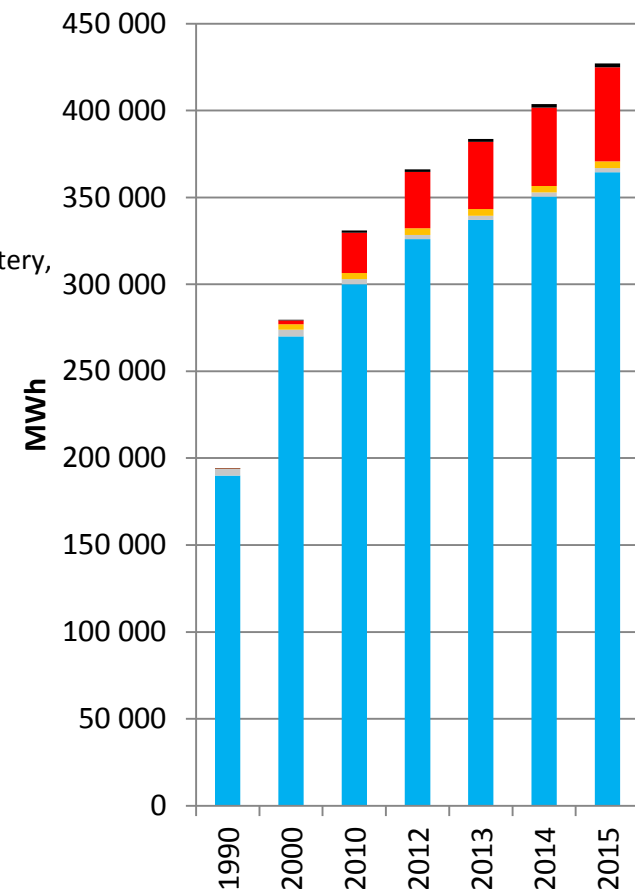
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+ 33 1 47 78 46 00
c.pillot@avicenne.com

THE WORLDWIDE BATTERY MARKET 1990-2015

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, 2015



2015: Estimations

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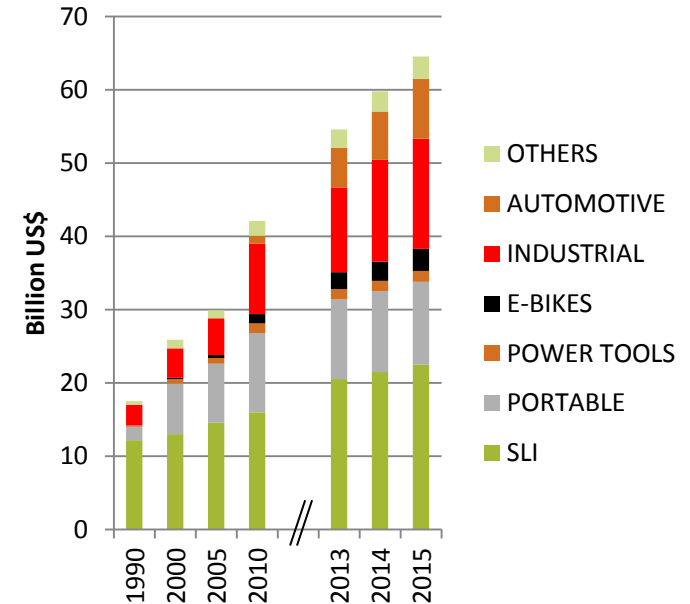
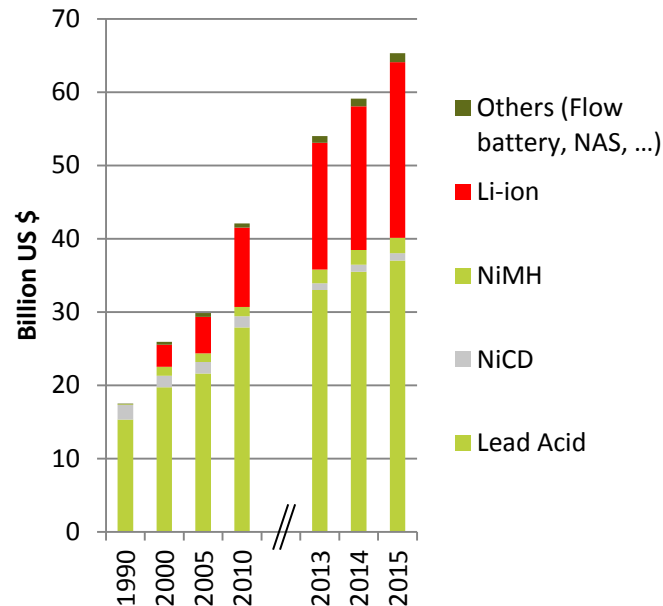
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THE WORLDWIDE BATTERY MARKET 1990-2015

60 BILLION US\$ in 2014 – Pack level¹

5% AVERAGE GROWTH PER YEAR (1990-2014)



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, 2015

2015: Estimations

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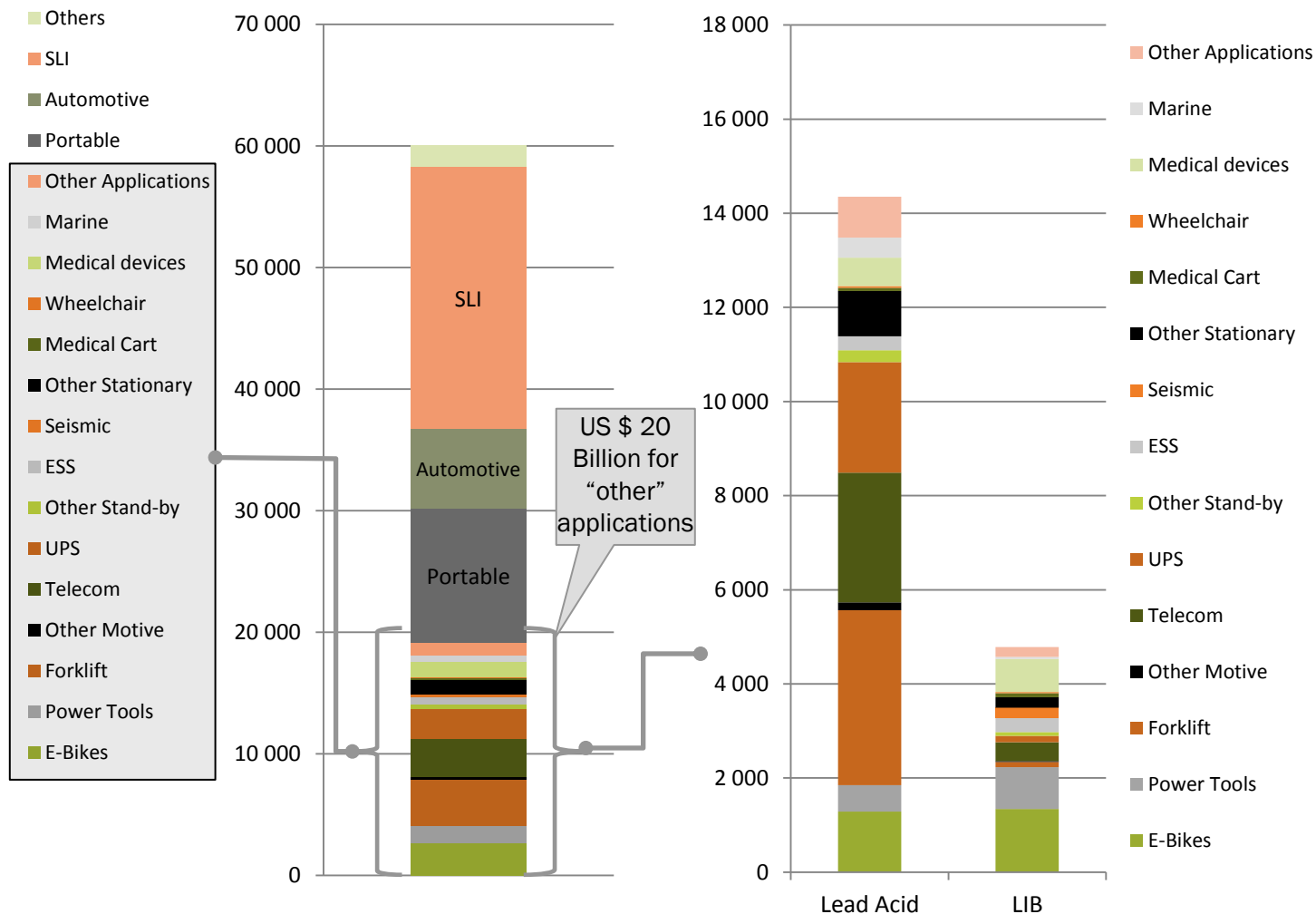
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THE WORLDWIDE BATTERY MARKET IN 2014: US \$ 60 BILLION

Battery market in 2014 (M\$)



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

Source: AVICENNE ENERGY, 2015

LI-ION IN 2014

MAIN APPLICATIONS: CELLULAR, NOTEBOOK

5 400 M cells – 46 000 MWh

13 600 M\$ (2)

CAGR 2004/2014

+21 % per year in Volume

+14% per year in value

Future trends in the
rechargeable battery
market

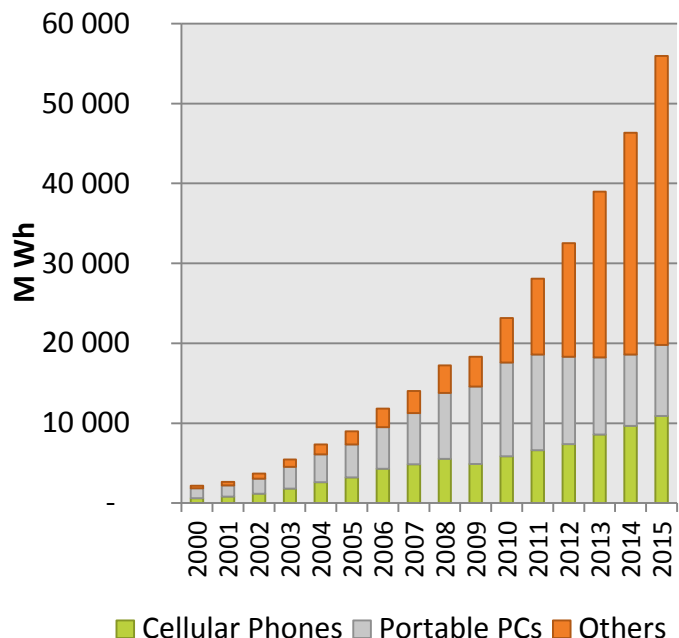
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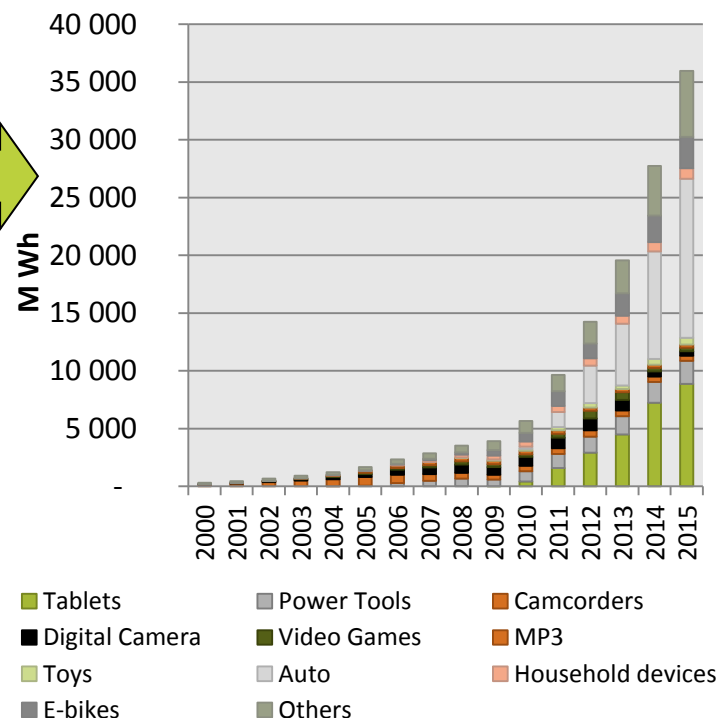
Christophe PILLOT
 + 33 1 47 78 46 00
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**Li-ion Battery sales,
MWh, Worldwide, 2000-2014 (1)**



(1) 2015 estimation data
 (2) Cell level

**Li-ion Battery sales,
MWh, Worldwide, 2000-2014 (1)**



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LI-ION IN 2014

MAIN APPLICATIONS: CELLULAR, NOTEBOOK

5 250 M cells – 45 000 MWh

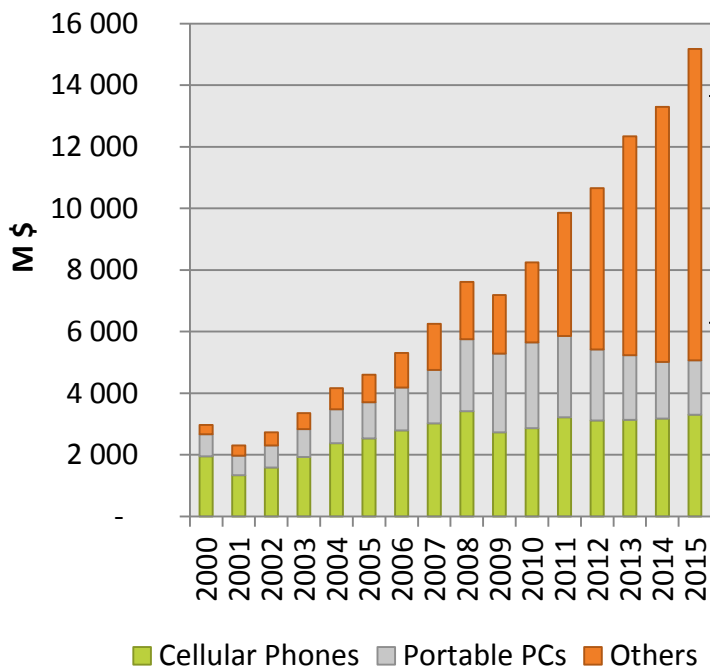
13 300 M\$ (2)

CAGR 2004/2014

+20 % per year in Volume

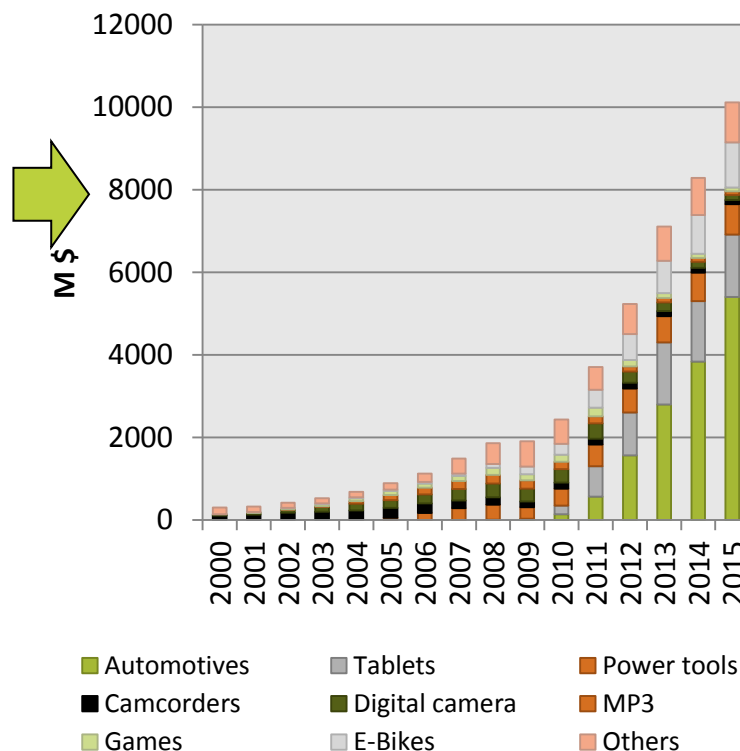
+14% per year in value

**Li-ion Battery sales,
M\$, Worldwide, 2000-2014 (1)**



(1) 2015 estimation data
 (2) Cell level

**Li-ion Battery sales,
M\$, Worldwide, 2000-2014 (1)**





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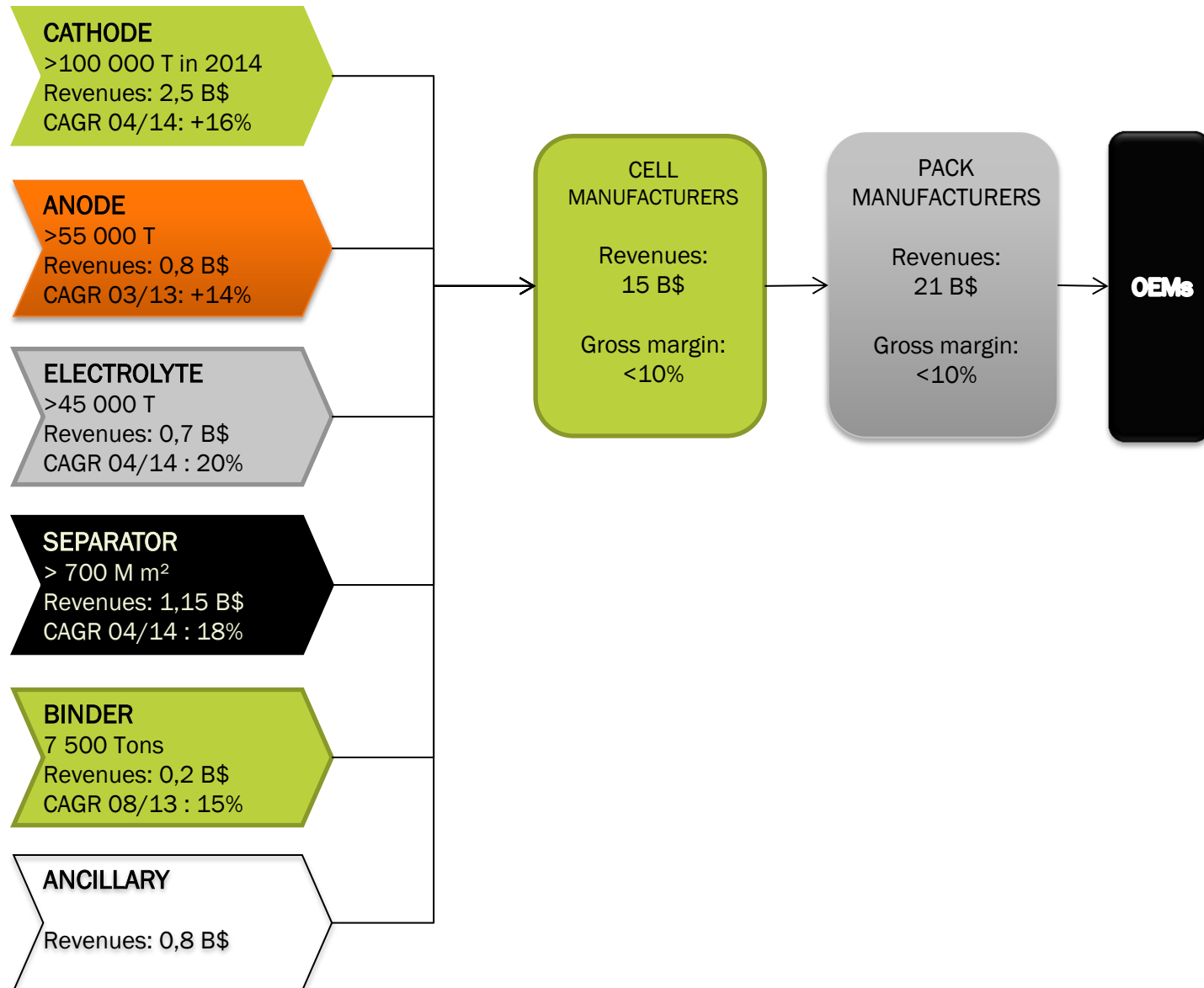
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LI-ION VALUE CHAIN – MARKET DEMAND



Future trends in the
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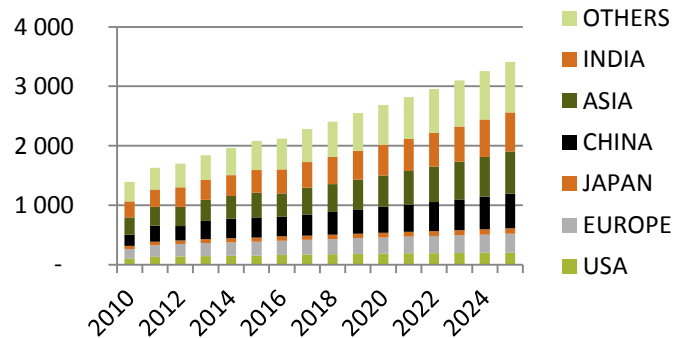
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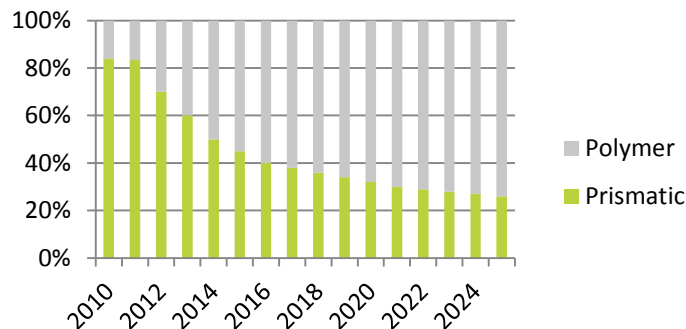
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CELLULAR PHONES FORECASTS 2010-2025

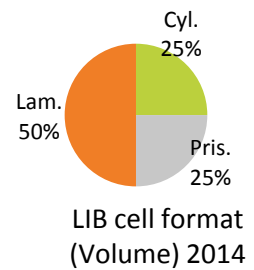
Cellular phones demand (M Units)
CAGR 2010-2025: +6%



LIB cells demand 2014-2025
Polymer penetration: 50% -> 75%



Source: AVICENNE ENERGY Analyses



Cellular Phones market Drivers

- Emergent market
- Renewal ratio increase
- Smartphone penetration increase

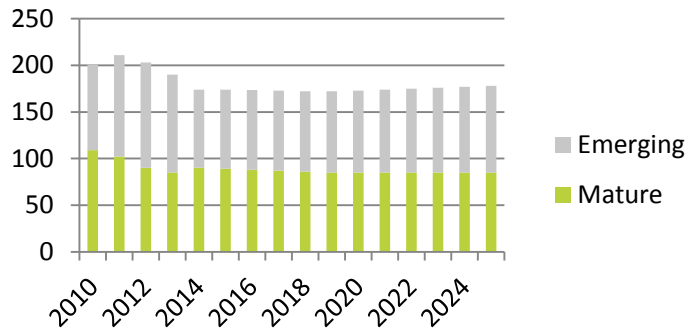


LIB cells for cellular phones trends

- Laminates ratio increase
- Increase of Thickness
- Increase of >1400 mAh capacity

PORTABLE PCS FORECASTS 2010-2025

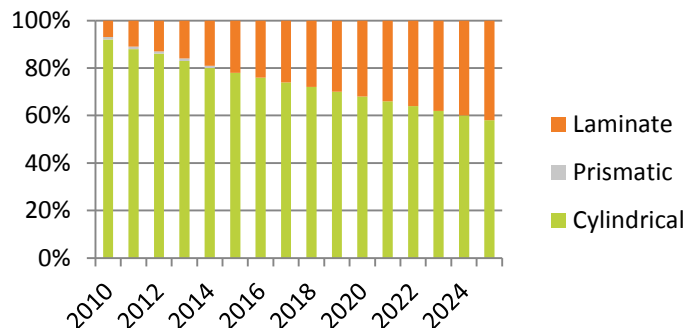
Portable PCs demand (M Units) 2014-2025 – Almost stable



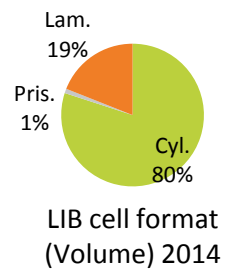
Source: IDC, Gartner, AVICENNE Energy

LIB cells demand 2014-2025

Polymer penetration: 20% -> 40%



Source: AVICENNE ENERGY Analyses



Portable PCs market trends

- 🔗 Mature market stable or decreasing
- 🔗 Growth driven by Emerging market
- 🔗 Ultrabook is increasing (20⁽¹⁾ to 60% in 2013⁽²⁾)
- 🔗 ASP decreasing (<499\$ Portable PCs increase from 25% in 2010 to 33% in 2012)

(1) Samsung & AVICENNE (2) Intel

LIB cells for portable PCs trends

- 🔗 Thinner cells
- 🔗 Polymer penetration increasing from 7% in 2010 to 28% in 2025
- 🔗 > 2800 mAh for Premium/corporate
- 🔗 2.2 Ah for consumer, emerging market

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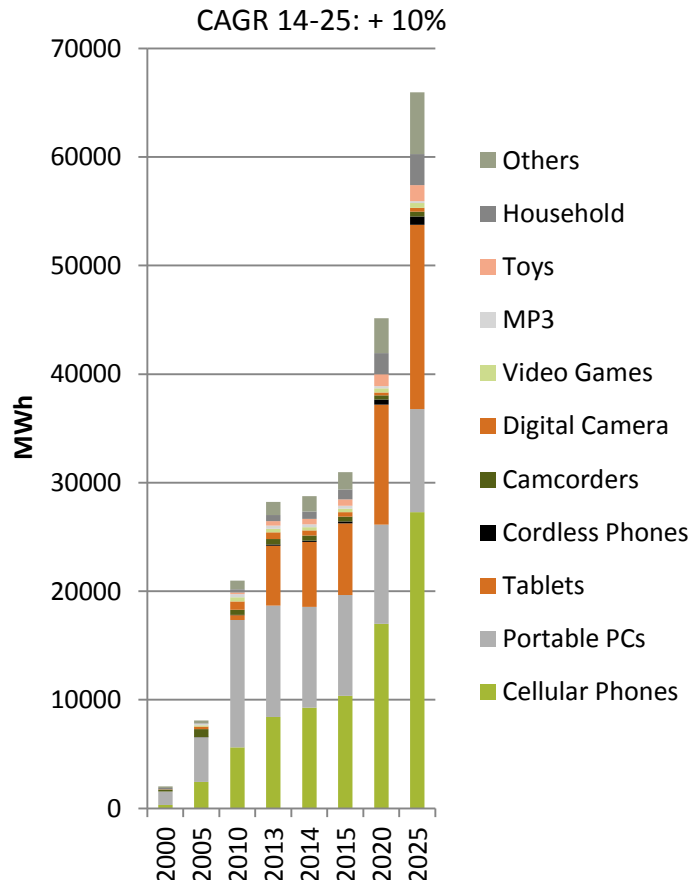
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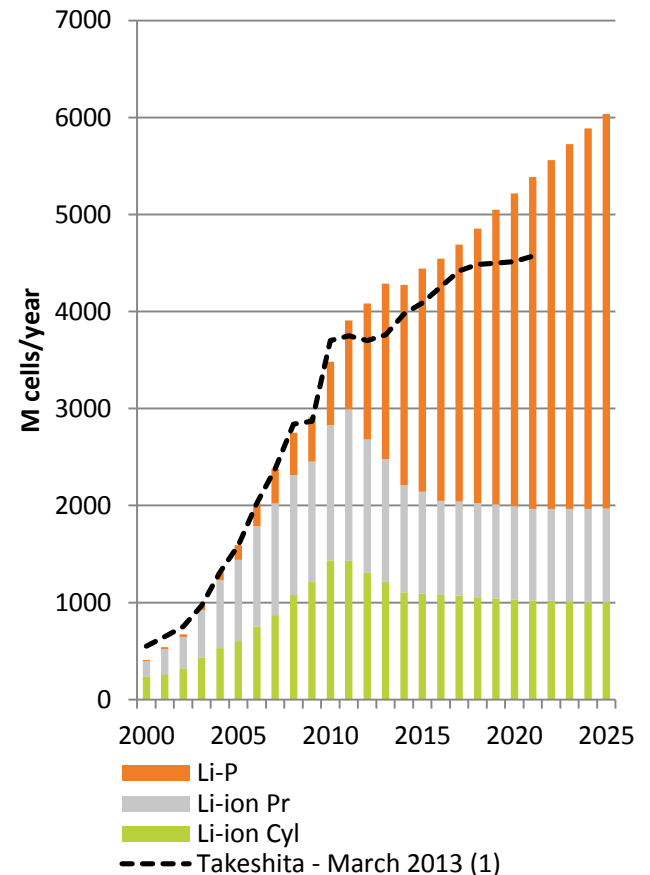
2025 LIB FORECASTS FOR PORTABLE ELECTRONIC DEVICES

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



Source: AVICENNE ENERGY Analyses

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



(1) Source: Takeshita, Battery Japan 2013 BJ-3 conference
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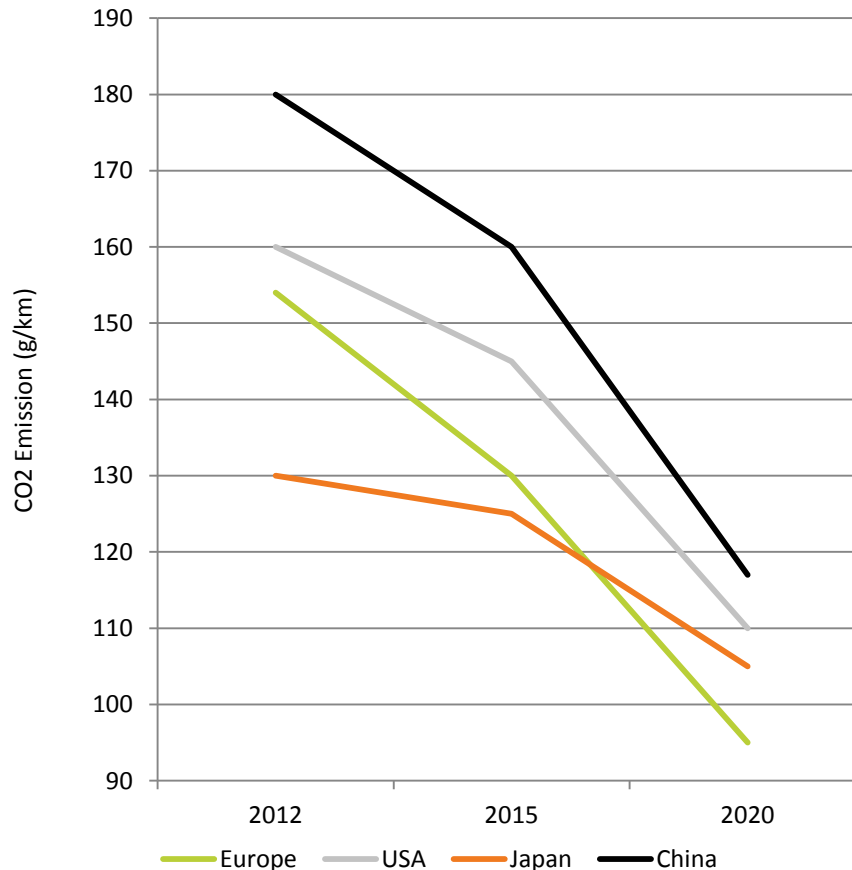
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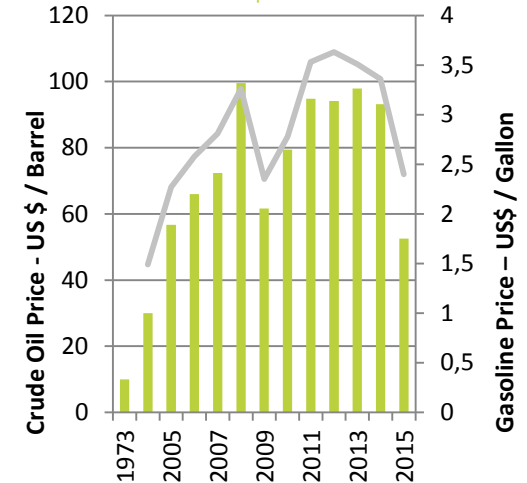
Christophe PILLOT
+ 33 1 47 78 46 00
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WHY X-EV ?

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%



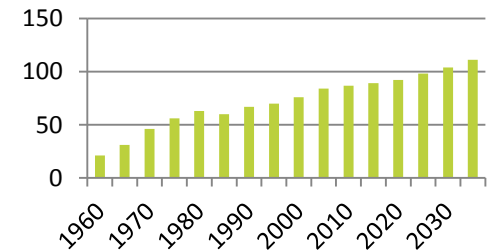
Price of the WTI¹ barrel of oil, US \$



Source:
<http://www.eia.doe.gov/emeu/steo/pub/contents.html>

Petroleum consumption worldwide 1960-2030

Million barrel per day



Source: Energy Information Administration, US Government

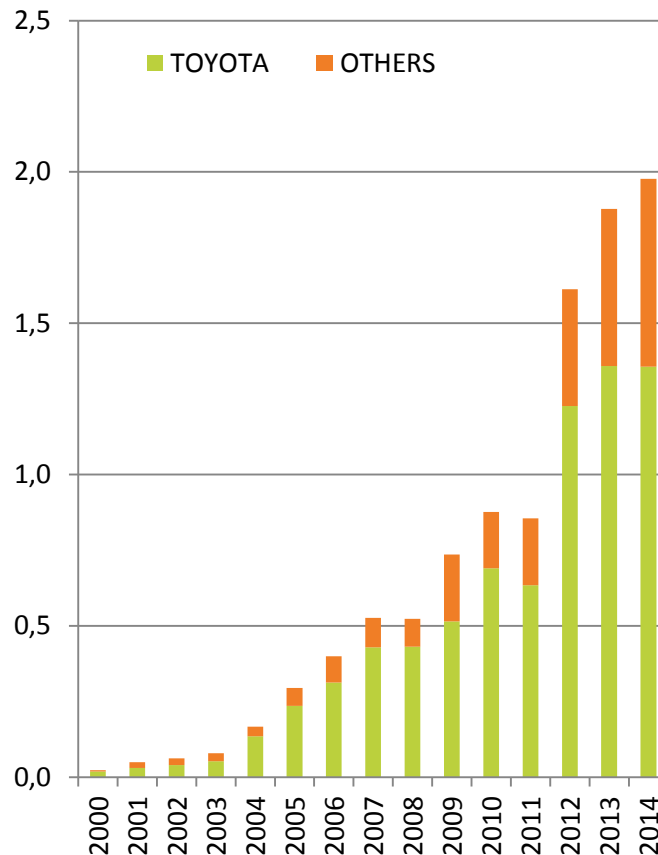
Note
¹ WTI: West Texas Intermediate

HEV WORLDWIDE IN 2014

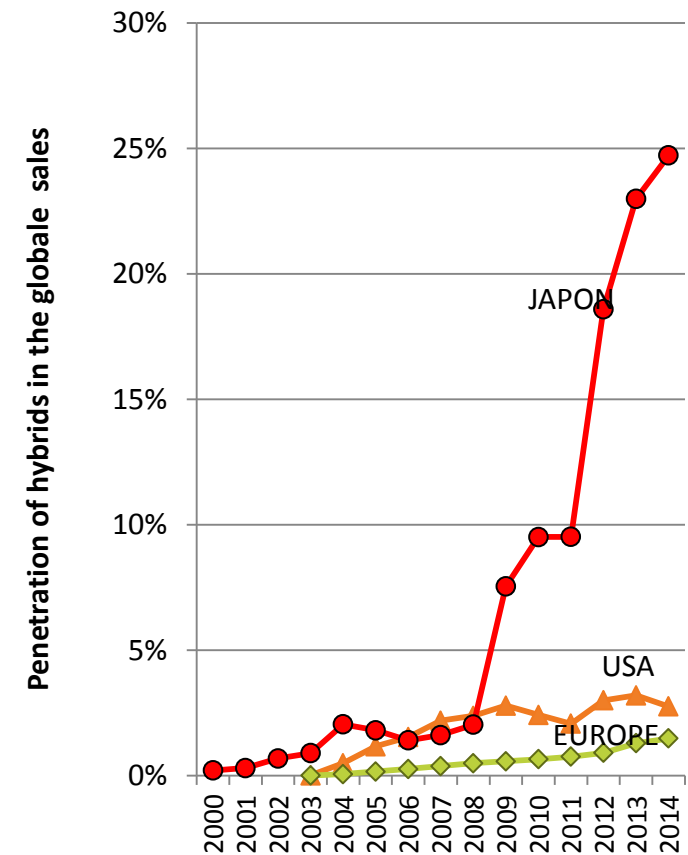
2 M HEV

Growth 2013-2014: +5%
From 1,9 M to 2 M HEV

HEV sold per year, M units,
worldwide, 2000 - 2014



Penetration of hybrids in the
global sales, 2000-2014



Source: TOYOTA, HONDA, NISSAN, FORD, GM, HYUNDAI, MERCEDES, GM, BMW, VW, PORSCHE... Compilation AVICENNE ENERGY
Micro hybrid not included



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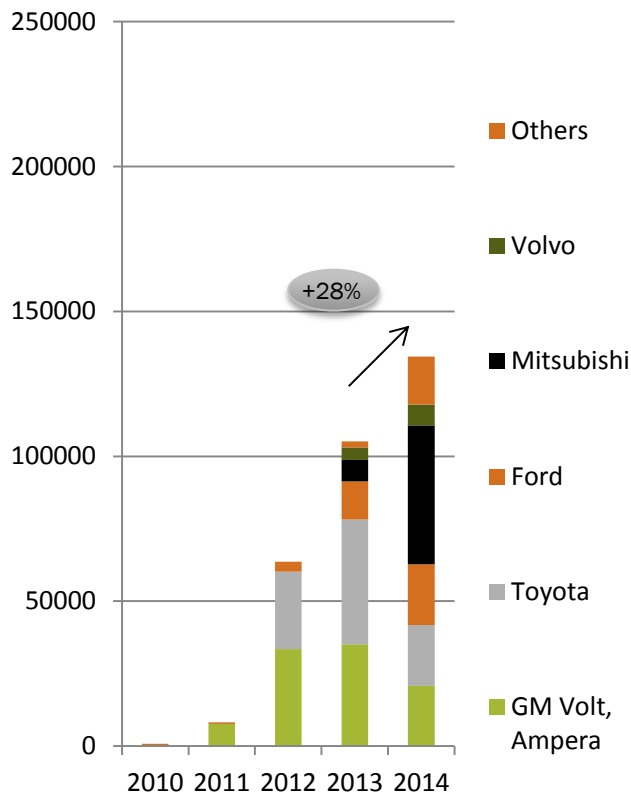
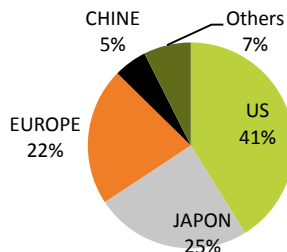
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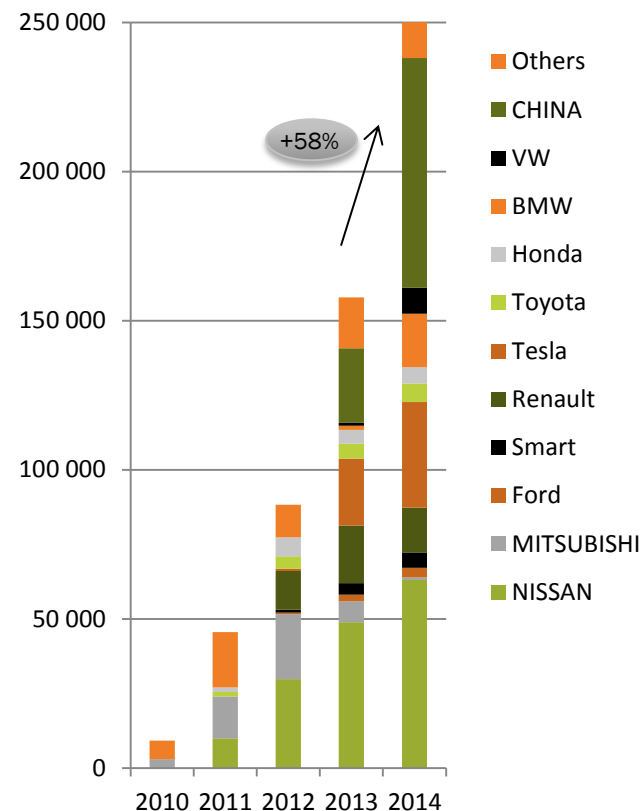
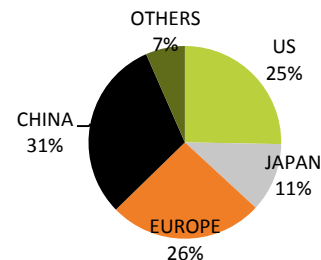
Christophe PILLOT
+ 33 1 47 78 46 00
c.pillot@avicenne.com

P-HEV & EV SALES 2010-2014 (YEARLY)

P-HEV sales



EV sales



Source: AVICENNE ENERGY Analyses

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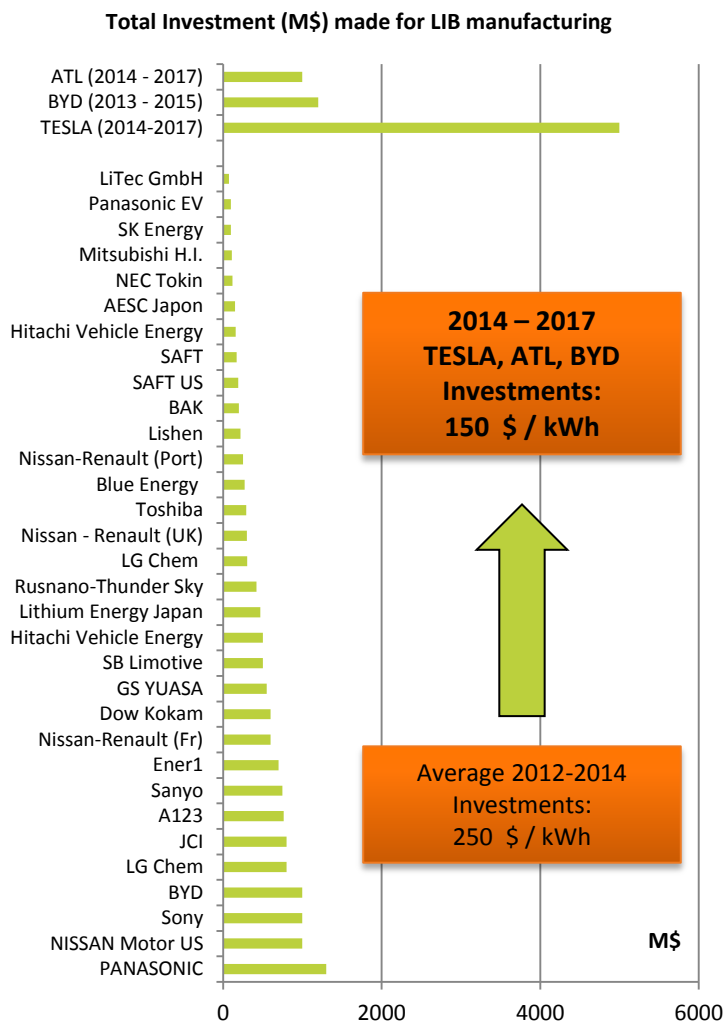
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+ 33 1 47 78 46 00
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LIB MANUFACTURING INVESTMENTS 2009-2015

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, Feb 2015



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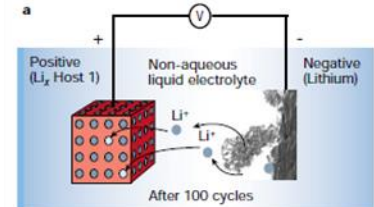
SAFETY ISSUES

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.

- 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 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.
CONSEQUENCES: All the 787 worldwide are grounded. Considerable losses for Boeing.













SAFETY IS A SINE-QUA-NON SELECTION CRITERIA FOR BATTERY TECHNOLOGIES

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

Cathode		LCO	NMC	LMO	LFP	High V	Sulfur
SAFETY							?
xEV ?		NO	YES	YES	YES	?	?

Anode		Graphite	Hard Carbon	Soft Carbon	LTO	Si/C	Li Metal
SAFETY							
xEV ?		YES	YES		No (1)	?	?

Electrolyte		Liquid	+ Additive	Gel Polymer	5 V	Polymer membrane	Solid
SAFETY					?		
xEV ?		NO	YES	YES	No	YES	> 2025

Separator		PE, PP membrane	+ coating	Non woven	Polymer membrane	Solid
SAFETY						
xEV ?		YES	YES	YES	YES	> 2025

BMS	<ul style="list-style-type: none"> Most of the BMS function is to manage the safety of the cell & the battery pack: <ul style="list-style-type: none"> Overcharge management Over voltage management
-----	--

Packaging	<ul style="list-style-type: none"> Use "safer" material in the pack: <ul style="list-style-type: none"> Flame retardant, High shock resistance
-----------	--

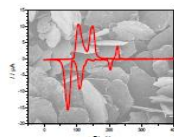
Thermal	<ul style="list-style-type: none"> Thermal management improve both the safety and the life time
---------	--

 Very Safe  Unsafe

(1) Low energy density ; mostly developed for stationary applications, or LV start light & ignition batteries

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

TIME TO MARKET FOR NEW MATERIALS IN LIB INDUSTRY



1970ies



1980ies



1991



2004



2010

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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	Li Metal Non Si Alloys	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

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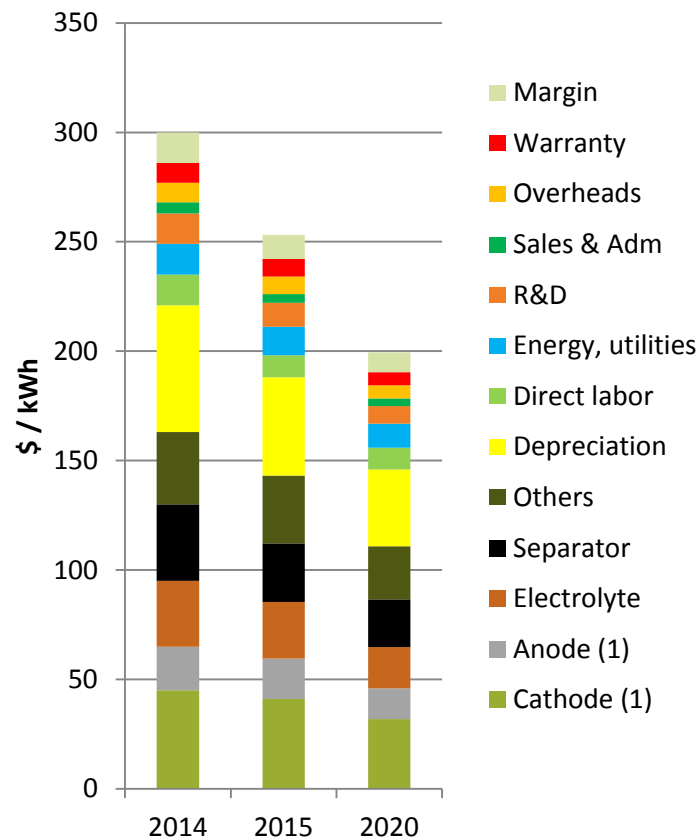
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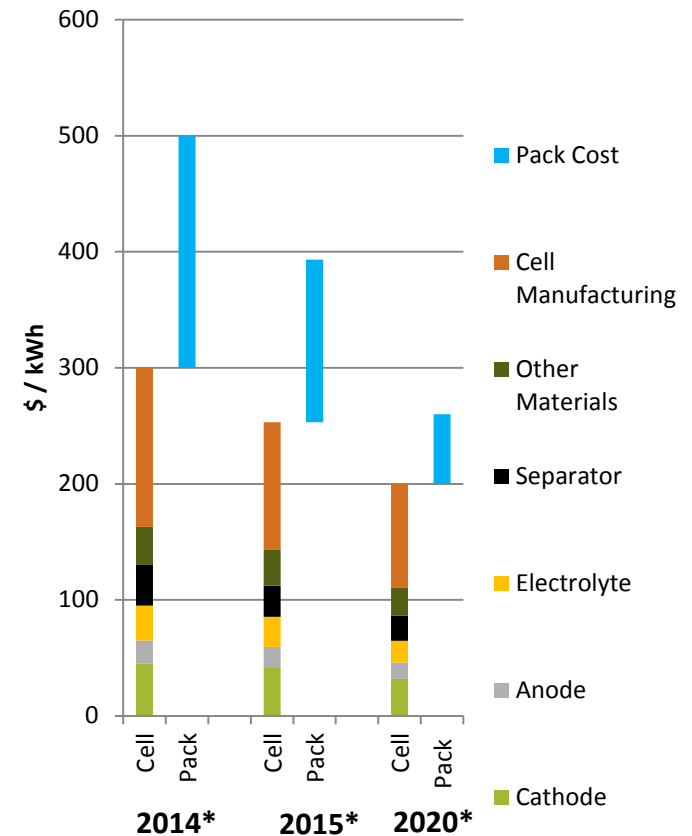
LI-ION BATTERY COST 2014-2020

LIB cell average cost (36Ah pouch)
(EV design ; LMO/NMC cathode)



(1) Active materials only

LI-ION BATTERY PACK COST
FOR EV



* For Production > 100 000 packs/year



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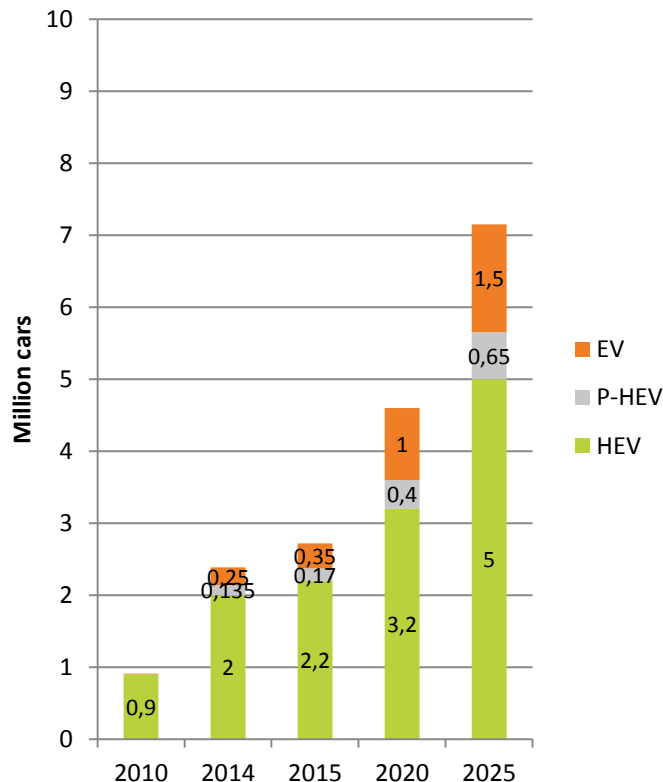
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EV, P-HEV, EV 2025 FORECASTS

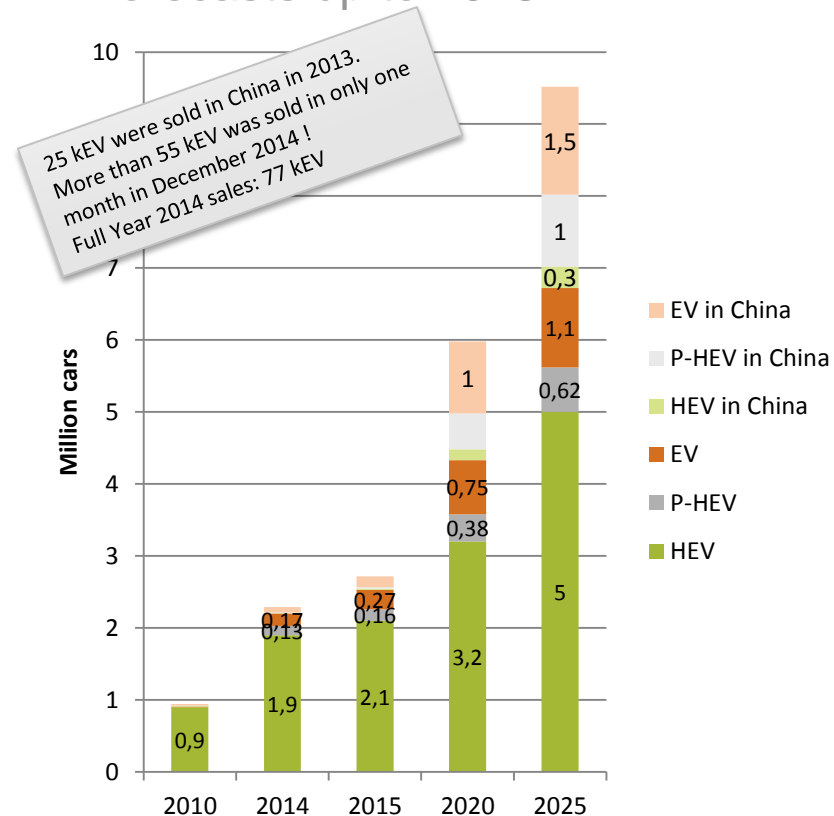
Scenario 2: thanks to very high incentives, China could change the game



S1: HEV, P-HEV & EV market forecasts up to 2025



S2: HEV, P-HEV & EV market forecasts up to 2025



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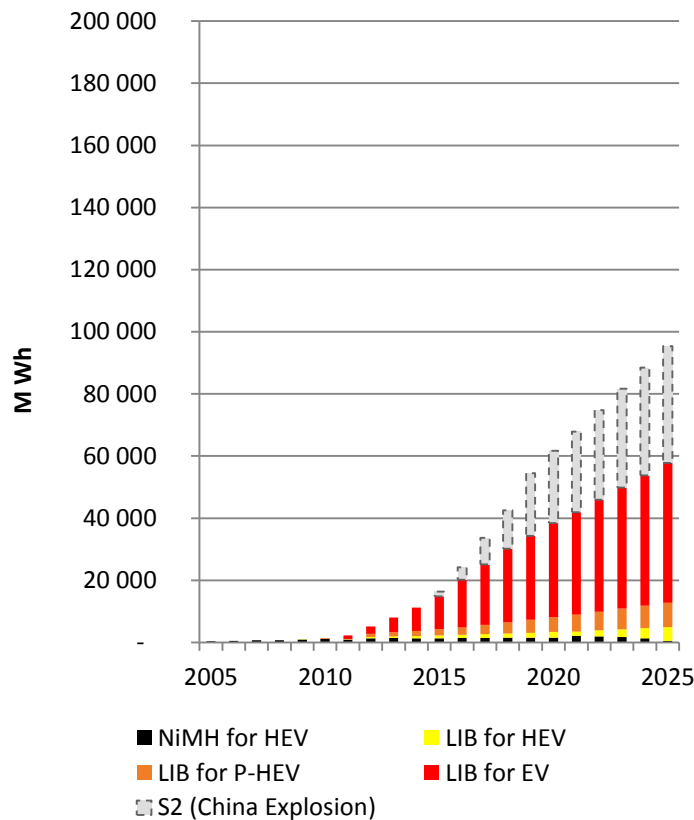
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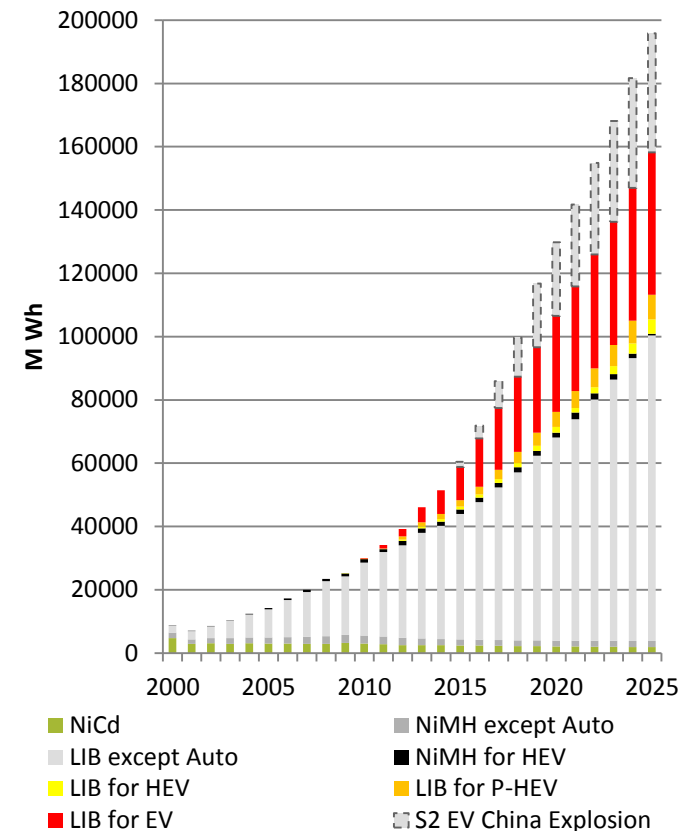
TOTAL BATTERY DEMAND 2025 FORECASTS

Scenario 2: thanks to very high incentives, China could change the game

EV, HEV & P-HEV Battery needs (MWh)
CAGR 2014-2025: +16% / S2: +22%

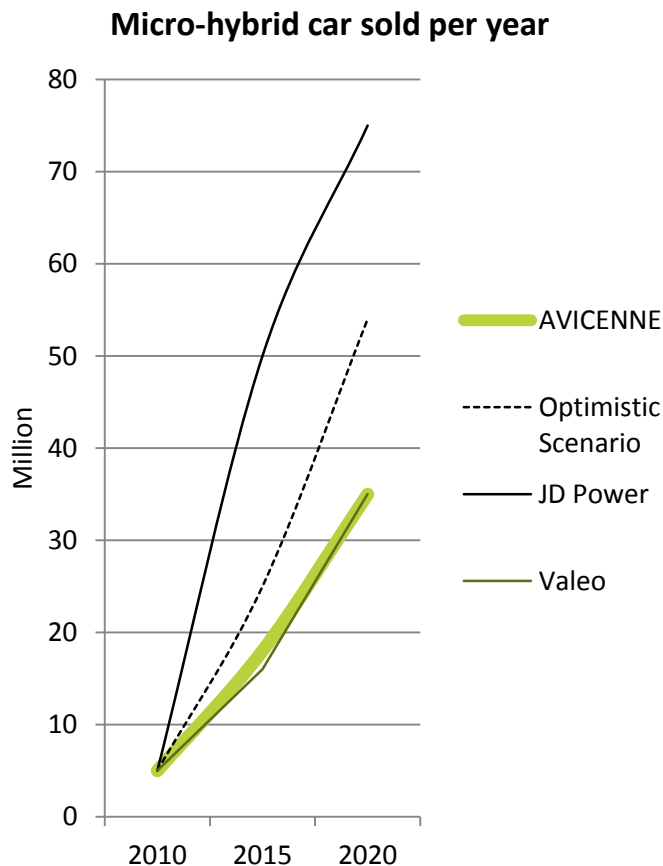


Total battery demand (MWh)
CAGR 2014-2025: +11% / S2: +13%



35 MILLION MICRO-HYBRIDS CAR IN 2020

Micro-hybrids car market 2010-2020



Micro-hybrid batteries

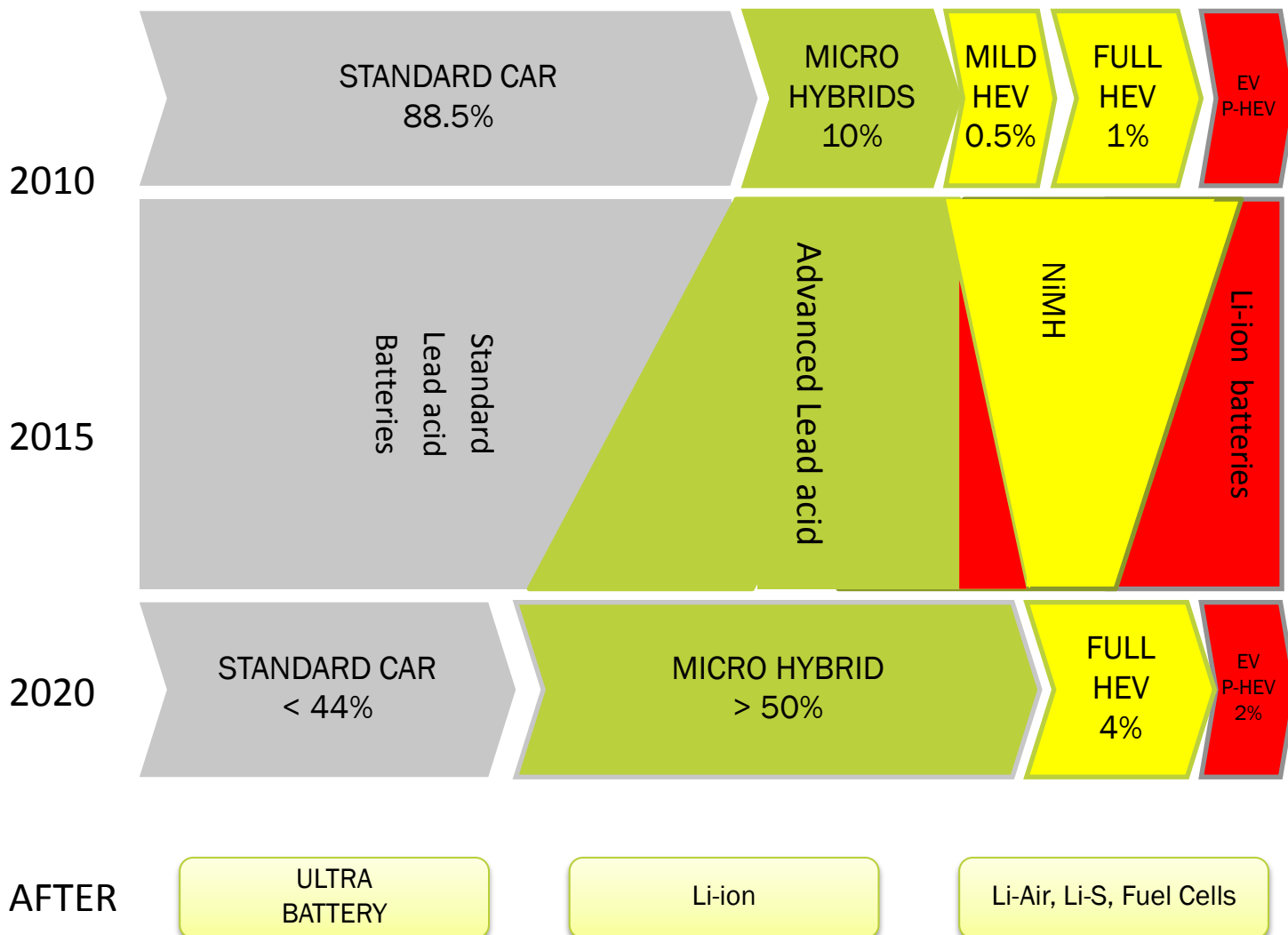
- ⌚ Powered today by Advanced lead acid batteries (sometimes in conjunction with super capacitors)
- ⌚ LTO will also penetrate this market (Toshiba -> Suzuki)
- ⌚ Panasonic develop new NiMH cell to adress the micro-hybrid market

Advantages of micro-hybrid compare to HEV

- ⌚ 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

	Micro-hybrid	Full HEV
Battery	Advanced lead acid	NiMH or LIB
Cost (\$)	300	3000
Fuel saving	5%	20%
Million Vehicle sold per year in 2020	35	3.5

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





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Future trends in the
rechargeable battery
market

ICBR
2015

September 23-25, 2015
Montreux, Switzerland

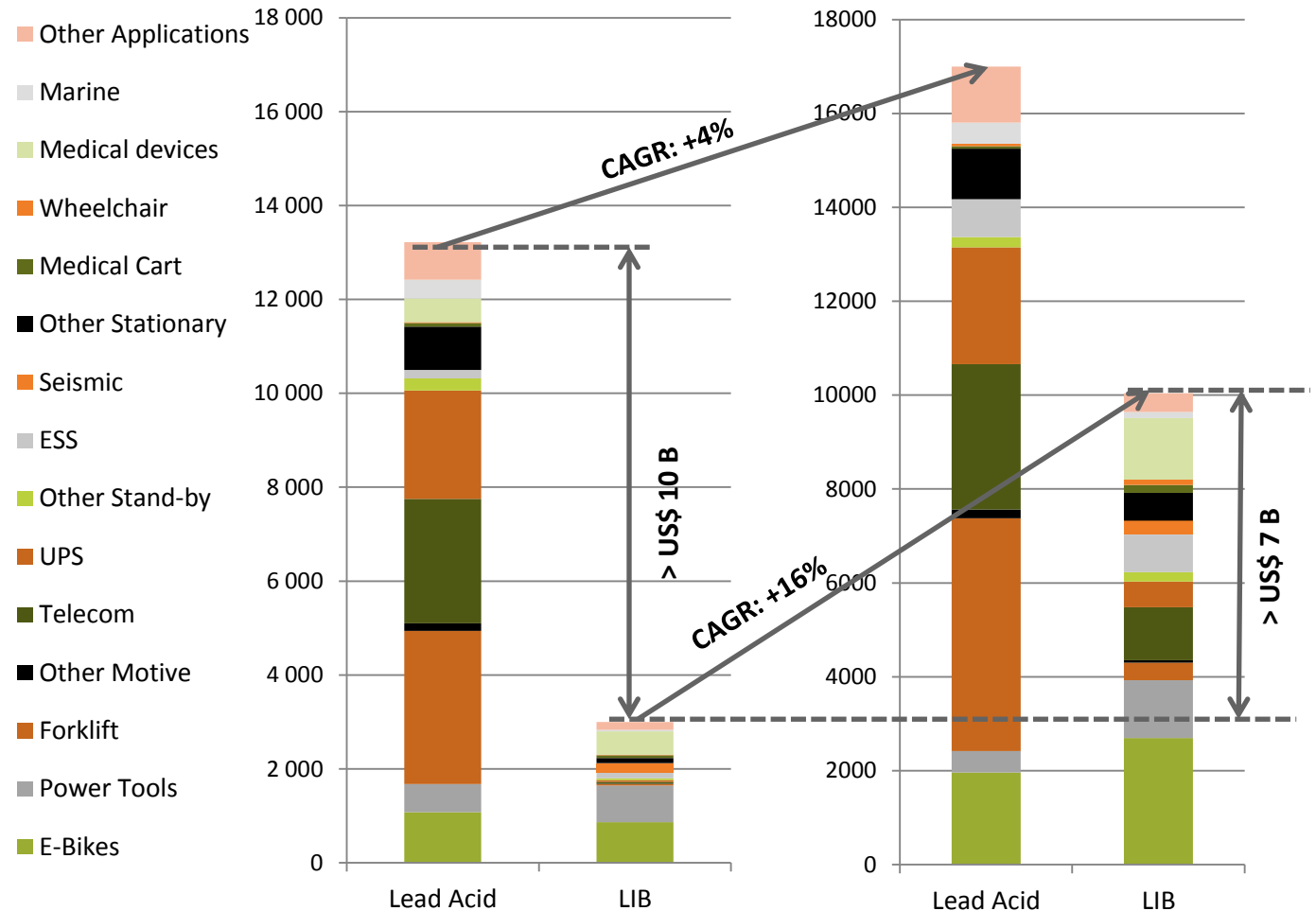
CONTACT

Christophe PILLOT
+ 33 1 47 78 46 00
c.pillot@avicenne.com

"OTHER APPLICATIONS" 10 B\$ POTENTIAL MARKET¹

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



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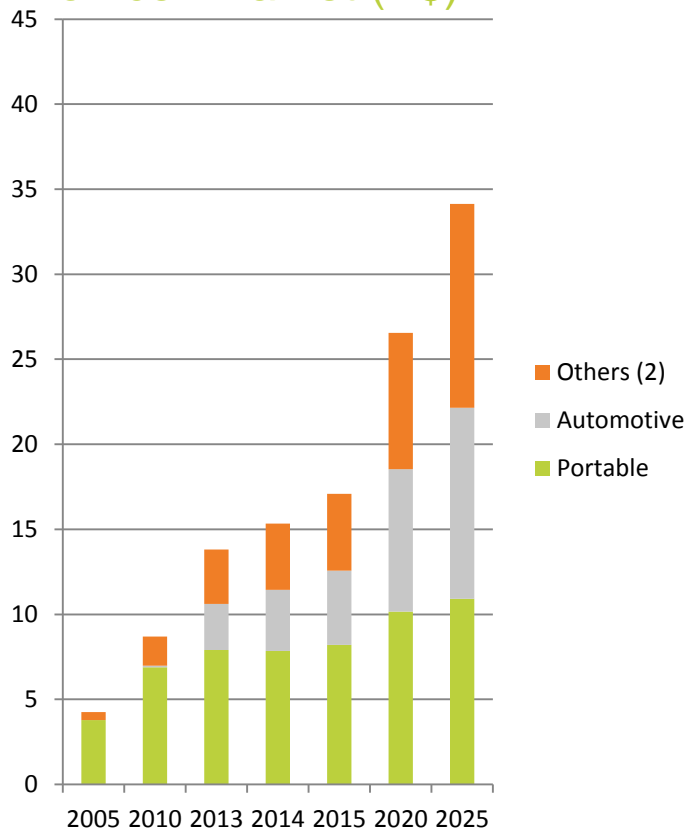
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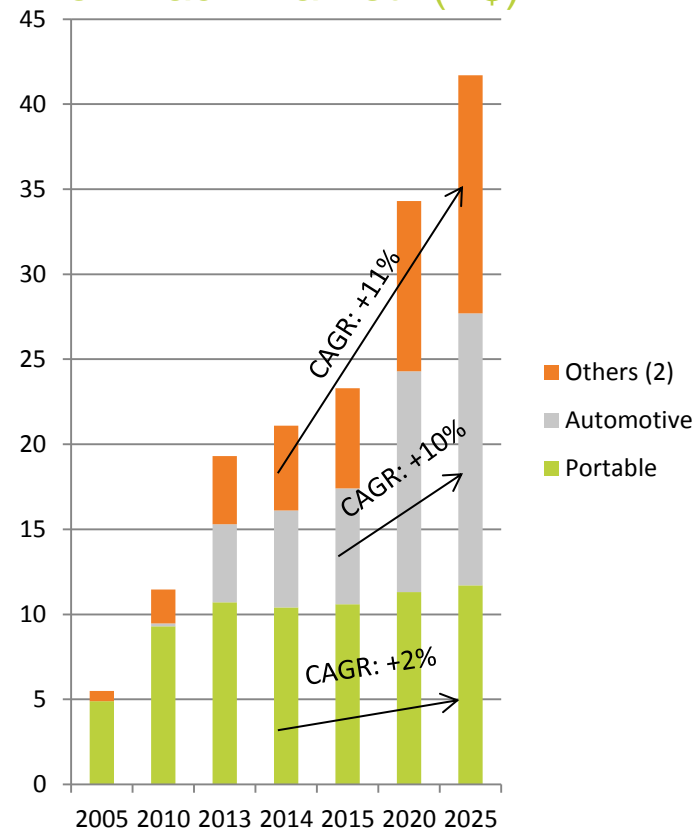
LI-ION CELL & PACK MARKET DETAILS

2014 -2025 { Portable: from 29 to 65 GWh
Automotive: from 10 to 60 GWh / S2: 100 GWh
Others: from 7 to 32 GWh

Li-ion cell market (B\$)



Li-ion Pack market¹ (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...

S2: Chinese EV market explosion

Source: AVICENNE ENERGY Analysis 2014

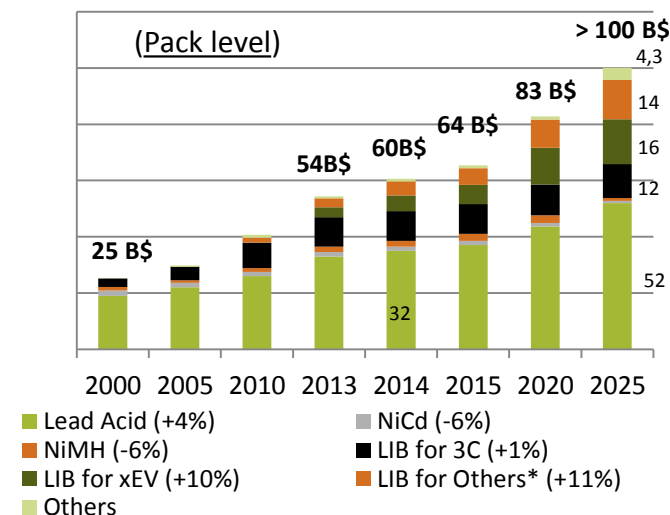
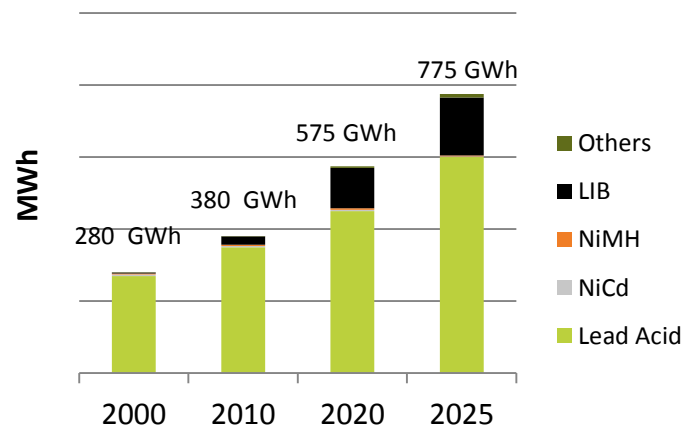
TAKEAWAYS

Battery Market 2010-2025

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
- Huge Chinese Market appears in 2014: to be followed !
- 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 will represent less than 5% of the total battery market

RECHARGEABLE BATTERY MARKET WORLDWIDE 2000-2025



(CAGR 2014-2025)

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

CONTACT

Christophe PILLOT
+ 33 1 47 78 46 00
c.pillot@avicenne.com

THANK YOU



Christophe PILLOT
AVICENNE ENERGY
c.pillot@avicenne.com
Phone: +33 1 47 78 46 00
Mobile: + 33 6 88 82 79 49

