The Lithium-Ion Battery Value Chain

F-Cell Conference

Stuttgart October 09, 2012

Content

Introduction

Roland Berger
Strategy Consultants

Roland Berger has extensive project experience in all aspects of the (Automotive) battery market

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LISHEN Power Your Life! 天津力神电池股份有限公司 Tianjin Lishen Battery Joint-Stock Co., Ltd.
DOW KOKAM
SB LiMotive A joint company of Samsung and Bosch

SELECTED PROJECTS

- **Market and technology studies** Li-Ion batteries for **raw material suppliers** (3 projects with focus battery value chain on **Japan, Korea, and China)**
- **Production cost benchmarking** for Li-Ion battery materials (cathode, anode, separator, electrolytes)
- **Market entry studies** Cathode Active Materials (CAM)
- **Acquisition target search** for battery materials (CAM, electrolytes)
- Market study and **partnering strategy** for global Japanese manuf. of **Li-Ion batteries**
- **Site selection Europe** for Japanese **Li-Ion manufacturer**
- **Market studies** on the **global LiB market** for **passenger cars** and **commercial vehicles** as well as **for other industries (High end consumer goods, ESS)**
- **Market entry strategy** Europe for Asian battery manufacturer
- **Strategy development** for European battery manufacturer
- Strategy development Commercial vehicle for Asian battery manufacturer
- **Analysis of standardization impact** on European Li-Ion-battery market
- **Trend analysis eMobilty** in the Triad for Chinese battery manufacturer / State-owned EV manufacturer association
- **European key-account strategy** for overseas battery manufacturer
- **Study** on use of **different battery types** for **European** battery manufacturer **association**

Source: Roland Berger

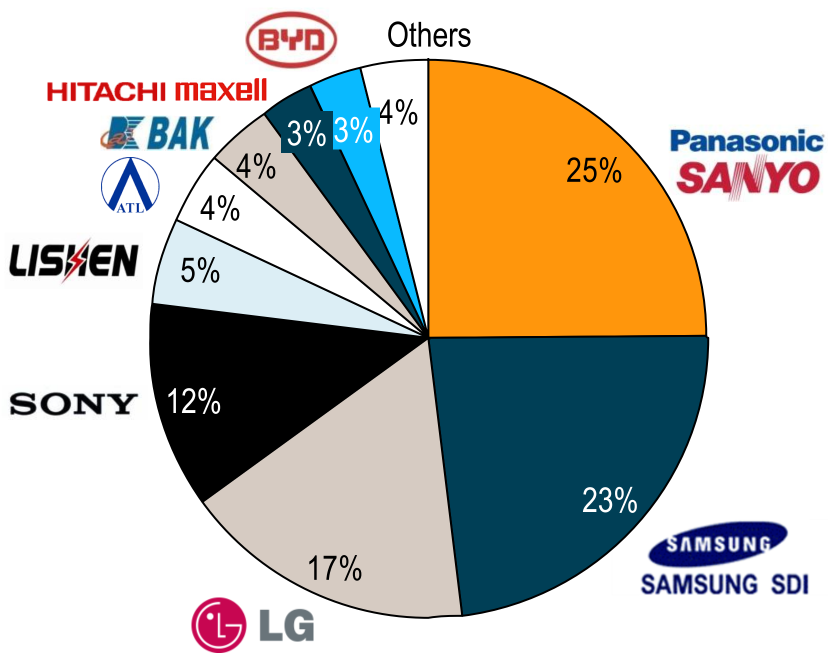
Global Market Overview on Li-ion Batteries

Roland Berger
Strategy Consultants

Worldwide Li-ion battery market by value and volume (2011)

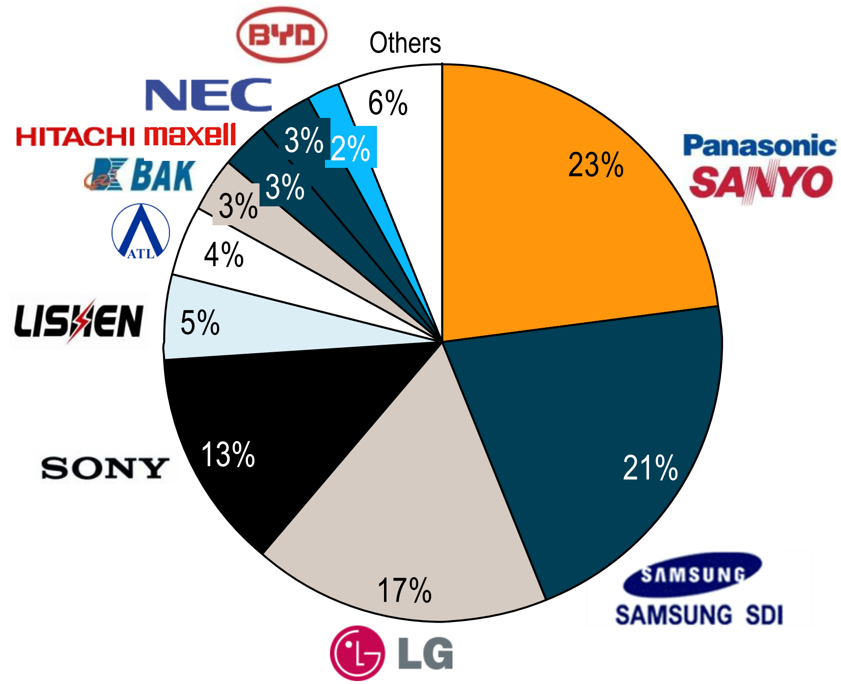
Worldwide Li-ion battery market by volume

TOTAL CELLS: 4.5 BN



Worldwide Li-ion battery market by value

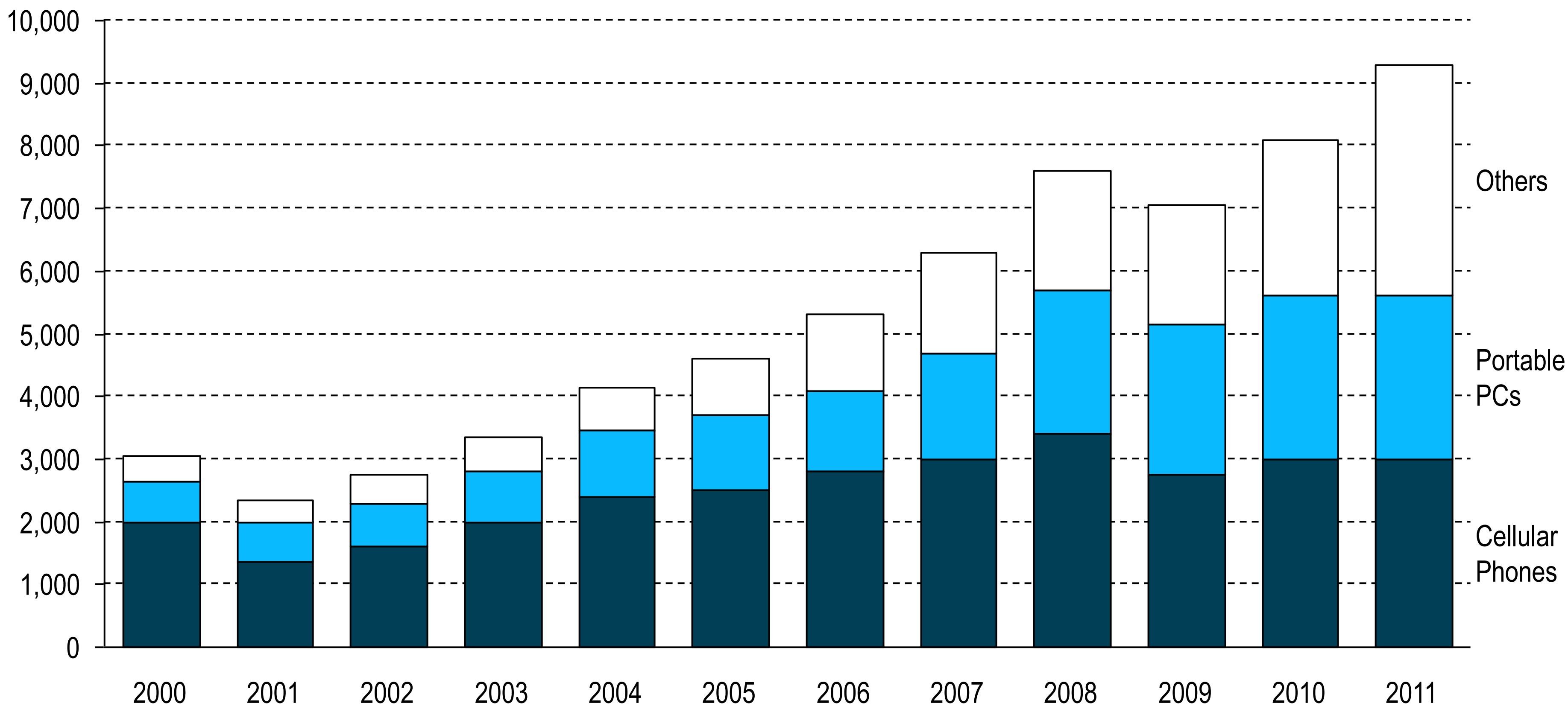
TOTAL VALUE USD 9.3 BN



Source: Avicenne Compilations, March 2011

Battery market by major applications

Li-ion battery sales, worldwide, 2000-2011 [USD m]



Source: Avicenne Compilations, March 2011

Automotive xEV

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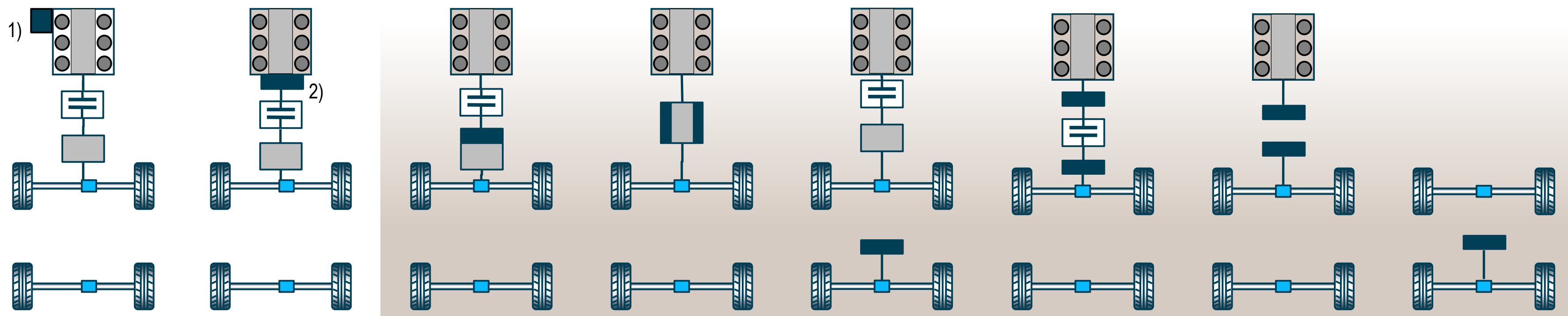
There are different options for electrifying powertrains – Technical layout depending on application and vehicle segment

PURE ELECTRIC DRIVING POSSIBLE

Micro/mild hybrid		Full hybrid (PHEV option)			PHEV		EV
Belt-driven starter-generator	**Integrated starter-generator**	**Parallel hybrid**	**Power-split hybrid**	**Second electric axle**	**Serial hybrid** (parallel option)	**Serial hybrid** (range extended)	**Battery electric vehicle**



Main applications (vehicle segments)

Mixed operation, incl. long distance
> Upper medium class/premium class, large SUVs, sports cars, transporters/vans

Urban/rural
> Mid-size cars, MPVs, small SUVs, light delivery trucks, sports cars

Urban
> Mini & small cars, small vans, mini vans, fun cars

1) Belt-driven starter-generator
2) Integrated starter-generators

Source: Roland Berger

Battery capacity assumptions were used wherever first hand data was unavailable

Battery specification assumptions

		BATTERY CAPACITY	BATTERY POWER
Light vehicles	**Mild**	0.5 kWh	40-45 kW
	Full	1.4 kWh	40-45 kW
	PHEV Parallel	12 kWh	85-100 kW
	PHEV serial	12 kWh	100-110 kW
	EV	22 kWh	100-110 kW
Buses	**HEV**	12 kWh	120 kW
	EV	70 kWh	120 kW
Trucks	**MD - HEV**	9 kWh	90 kW
	MD - EV	70 kWh	90 kW
	HD - HEV	12 kWh	120 kW
	HD - EV	100 kWh	120 kW

Source: Expert interviews, industry reports, Roland Berger analysis

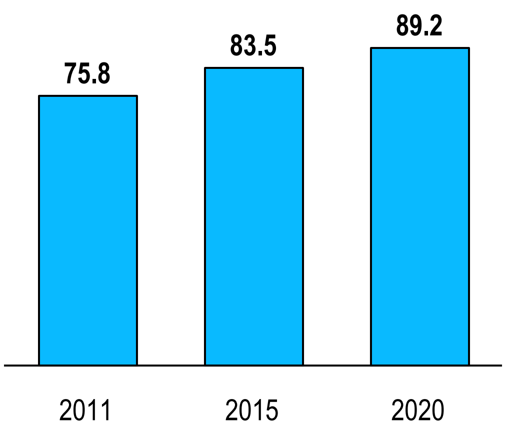
Despite stagnating growth in Triad markets, vehicle sales are developing strongly due to emerging markets' growth

Automotive – End-user user markets

Market development

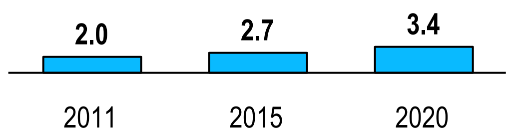
Passenger vehicles [m]

PC + LCV (Class 1-3)

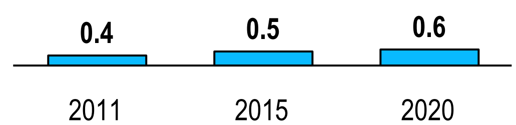


Trucks [m]

Class 4+



Buses [m]



Comment

Passenger vehicles

> Global passenger car sales are expected to grow at 2% and 1% annually through 2015 and 2020

> While TRIAD markets are largely stagnating, China, India and Brazil are the main growth drivers

Trucks

> Rising global transportation demand will lead to strong growth especially in heavy truck sales

> Annual growth between 2011 and 2015 will be 8%, between 2015 and 2020 a further 5%

Buses

> Bus sales are largely replacement sales, as bus fleets, especially in emerging economies, are being successively upgraded

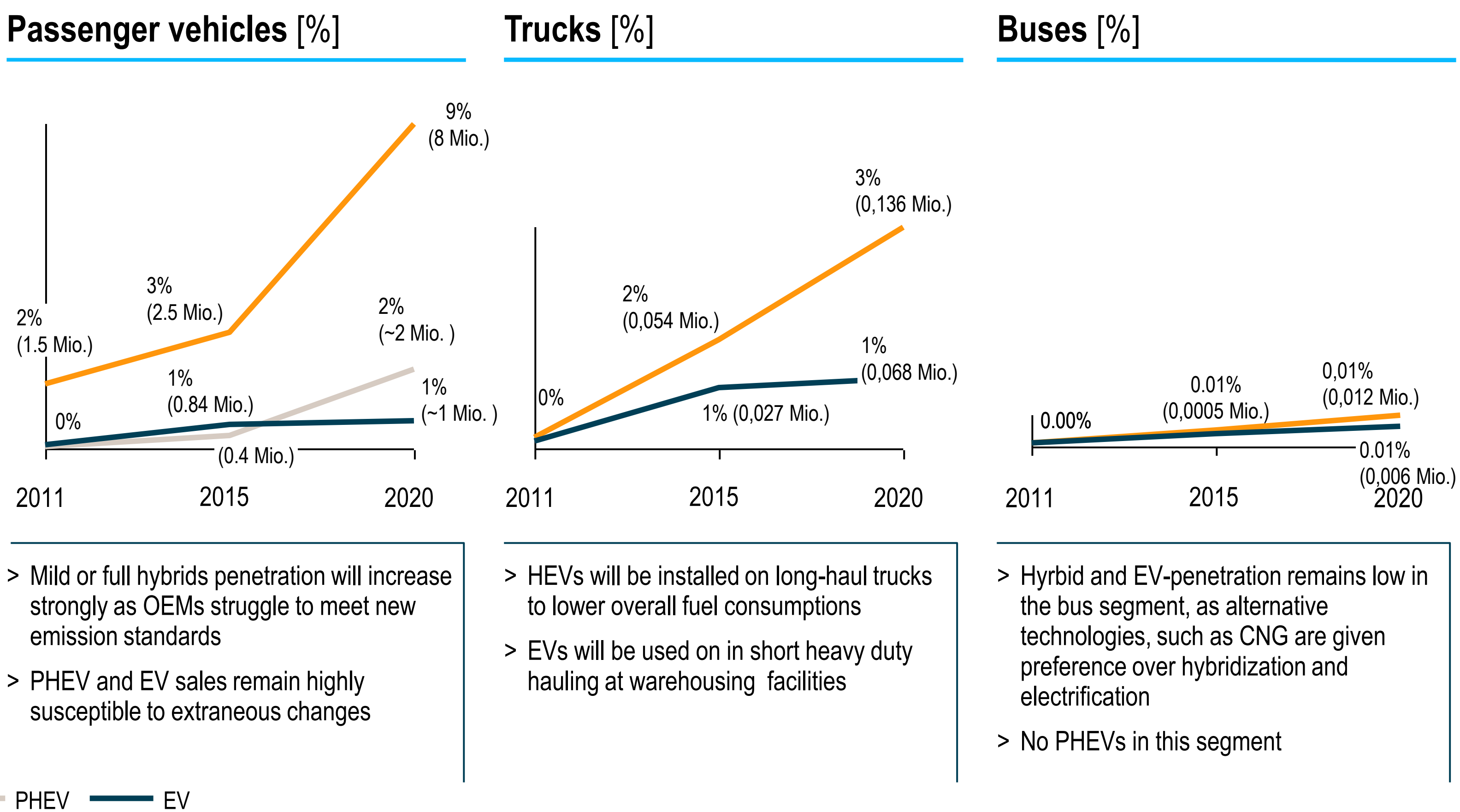
> Annual growth between 2011 and 2015 will be 5%, between 2015 and 2020 a further 4%

Source: Expert interviews, industry reports, Roland Berger analysis

Hybrids and will be adopted widely on passenger vehicles and trucks, while plug-in and EV penetrations rates remain lower

Automotive – HEV, PHEV, EV penetration

EV-penetration



Comment

Passenger vehicles
- > Mild or full hybrids penetration will increase strongly as OEMs struggle to meet new emission standards
- > PHEV and EV sales remain highly susceptible to extraneous changes

Trucks
- > HEVs will be installed on long-haul trucks to lower overall fuel consumptions
- > EVs will be used on in short heavy duty hauling at warehousing facilities

Buses
- > Hyrbid and EV-penetration remains low in the bus segment, as alternative technologies, such as CNG are given preference over hybridization and electrification
- > No PHEVs in this segment

Source: Expert interviews, industry reports, Roland Berger analysis

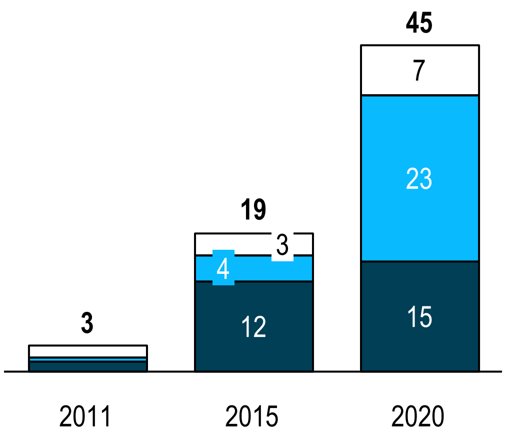
In terms of total energy demand, passenger vehicles will contribute by far the largest share

Automotive – Total energy demand

Market development

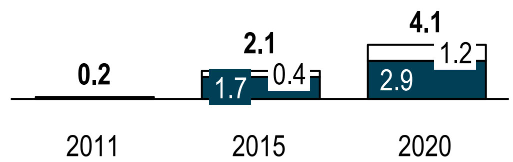
Passenger vehicles [GWh]

PC + LCV (Class 1-3)

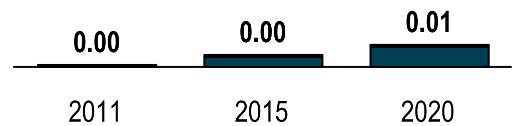


Trucks [GWh]

Class 4+



Buses [GWh]



Comment

Passenger vehicles

> HEVs only account for a small portion of the total energy demand

> All three segment will grow by between 50% and 70% between 2011 and 2015 and by up to 50% thereafter

Trucks

> HEVs will installed mainly on long-haul trucks to lower overall fuel consumptions

> EVs will be used mainly on in short heavy duty hauling, e.g. at warehousing facilities

Buses

> Hybrid and EV-penetration remains low in the bus segment, as alternative technologies, such as CNG are given preference over hybridization and electrification

> No PHEVs in this segment

HEV | PHEV | EV

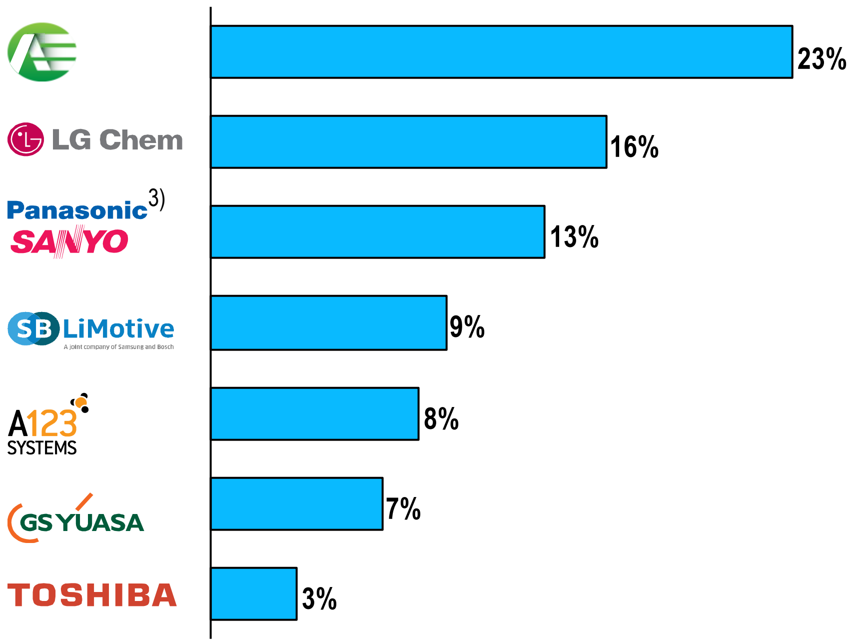
Source: Expert interviews, industry reports, Roland Berger analysis

In Passenger vehicles, especially Korean manufacturers dominate the non-captive markets

Key industry participants in 2015 (Passenger vehicles)

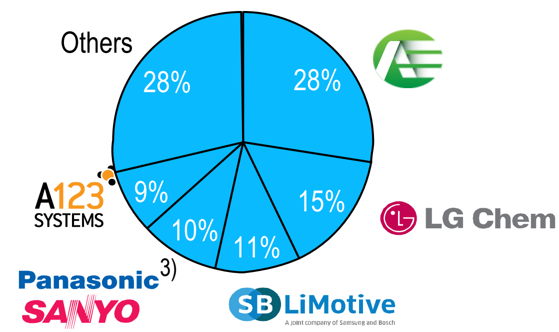
Expected 2015 global market share[1] [USD based[2]]

∑ = USD 8.6 bn

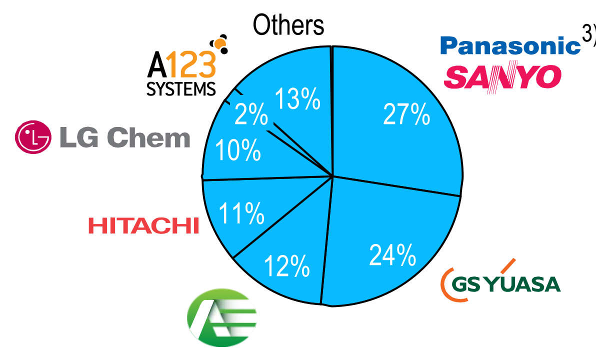


Expected 2015 global market share[1] [kWh based]

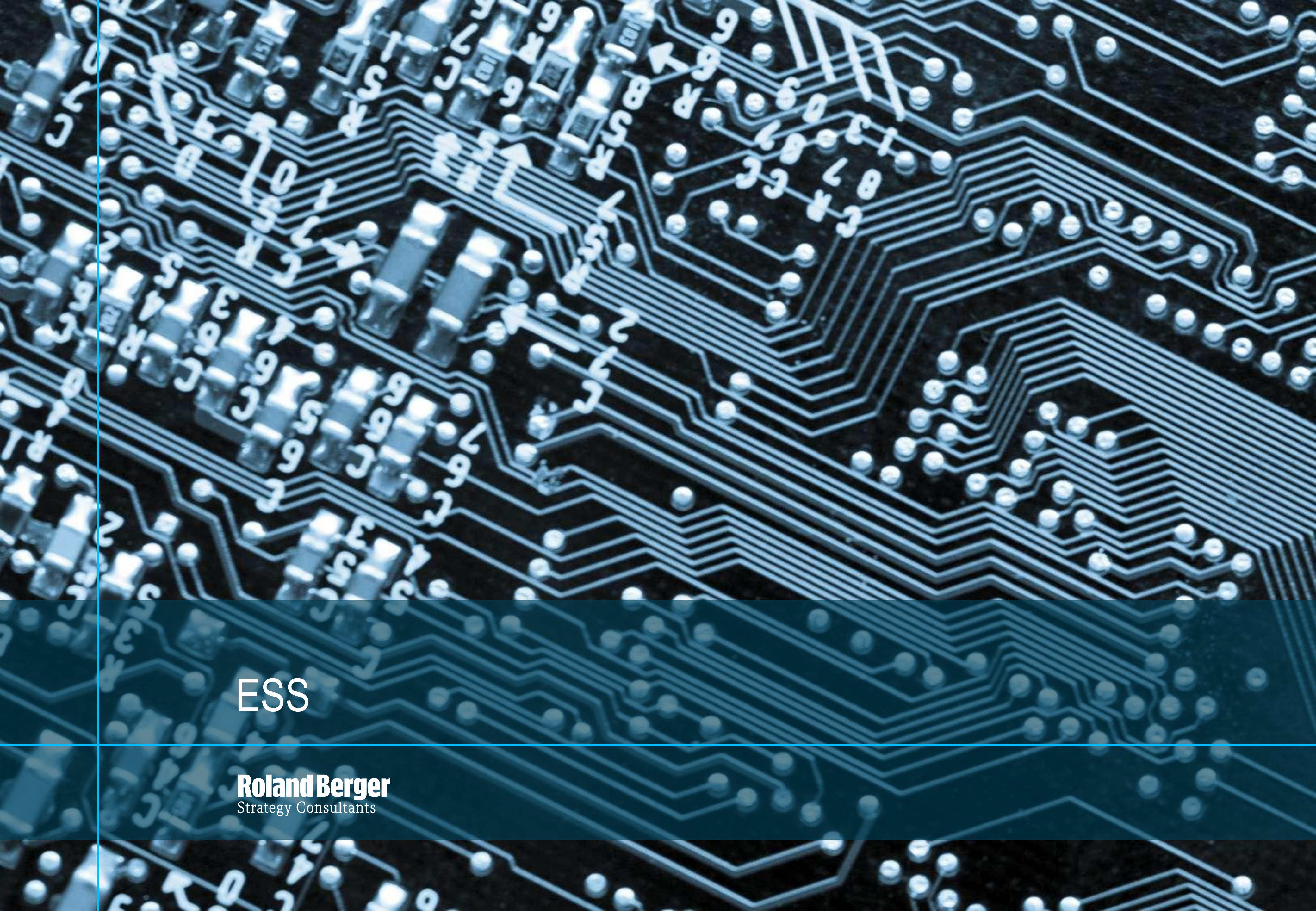
PHEV and EV [kWh]



HEV [kWh]



1) Accuracy level: +/- 2% 2) Market value derived using USD 730/kWh for hybrids, USD 560/kWh for PHEV, and USD 400/kWh for EV in 2015 3) Includes Primearth's share



ESS

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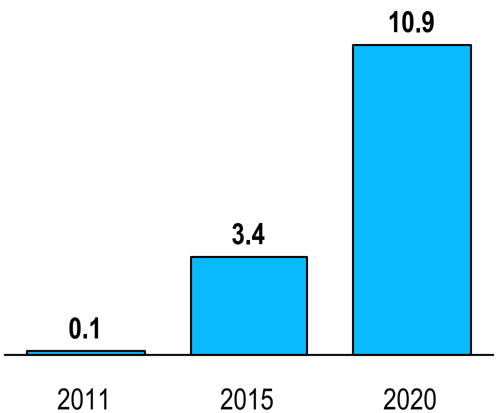
Strategy Consultants

Lithium-ion batteries are still at an early stage of development in ESS applications and growth patterns remain volatile

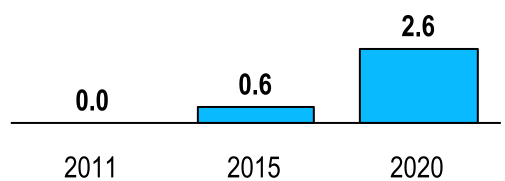
ESS – End-user markets and LiB penetration

Market

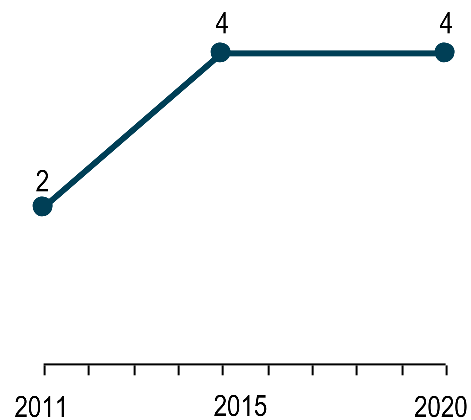
Total newly installed storage capacity [GW]



Newly installed LiB storage capacity [GW]



Average discharge rate [h]



Comment

> Strong growth in installation of renewable energy power plants will create a growing demand for on-grid energy storage or load-leveling applications

> Lithium-ion power are but one in a range of technologies competing in this segment

> Unlike in other segments LiB installation is somewhat volatile depending on projects undertaken in any given year

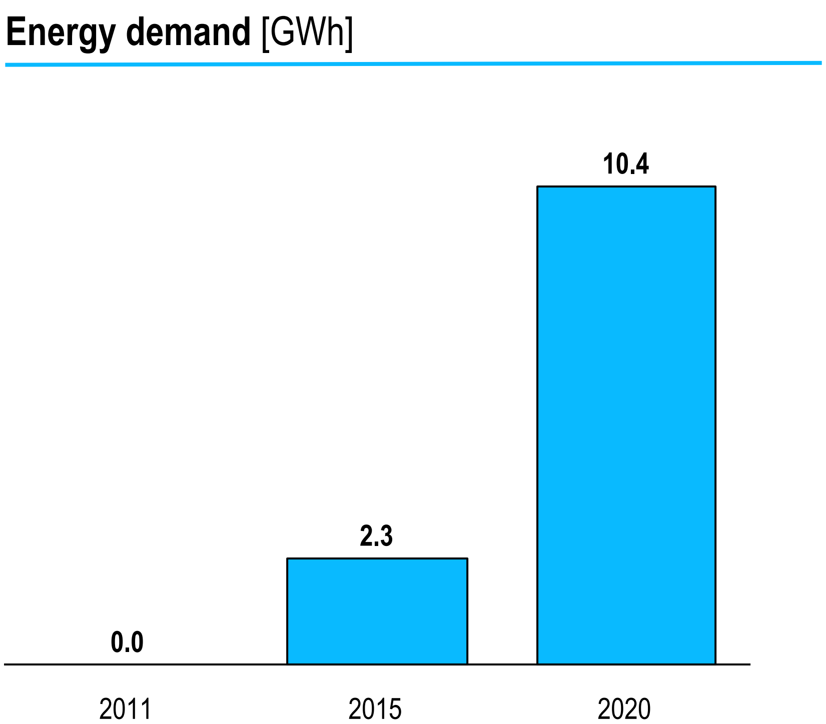
> Average discharge rates will increase also, as Lithium batteries are deployed more widely in the 6-12 our storage range

Source: Expert interviews, industry reports, Roland Berger analysis

Energy Demand Forecast

Forecast

Market



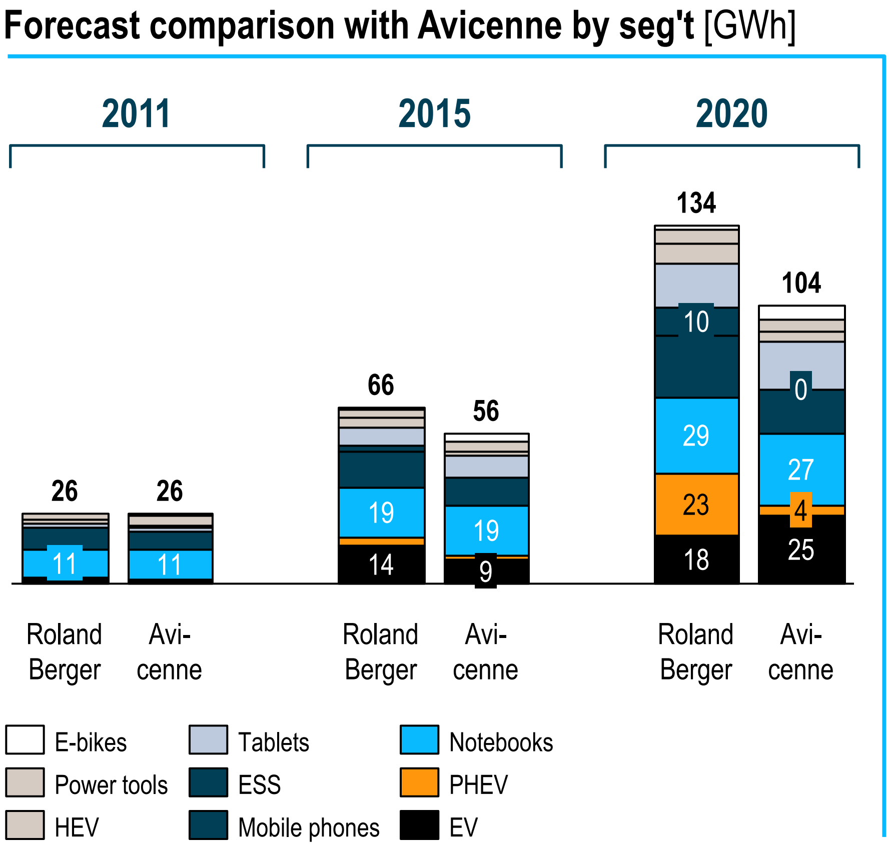
COMMENT

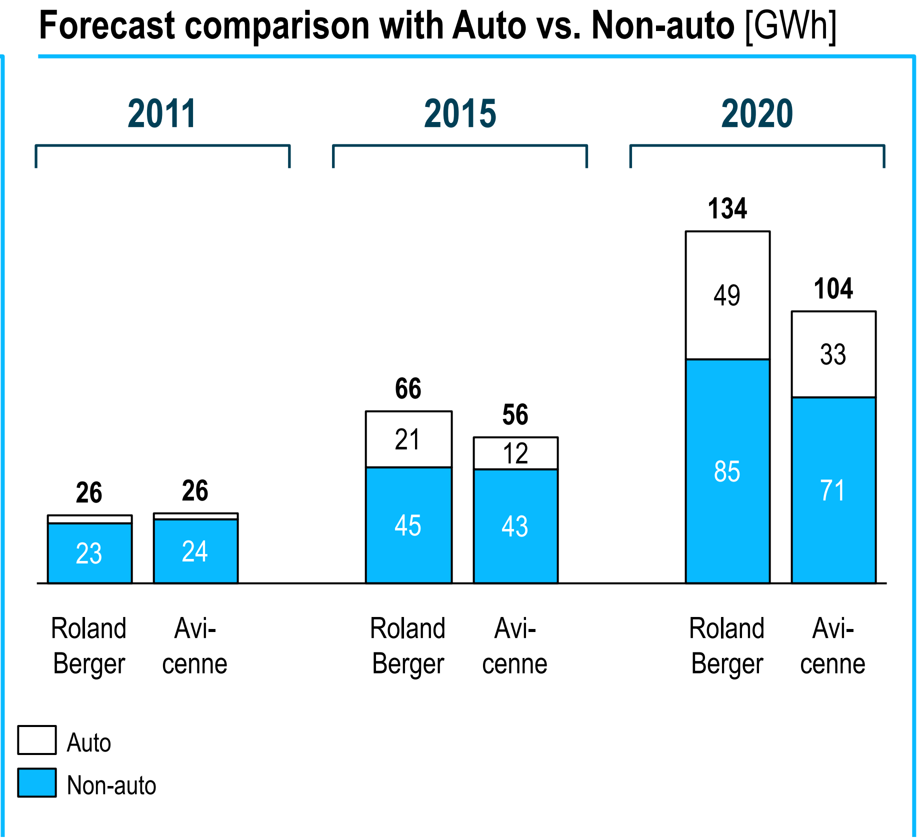
> Demand for Lithium-type ESS applications will grow by 35% annually on average between 2015 and 2020

Source: Expert interviews, industry reports, Roland Berger analysis

In terms of GWh RB forecast largely aligned in non-automotive segments; major difference in automotive segment forecast

GWh forecast comparison with Avicenne





Source: Roland Berger, Avicenne

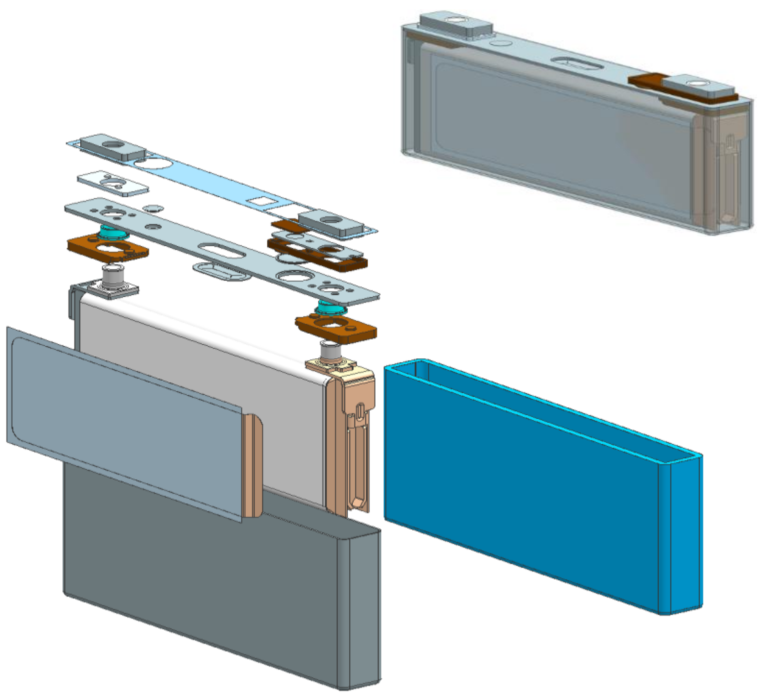
Cell Manufacturing Economics

Roland Berger
Strategy Consultants

We use a realistic reference cell for our analysis throughout this study – Over 96 Wh

Typical 96 Wh PHEV cell – Cell specifications

CELL DESIGN



MAIN SPECIFICATIONS

> 26 Ah/3.7 V

> Energy capacity: > 96 Wh

> Specific energy: 135 Wh/kg

> Cell dimensions: 85 x 173 x 21 mm

> Active materials:
  – Cathode: NCM ternary mix
  – Anode: Graphite mixture
  – Electrolyte: EC/DMC/EMC 1m LiPF6
  – Separator: PE (20µm)

> Prismatic Al-housing (0.8 mm) including lid and feed-throughs (Al, Cu posts)

> Major area of application in PHEVs

Source: Roland Berger

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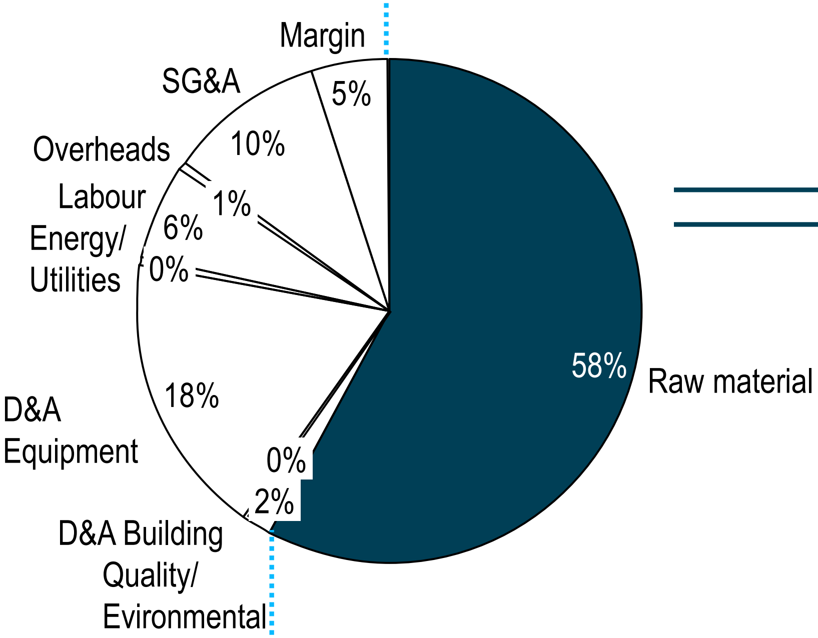
In a typical 96 Wh PHEV cell cathode material[1)] accounts for up to 39% of cell material costs

Typical 96 Wh PHEV cell – Cell cost structure 2015

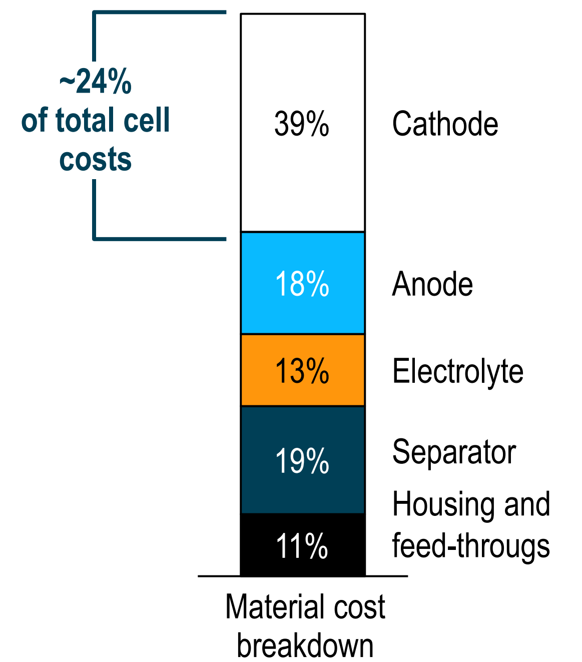
Cell cost breakdown, 2015

Total cost: approximately USD 23.3/cell (~ 243 USD/kWh)



Cell material cost split, 2015

USD 13.4/cell



1) Including carbon black content, foil and binder cost

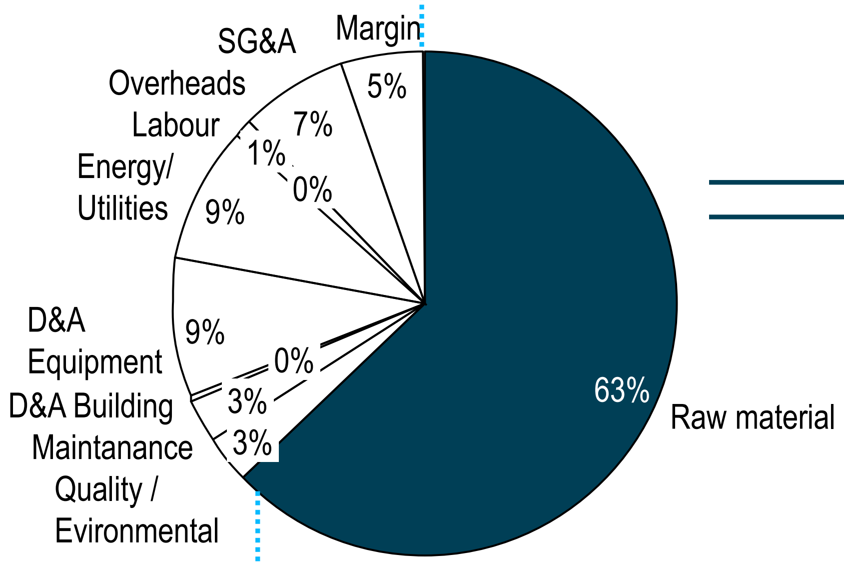
Source: Expert interviews, Roland Berger price calculation

... while CAM raw materials nickel, cobalt and manganese and lithium account for as much as 63% of cathode material cost

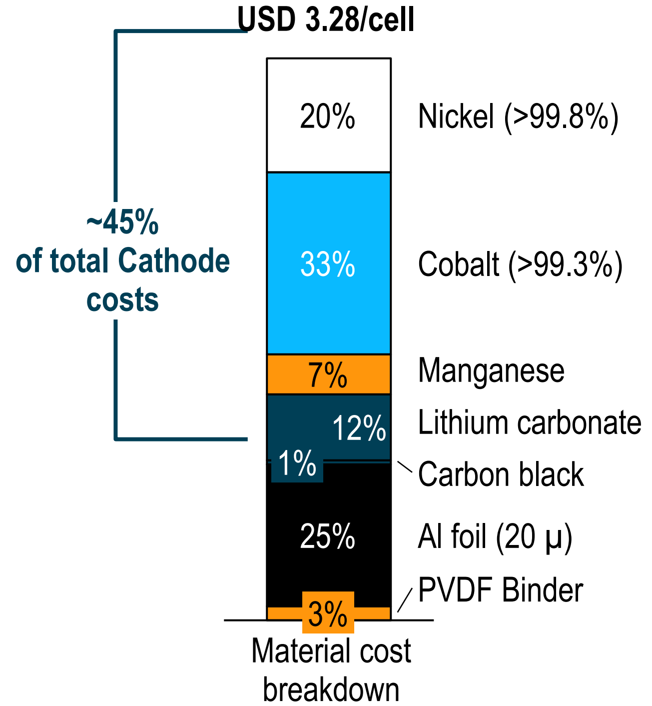
Typical 96 Wh PHEV cell – Cathode cost structure (NCM ternary mix CAM) 2015

Cathode cost breakdown, 2015[1)]

Total cost: approximately USD 5.22/cell



Cathode material cost split, 2015

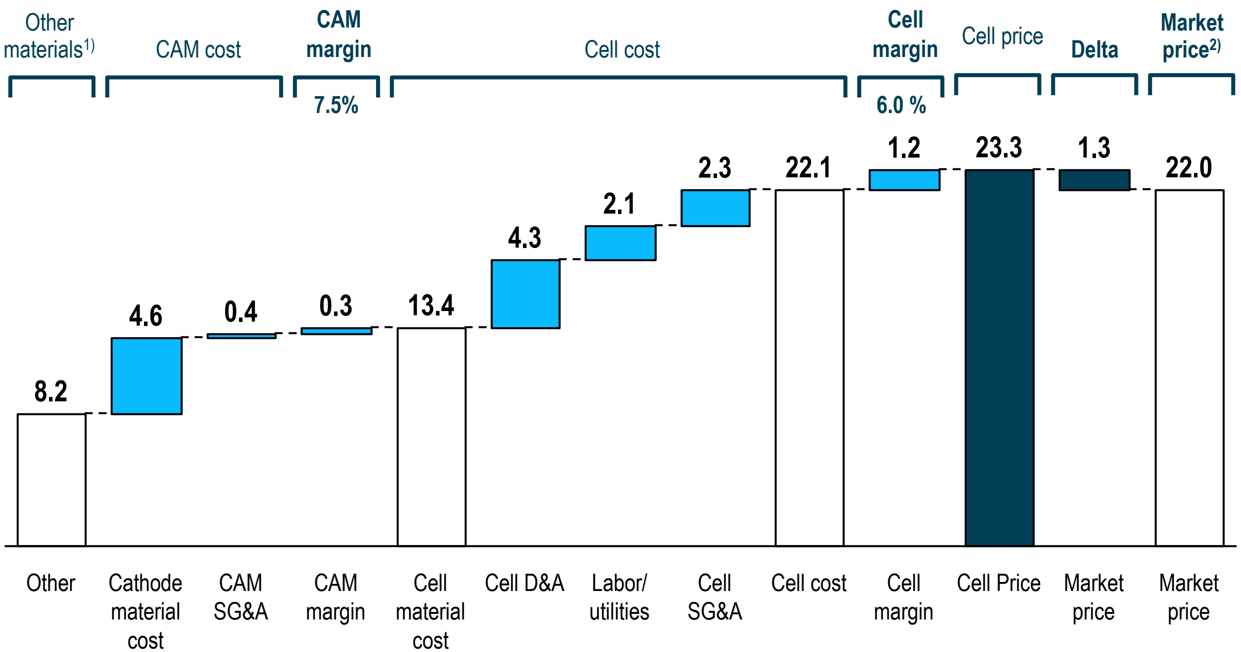


1) Carbon black, foil and binder manufacturing costs included in raw material cost, manufacturing costs shown are those of the CAM manufacturer. Excluding carbon black, foil and binder cost, raw material share equals 55%

Source: Expert interviews, Roland Berger price calculation

According to our bottom-up calculation, declining cell prices will put pressure on CAM and cell manufacturer margins in 2015

Typical 96 Wh PHEV cell – Cell price breakdown 2015



MARGIN PRESSURE

> Any price decrease below USD 24 will have direct impact on CAM and cell manufacturer margins

1) Anode, separator, electrolyte, housing 2) Expected market price based on expert interviews

COMMENT

> For a typical CAM manufacturer
– Raw materials account for up to 55% of total cost
– D&A and utilities account for up to 25% of total cost

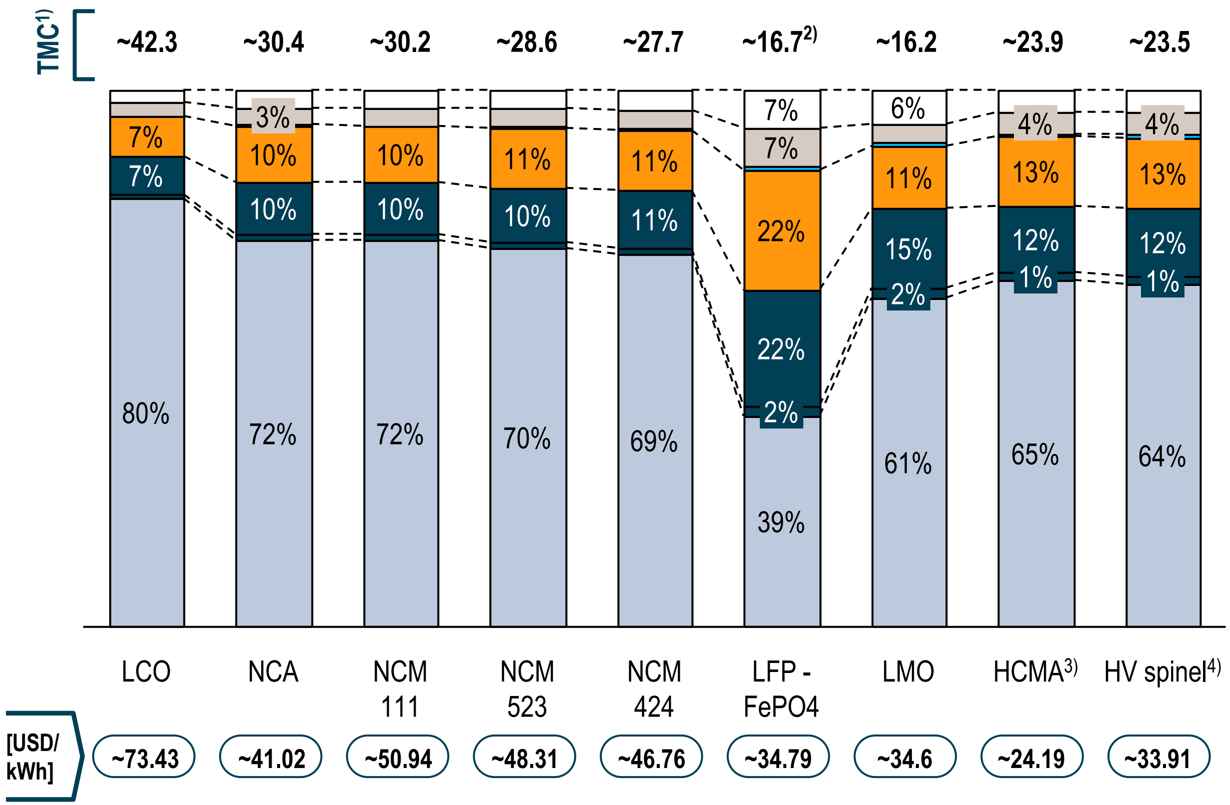
> For a typical cell manufacturer
– Raw materials account for up to 58% of total cost
– D&A and utilities account for up to 19% of total cost

> In view of their limited ability to offset sales price declines, CAM and cell manufacturers will compete over a shrinking profit pool

Source: Industry reports, experts interview, Roland Berger analysis

LCO has the highest material costs, followed by NCA and NCM; LFP and LMO are the least expensive

Manufacturing cost calculation 2011 [USD/kg]



1) Total manufacturing costs 2) High quality differences 3) Not available until 2015 4) not available until 2020

Quality/Environment | Maintenance | D&A Other | D&A Equipment | Energy/Utilities | Labor | Raw materials

COMMENT

> LCO is the most expensive material due to high cobalt content

> The material costs of NCA as well as all NCM materials are largely driven by cobalt (however they also have a higher energy density)

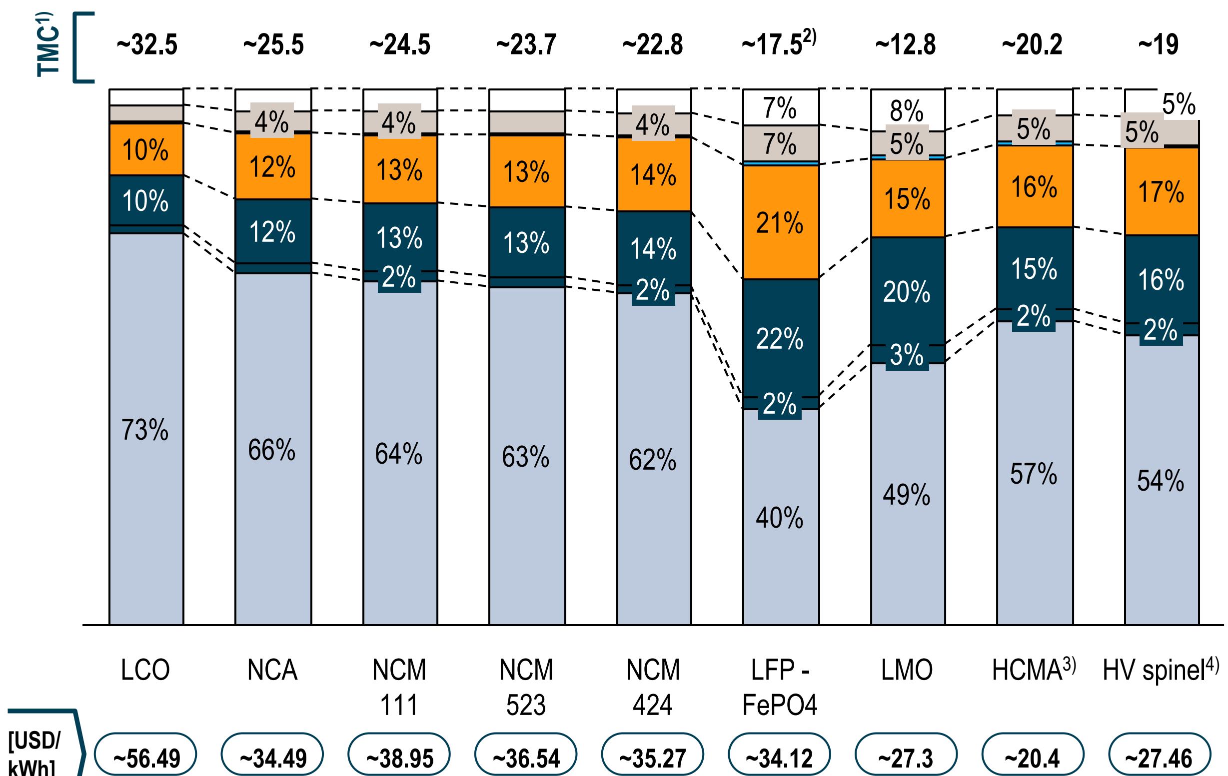
> The low material costs of LFP are partly compensated by higher energy costs (+50-100%), higher investments (+15%) and higher quality costs

> NCM and NCA have similar equipment investments; LMO has significantly lower material costs and investment but is typically only used in blends with NCM or NCA

Source: Industry reports, experts interview, Roland Berger analysis

Falling cobalt prices will favor cobalt-intensive materials, LFP manufacturing costs are set to increase as energy costs go up

Manufacturing cost calculation 2015 [USD/kg]



1) Total manufacturing costs 2) High quality differences 3) not available until 2015 4) not available until 2020

Quality/Environment | Maintenance | D&A Other | D&A Equipment | Energy/Utilities | Labor | Raw materials

COMMENT

> According to latest analyst reports the prices of nickel, cobalt and magananese will decline through 2015

> Largely as a result thereof CAM material costs will decrease by between 7% and 22% between 2011 and 2015

> The costs of LFP will increase largely as a function of higher energy and utility costs which account for 30% of total cost

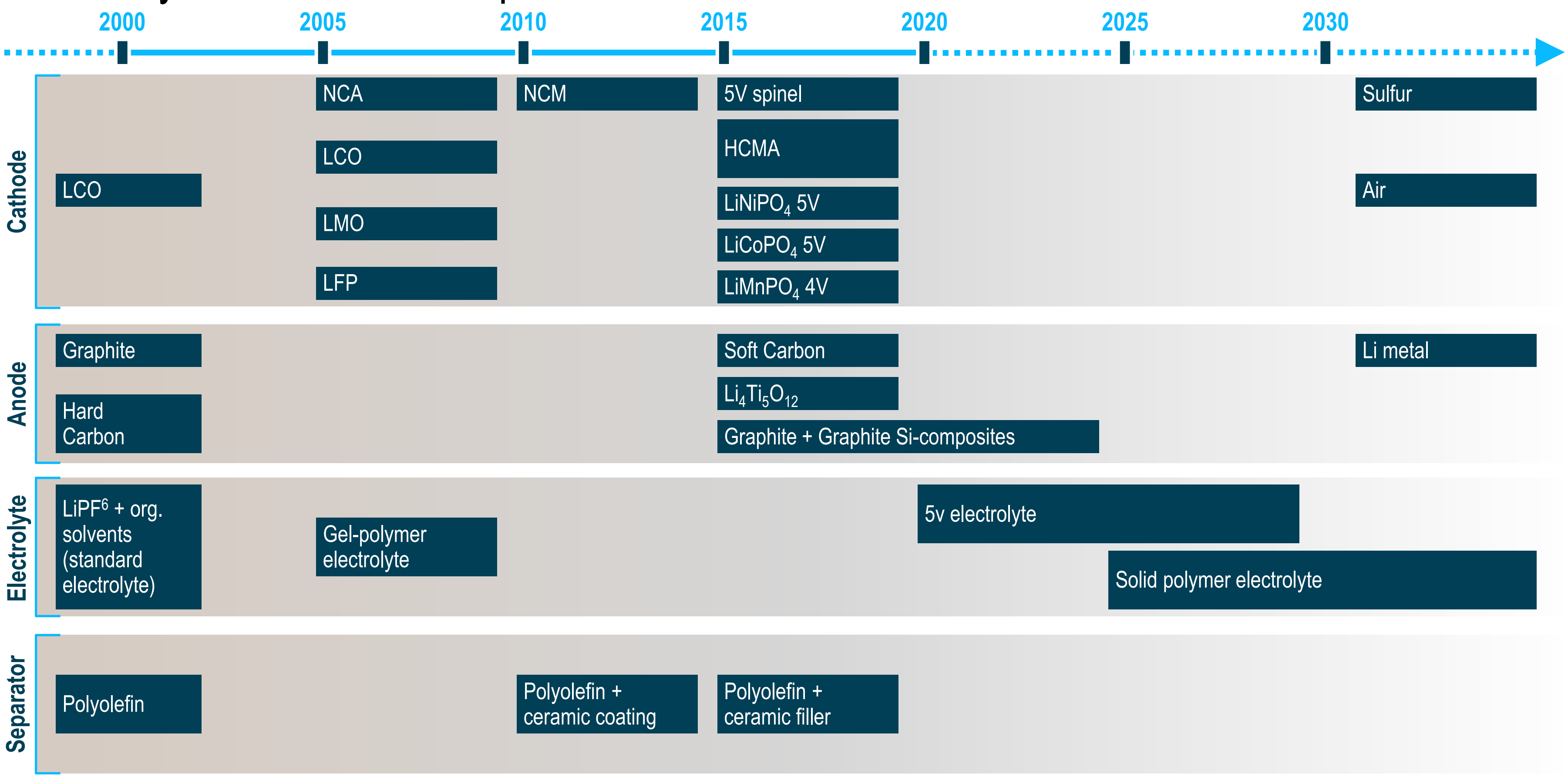
> If HCMA is ready by 2015, this will offer a significant cost advantage over other CAMs due to higher energy density compounded by lower material cost

Technology Roadmap and Future Trends

Roland Berger
Strategy Consultants

Major innovations in cathode material technology are expected to emerge only after 2015

Li-Ion key materials roadmap



Source: Avicenne compilation, Kai-Christian Möller, Frauenhofer ISC

Battery Systems Cost Projections

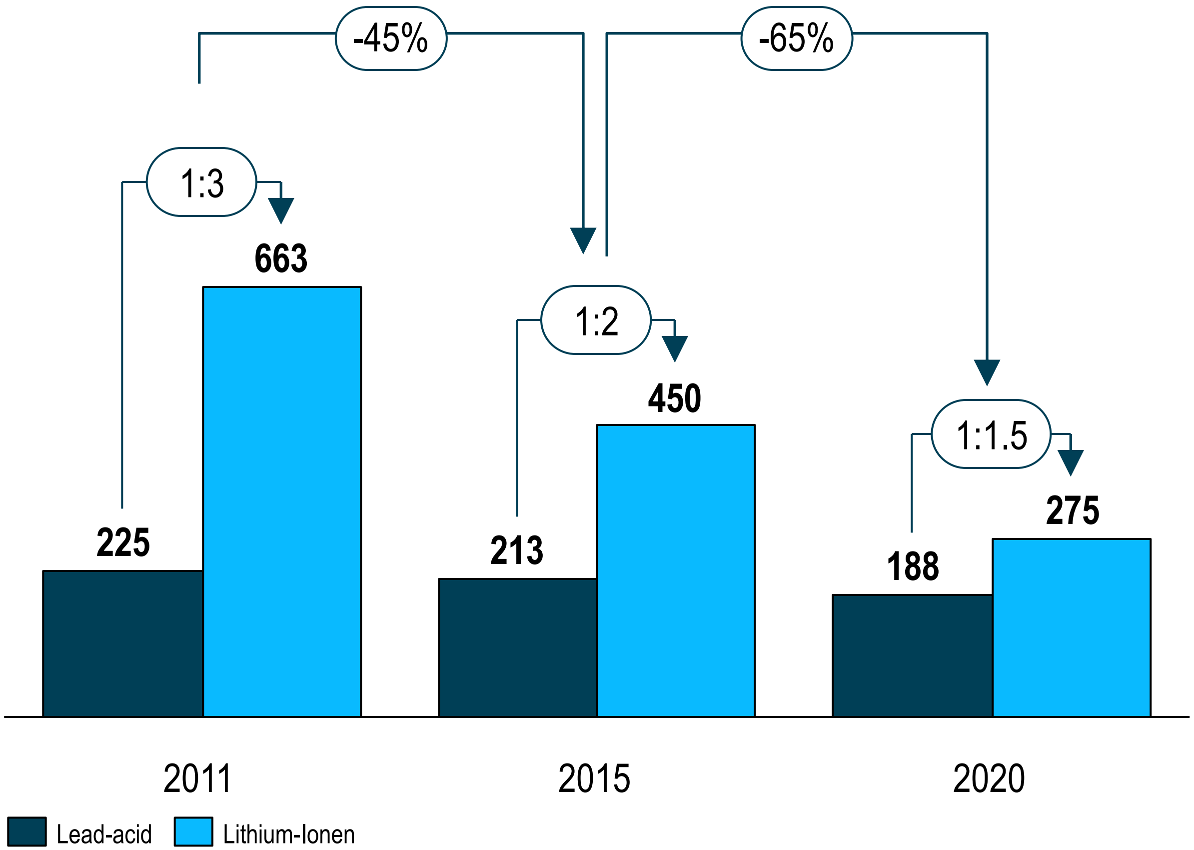
Roland Berger
Strategy Consultants

Electric Vehicle Battery Systems Cost Comparison and Forecast (USD/kWh)

Battery system (complete system without charger)	**2012**	**2015**	**2020**
Li-ion (includes sophisticated BMS & cooling)	600-750	400-500	250-300
NiMH (includes simple BMS & cooling for HEV only)	500-700	400-500	350-400
NiCd (includes simple controller)	400-600	350-450	300-350
Lead-acid (includes simple controller)	220-250	200-220	180-200

Cost Difference Between Li-Ion and Lead-acid Batteries for Long Cycle Life Applications

Cost development of Lead-acid vs. Lithium-Ion batteries [USD/kWh]



COMMENT

> The cost factor between lead-acid and Li-ion batteries will move from 1:3 today to 1: 1.5 by 2020

> This is a result of the drastic cost reduction for Li-ion battery system costs with an average annual rate of 9-10 %, whereas lead-acid is limited to 2-3 %

Conclusions

> Hybrid electric vehicle batteries is the fastest growing market segment of the total xEV market, with 8 million HEVs and 3 millon EV/PHEVs on the road globally by 2020

> The overall growth of the Li-Ion battery market up to 2020 is still dominated by consumer batteries with a market share of 63% and 37% for xEV batteries

> Our value chain analysis reveals that cathode materials are the major cost drivers but new developments will drive the total battery system cost for Li-ion batteries down from 650 USD/kWh today, to about 270 USD/kWh in 2020

> Lower cost combined with excellent cycle and calendar life makes Li-ion batteries a competitive candidate in many industrial, grid storage and renewable energy storage systems, where lead-acid systems are widely used today

Please contact us for further information

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It's character that creates impact!

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