E-mobility Roadmap for the EU battery industry

RECHARGE

July 2013

The European Association for Advanced Rechargeable Batteries

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Foreword

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Authors.

This publication has been prepared by RECHARGE aisbl.

The membership of **RECHARGE** includes suppliers of primary and secondary raw materials to the battery industry, rechargeable battery manufacturers, original equipment manufacturers, logistic partners and battery recyclers.

RECHARGE is following the continuously changing regulatory and legislative environment for rechargeable batteries and is a recognized expertise centre for advanced portable and industrial rechargeable battery technologies.

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Content

1. Executive Summary

A Roadmap covering Technical, Industrial and Business aspects is proposed for the development of a Battery Industry in Europe able to respond to a penetration, by 2020, of 2-4 % Electric Vehicles and 4-8 % Hybrid Electric Vehicles of the total sales of 4-wheeled vehicles.

1.1. Technical Roadmap.

Lithium-ion batteries are the reference technology for plug-in and full electric vehicles (PHEVs and BEVs) of the coming years (as well for two-and three-wheel vehicles). While other types of batteries, including lead-acid and nickel-metal hydride (in the first generation of the Toyota Prius hybrid) will continue to retain considerable market share in the short term, lithium-ion batteries are expected to dominate the market by 2017 (within the SLI market or the e-mobility market).
The e-mobility roadmap shall assume that the lithium-ion chemistry will reach its highest practicable energy density through the development of new active materials, such as high voltage cathodes (one of the key component of the battery), high energy anodes and new electrolytes. There are significant and fundamental technical challenges to overcome before these technologies can be deployed, such as the development of a more stable electrolyte at a high voltage.

Globally, significant efforts are already organized in the European Institutions for the technical development of the Li-ion battery and objectives are clearly described for the materials development.

A weaker position is observed in the cell technology and process development: battery innovation is pulled by the portable market in Asia. Due to the portable battery industry hard competition for IT applications, there is a permanent incentive for innovation in the portable batteries technology, mainly in Asia. In a second step, the portable industry is used as a "laboratory" to introduce innovation in the industrial battery industry. In Europe, due to the nature of the work, Universities have a limited involvement in this subject. Design of electrodes, electrolyte and cells for automotive application, and more generally for e-mobility will require significant effort in order for Europe to remain competitive.

In the engineering of battery systems and their integration in vehicles, largely linked to the automotive companies individual development plans, a stronger vertical cooperation with the battery industry would improve the efficiency of the e-vehicle development, in a more integrated approach that may be supported by public initiatives. This is an opportunity for Europe.

The challenge in Li-ion recycling is mainly economic: processes have been developed, allowing close-loop recycling of the present Li-ion products, but these processes have to be adapted for recycling of the Electric Vehicle batteries. Current recycling costs have a strong economic impact that could jeopardize the electric Vehicle business model and future. Treatment cost optimization is required that includes further technical development (scale effects will not be sufficient enough to eliminate the negative economic balance of this operation). In addition, establishing recycling qualitative and quantitative objectives, based on scientific calculations, would be helpful both for the recyclers and the car manufacturers.

1.2. Industrial Roadmap.

The European Battery Manufacturing Industry has currently a lower production capacity than its Asian and American counterparts. Therefore, the EU Battery industry - from specialized components suppliers to the recycling industry - needs to adapt in case of a significant development of the E-mobility market.

In such a scenario, significant investments will be needed from 2014 onwards. It appears that the industrialization of Li-ion batteries is capital-intensive: approximately 5.0 billion € investment will be required to fulfill the requirements of the roadmap to 2020 (200 M€ per GWh of battery capacity installed).

It represents a significant financial burden for the existing EU Battery Manufacturing Industry. In Europe, the Battery Industry level of investment is still low, particularly compared to the Asian competitors. These are backed-up by the growing market of portable equipment. This opportunity does not exist in Europe where the E-mobility Battery industry relies on the willingness of the EU car manufacturer to adopt the European battery technology. In addition, the supply chain for E-mobility batteries has to be re-structured: the usual lead-acid battery suppliers of the automotive industry (Enersys, Exide, JCI) are not significant producers of Li-ion in Europe, leaving few available Tier 1 local suppliers for Li-ion batteries in Europe.

At stake are the global consequences on the employment: the e-mobility deployment may bring up to 300.00 new employments, mainly in the battery and components manufacturing sectors (30%), but also in the distribution and services sectors of the economy, which is usually in the hands of small and medium sized enterprises.

1.3. Business Roadmap.

The business roadmap for the development of the Battery Industry in Europe is still wide open but needs to be defined shortly. The cost benefits brought by high production volumes of industrial e-mobility batteries are highly dependent on the uptake of EV market.

Most forecasts are showing that the cost of the lithium-ion batteries for EV can't decrease under 250€/kWh in 2020, without unrealistic assumptions on the battery technical progress and manufacturing technology. Therefore, the price difference between Electric vehicles and ICE vehicles justifies the implementation of external incentives. In addition, the capital investment is high, and due to the large worldwide competition pressure on prices, the return on investment may be long for the European industry.

To support these risks, there is a need for the EU Battery industry to have a clear market access and a strong financial backing. In this field, the model of a Joint Venture (JV) between the Battery industry and the Automotive industry has not been widely considered in Europe. It is not clear if the European automotive industry will prefer this model, or if they prefer a horizontal model of standard supply of batteries. In the latter case, the EU Battery Industry will face strong competition from Asian and American

competitors. The Asian Battery industry is backed up by a strong portable rechargeable battery market development. This does not exist in Europe. Therefore the EU Battery Manufacturing Industry needs to build a strong alliance with their e-mobility clients to secure their business development.
Currently, there is a handful number of manufacturers having invested in Europe for cells manufacturing (SAFT, Li-tec, Batscap (Bolloré), SB Limotive for the more significant): this represents less than 5% of the investment done or anticipated in the world before 2015.

There is a high risk that the EU Battery industry can't make decisions to invest in Europe until the market becomes a reality… with imported battery systems or cells, corresponding to a transfer of control of the E-mobility industry value chain to Asia. This may have negative consequences on the development of such a Battery Industry in Europe at short term. On the longer term, it is expected that the e-mobility industry will have a need for local manufacturing of the cells and batteries for a growing market. Under such conditions of Business-as-Usual, the control of the investment capital for battery manufacturing facilities will probably originate from non-European based companies.

Finally, the risk exists that the industrial development of the cell manufacturing in Europe is delayed, as well as the investment in the components manufacturing and recycling industry.

1.4. Conclusions.

A SWOT model has been used to summarize the conclusions of the analysis, presented in the table below.

European battery industry SWOT analysis for the E-mobility

	Positive	Negative
Internal	**Strengths** • Li-ion technology availability for e-mobility based on intensive usage and industrial experience in IT industry, and others. • High scientific level for materials R&D, well organized R&D structures in Europe. • Battery Cost and performance roadmaps available for H2020. • Historical presence of High technology battery industry in Europe. • Technical and legal base for « close loop » battery industry (including manufacturer, user, recycler and raw materials manufacturer).	**Weaknesses** • Battery price/performance still makes ICE mobility more competitive. • Limited R&D resources to innovate in Process (cell, and system manufacturing level) • Limited size of the industry in Europe, due to limited access to the asian IT industry, and high CAPEX consuming industry. • (supposed) temporary overproduction of Li-ion batteries in 2013!
External	**Opportunities** • Significant European local market anticipated for the E-mobility • Mobility industry in Europe (road, rail,..) is under competitive stress on a worldwide base: new employments at stake with the deployment of E-mobility.	**Threats** • Limited partnerships inside European E-mobility value chain, limiting market access confidence. • Transfer of control of E-mobility industry value chain to of Asia. • Market acceptance unclear, with several risks (cost/performance leading to low demand, safety, transport).

When placed in the context of the projected Roadmap for E-mobility, this analysis of the status of the EU Battery Industry raises questions about the potential success of the development of a European Battery Manufacturing Industry and its associated activities in the supply of raw materials, components, services, and end of life management.

1.5. Proposals in support of these Roadmaps. *(see overview in table A – p.8)*

At technical Roadmap level,

A “push-approach” to stimulate innovation for the E-mobility battery technology in Europe:
Programs supporting further performance improvement and price reduction of the Li-ion batteries, particularly at cell technology and battery technology level, to push and accelerate the introduction of innovation directly in the industrial applications, such as E-mobility. These fields of industrial technology and process are potentially rich in innovation, and still relatively open.

- Programs supporting a stronger cooperation between the battery industry and the OEMs industry may improve the efficiency of these developments (vertical programs).
- Programs supporting the consolidation of the European legislative base to support a « green circular economy » for batteries, i.e. establishing recycling qualitative and quantitative objectives, based on scientific calculation.

At industrial Roadmap level,

A “pull-approach” to avoid heavy investments without corresponding market opportunities. This means first an efficient business roadmap approach. In such a case, the Industry will invest locally according to the market need. Consequently, due to the lack of large industrial investments in battery industry in Europe, a progressive ramp-up of the industrialization in Europe should be promoted:

- Support for existing, and the investment of new components and battery manufacturing facilities
- Support to pilots for innovative processes introduction in Europe, particularly for weak parts of the supply chain (see chart below - in orange and red are represented the sectors with few or no corresponding industry in Europe):

	Raw materials	precursors	Materials	components	system	integration	Recycling
Cells	Mn,Co,Ni, PO4	Carbonates, oxides	Li metal oxydes, PO4				
Cells	Li , Graphites	Li carbonates					
Cells	Al, Cu	Sheets	Casings, electrodes				
Cells	Fe, Steel	Sheets	Casings,				
Cells	Polymers	polymers	Separators				
Cells	Organic chemicals	Carbonates, LiPF6	Electrolyte				
Cells				cells manufacturing			
Battery	IC industry		IC component	PCB, electrotech.			
Battery	Plastics industry		molding	Casings			
Battery					Battery assembly		
Vehicle	Automotive industry				OEM vehicle assembly	Battery integration	
Recycler							treatment

At business Roadmap level,

The success of the E-mobility industry growth in Europe is linked to a global cooperation of the industry.

1. European funding should support projects creating a vertical structure, associating technical partners from the industry, and public organisms contributing to the market growth (cities, regions, projects organisms), so as to:
   - Organize and create visibility for the global supply chain in the field of batteries for e-mobility (battery materials and components manufacturers, battery manufacturers, OEMs, customers and recyclers).
   - Create and support markets for the product, by providing local favorable conditions and/or global incentives and regulations.
   - Provide consumer confidence in the e-mobility products availability and services.

2. Different types of funded projects should be promoted to support and associate the partners according to the type of market (2wheels, EV/HEV, buses and trucks, rail...): i.e. associations of industry and Cities for urban e-mobility deployment (parking, fast charging stations,...), associations of industry and Regions for public transport (Hybrid or electric buses incentives, etc...).

3. Funding and projects should aim at the reduction of threats on the expected market:
   - Support of the Li-ion technology acceptance: safety management (communication, standards, etc), recycling objectives transparency, clear transport regulations adoption
   - Support of the product cost acceptance during the growth transition period:
     - Providing a clear horizon for the possible financial incentives
     - Valuing the environmental impact and advantages of E-mobility based on a global LCA analysis (CO_2 reduction values, including logistics in case of non-local manufacturing), objectives for regulating e-mobility in big cities
   - Funding and projects aiming at reducing unfair competitiveness risks, through support and protection of manufacturing, with high health and safety standards, with high quality and environmental standards.

As a conclusive remark, Recharge would like to underline the recommendation made by the Boston Consulting Group Study on the Electric vehicle market development (BCG, 2010):

"As it stands today, the stage is set for a shakeout among the various battery chemistries, power-train technologies, business models, and even regions. OEMs, suppliers, power companies, and governments will need to work together to establish the right conditions for a large, viable electric-vehicle market to emerge. The stakes are very high."

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Table A - Proposals (P) for the Battery Roadmap *(by RECHARGE - July 2013)*

Categories	2017	2021	2025
R&D for batteries	P1 - Push - cell technology and battery technology level. Accelerate the introduction of innovation directly into the industrial applications of E-mobility. These fields of industrial technology and processes are potentially rich in innovation, and still relatively open P2 - Pull - For engineering of battery systems, support a vertical integrated cooperation between OEM & battery industry	Continue fundamental R&DI for next generation of electro-mobility	
Deployment actions	Lithium-ion batteries to dominate the market (Asia-sourced)	P1 - Pull - for investment in manufacturing processes P2- Pull - Prepare manufacturing of battery integrated design into e-vehicle P3/P4 - Pull - Invest in industrial recycling processes adapted for EV and new recycling objectives	P1/2 - Pull - Vehicle with European battery integrated designed commercialized P6/P7 - Pull - Deploy accross EU the success stories
Financial support	P9 - Push - Study valorization of environmental impact of electro-mobility versus other systems	P6/P7 - Push - Creation and support of markets for the product, through local favorable conditions and/or global incentives and regulations. Define & communicate possible affordable financial incentives. P9 - Pull - Apply environmental valorization to electro-mobility	
Legislative measures	P4 - Push - Support the consolidation of a European legislative base for a « green circular economy » for batteries. Establish recycling qualitative and quantitative objectives, based on scientific calculations. P8 - Push - Adopt & communicate clear transport (including packaging) regulation for Li-ion batteries P10 - Push - Prepare regulation aiming at reducing unfair competitive risks. Support and protect manufacturing with high health and safety standards, with high quality & environmental standards.	P4/P8/P10 - Apply regulation	New CO2 and exhaust emission regulation ? - (68-78 gCO2/km ?) - EURO ?
Recycling - reuse	P3 - Push - Recycling processes to be adapted for EV		
Cost curve	400$/kWh 200kWh/kg	270$/kWh 250kWh/kg	<200$/kWh 300Wh/kg
Green corridors		P6 - Push - cities & regions to participate in field tests through local regulation, supporting e-mobility	P6/P7 - Push - Deploy in cities & regions accross EU according to successfully tested business model
Infrastructure	P5 - Push - Support pilot projects for innovative processes introduction in Europe. Focus on weak parts of the supply chain in Europe (active materials, cell components)	P5 - Pull - Develop industrial manufacturing base for battery components	P5 - Pull - Produce cells & components on industrial scale in EU
Business model	P6 - Push - support projects creating a vertical business structure, associating technical partners from the industry, and public organisms contributing to the market growth (cities, regions). Structure market access. P7 - Push - Different type of funded projects should be promoted to support and associate the partners according to the type of market (2wheels, EV/HEV, buses and trucks, rail...) - deploy according to P6	P6 - Push - product acceptance through field tests & consolidation of market size	
User awareness & Education & Training	P8 - Push - Support Li-ion technology safety management (communication, standards, etc) in usage, transport, collection (battery information sheet)	P6 - Push - Information to consumers on test results of success stories	

2. Introduction

This document aims at identifying some of the expectations of the Battery Industry in the framework of the desired development roadmap in the electric mobility. It covers several aspects, from the technologies to the business requirements.

In the time scale of this program (Horizon 2020), technologies were only considered that are already in a significant state of industrialization and deployment, and that can have a valuable contribution to the market in 2020.

Many new technologies are under study or development for electrical energy storage: after the fuel cells, there is now a hype around lithium air, graphene, or other systems like Lithium sulfur. Nevertheless, their state of development is too early to evaluate their competitiveness after a future industrialization: performance, robustness, cost are largely uncertain. In addition, waiting for a "perfect" battery before moving on in the development of the electric car is not a constructive position. Doing this may be suicidal for the battery industry: future breakthroughs cannot be anticipated precisely neither on timing nor on content.

"Automotive propulsion batteries are just beginning the transition from nickel metal hydride to Li-ion batteries, after nearly 35 years of research and development on the latter. The transition to Li-air batteries (if successful) should be viewed in terms of a similar development cycle.[47]*"*

47 Lithium-Air Battery: Promise and Challenges G. Girishkumar,* B. McCloskey, A. C. Luntz, S. Swanson, and W. Wilcke, IBM research 2010.

On the contrary, our position is to present what can be expected from the available technology. The introduction of technology improvements will anyway require significant time: the necessary time to industrialize and commercialize a product once the development is considered finalized (i.e. prototype tested and validated by the Original Equipment Manufacturer – in this case typically the car manufacturer) is around 5 years (Fig. 1).

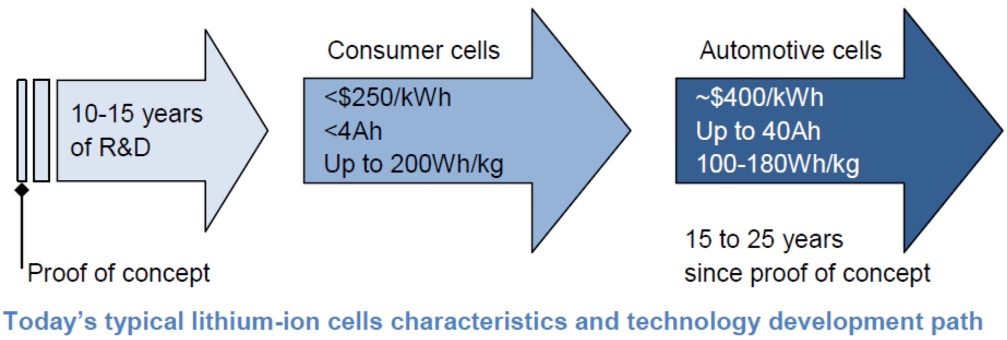


Fig. 1. Source "Element Energy", March 2012

Lithium-ion batteries are the reference technology for plug-in and full electric vehicles (PHEVs and BEVs) of the coming years. While other types of batteries, including lead-acid and nickel-metal hydride (in the first generation of the Toyota Prius hybrid) will continue to retain considerable market share in the short term, lithium-ion batteries are expected to dominate the market by 2017 (ref. 7: Deutsche Bank, 2009). Compared with other relevant battery types, lithium-ion batteries have the highest energy density (Fig. 2). Their cost is rapidly decreasing.

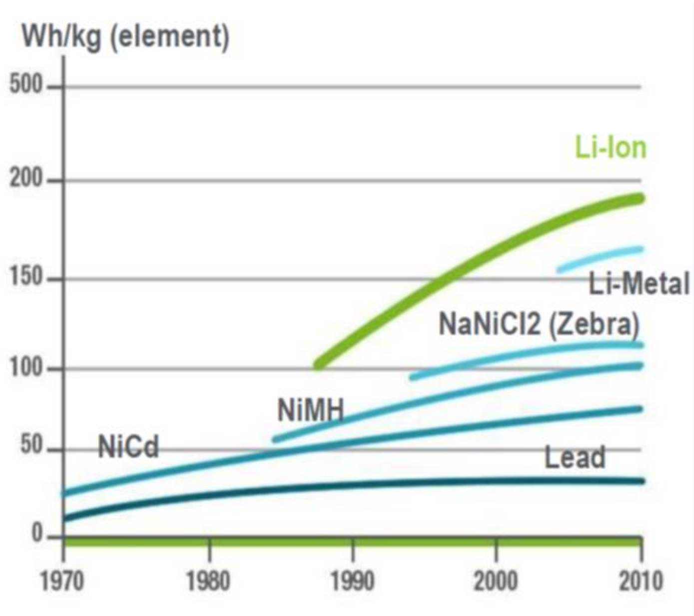


Fig. 2 : Source: Daimler 2011

Significant further improvements of the technology are expected in the coming years, since the status of maturity of the Li-ion is considered in the mid of the classical "S shape" curve of development.
The Li-ion technology includes several chemistries.
All Lithium-ion technologies are based on the same principle: Lithium-ions are stored in the anode (or negative electrode), and transported during the discharge to the cathode (or positive electrode) in an organic electrolyte (Fig. 3). The most popular materials are graphite for the anode, and a metal oxide for the cathode, based on Nickel, Manganese and Cobalt. All of these materials have good Lithium insertion or intercalation properties, allowing the large amount of energy storage.

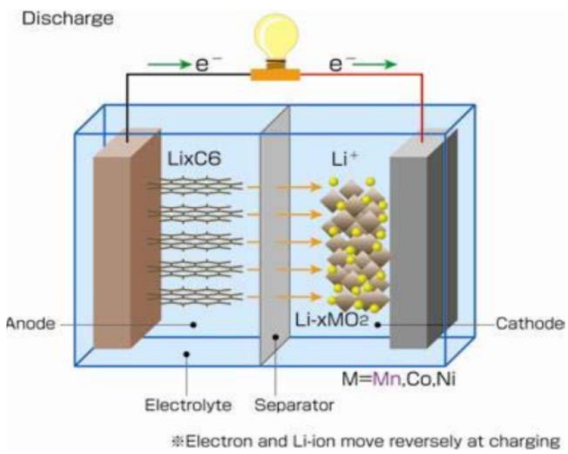


Fig. 3 Source: (Automotive Energy Supply Corporation, 2007)

Nevertheless, several oxide types, and several cathode types can be used, providing significantly different performances to the batteries.

Name	LCO	LNO	NCA	NMC	LMO	LFP	LTO
Full name	Lithium Cobalt Oxide	Lithium Nickel Oxide	Lithium Nickel Cobalt Aluminium Oxide	Lihium Nickel, Manganese Cobalt Oxide	Lithium Manganes e Spinel	Lithium Iron Phosphat e	Lithium Titanate
Cathode	LiCoO2	LiNiO2	Li(Ni0,85Co0,1 Al0,05)O2	Li(Ni0,33Mn0,33Co0,33)O2	LiMn2O4	LiFePO4	e.g.: LMO, NCA, …
Anode	Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	Li4Ti5O12
Cell voltage	3,7 - 3,9V	3,6V	3,65V	3,8 - 4,0V	4,0V	3,3V	2,3 – 2,5V
Energy density	150Wh/kg	150Wh/kg	130Wh/kg	170Wh/kg	120Wh/kg	130Wh/kg	85Wh/kg
Power	+	o	+	o	+	+	++
Safety	-	o	o	o	+	++	++
Lifetime	-	o	+	o	o	+	+++
Cost	--	+	o	o	+	+	o

Daimler analysis, Nationale Plattform Eletromobilität, 2010.

The selection of a battery technology depends on the application requirements regarding performance, life, safety and cost, with each battery type providing specific functionalities.The battery technology is often characterized by type of cell format.

Main type of cell format used for the Li-ion batteries are the following:

- hard case cylindrical or prismatic : these cells are generally having an aluminium with laser-welded or crimped cover. They contains liquid electrolyte (Fig. 4 and 5).

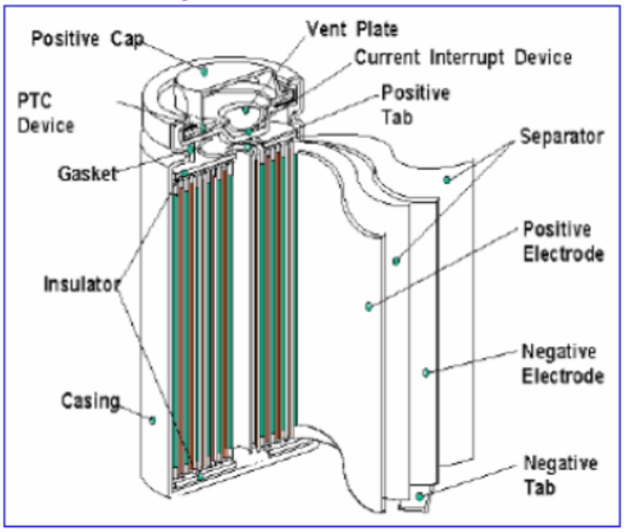


Fig. 4: cylindrical Li-ion cell

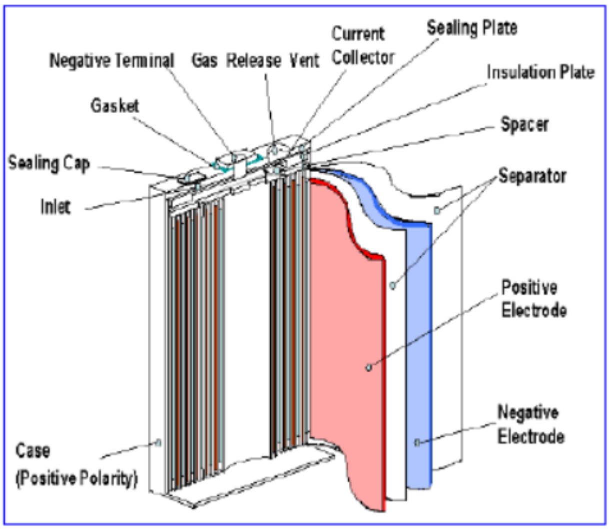


Fig. 5 : prismatic Li-ion cell

- Soft case or « pouch cells »: these cells are using a thin aluminized plastic as a bag, glued with different type of polymers for the tightness. In general, they contain electrolyte in a polymer, reason why they are often called “lithium-ion polymer” (Fig. 6).

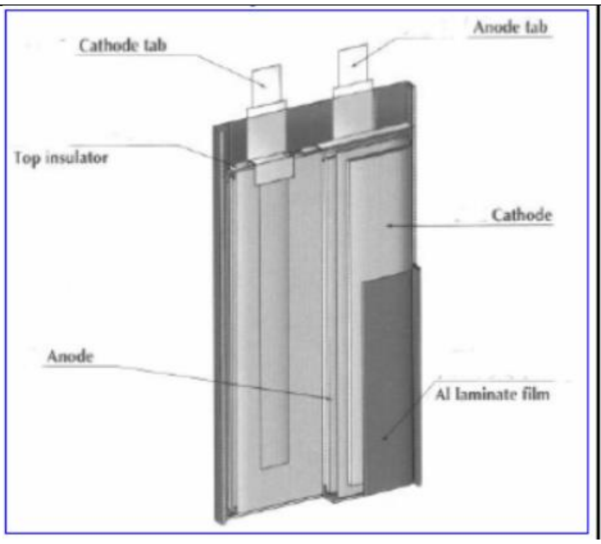


Fig. 6 Li-ion polymer cell

The cells are assembled to form battery packs and batteries, embedded in hard casing with electro-technical and electronic Battery Management Systems (BMS). The battery pack format and voltage is independent of the cell type, as shown in the graph of E-mobility battery sizes. The functional risk associated with batteries is the electrical risk (safety regulations changes above 60V) (Fig. 7).

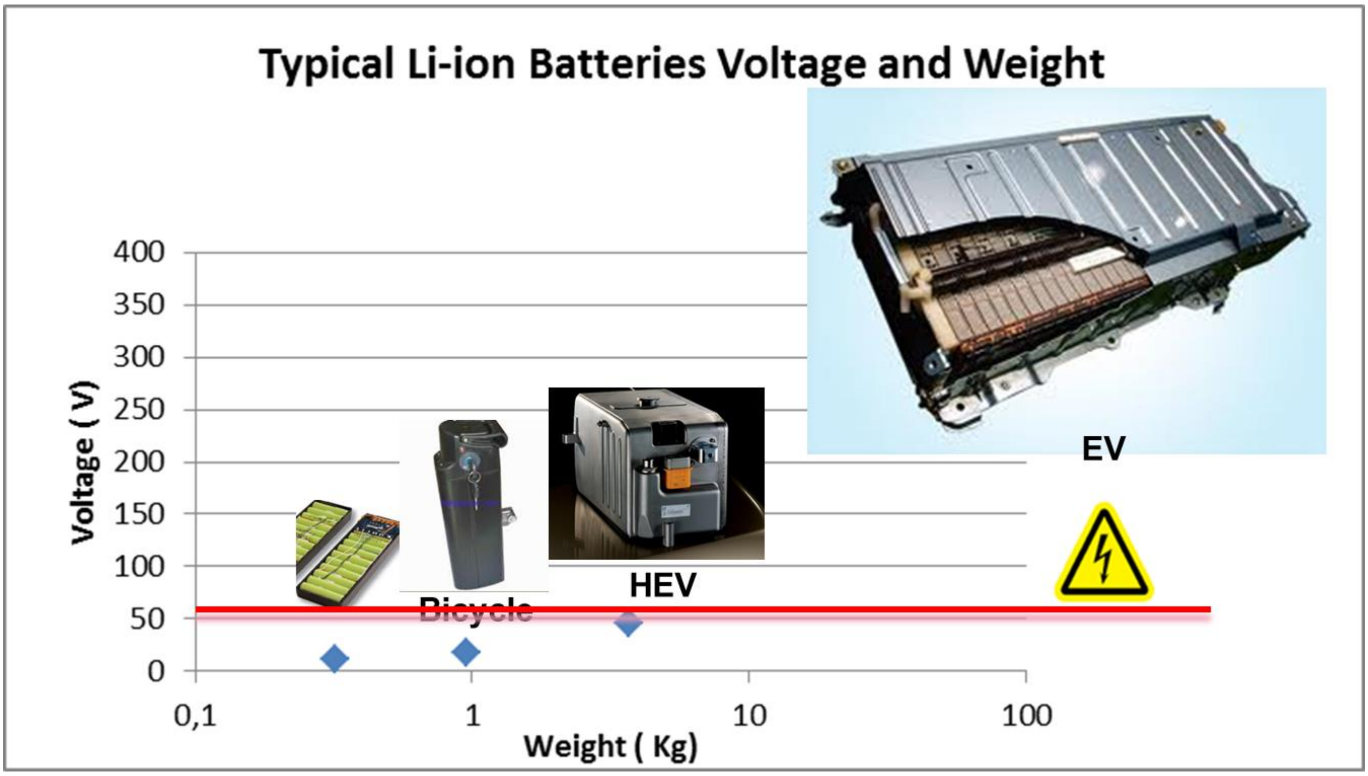


Fig. 7 : Li-ion batteries voltage and weight

A Li-ion battery is system-optimized to store and release energy according the user request. The technical criteria used to measure the efficiency of an energy storage system are the power and the energy density.

The objective of the technology is to optimize these criteria according the function required. An example below is given for the energy storage systems considered in E-mobility: the batteries still store much less energy than the liquid fuels (Fig. 8).

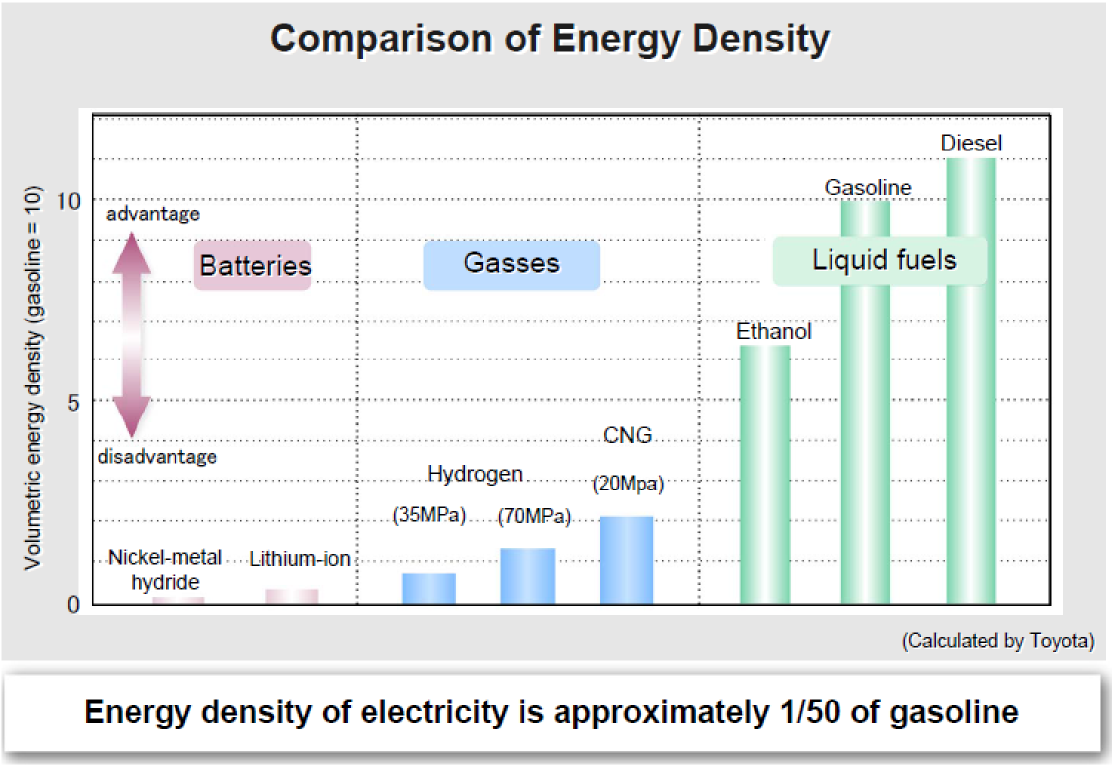


Fig. 8. Source : Toyota

3. Technical Roadmap

3.1. Worldwide funding programs and objectives

International support for battery R&D and industry development is considerable. The split of funding between R&D and industrial development varies by country; government support for these activities also varies widely.

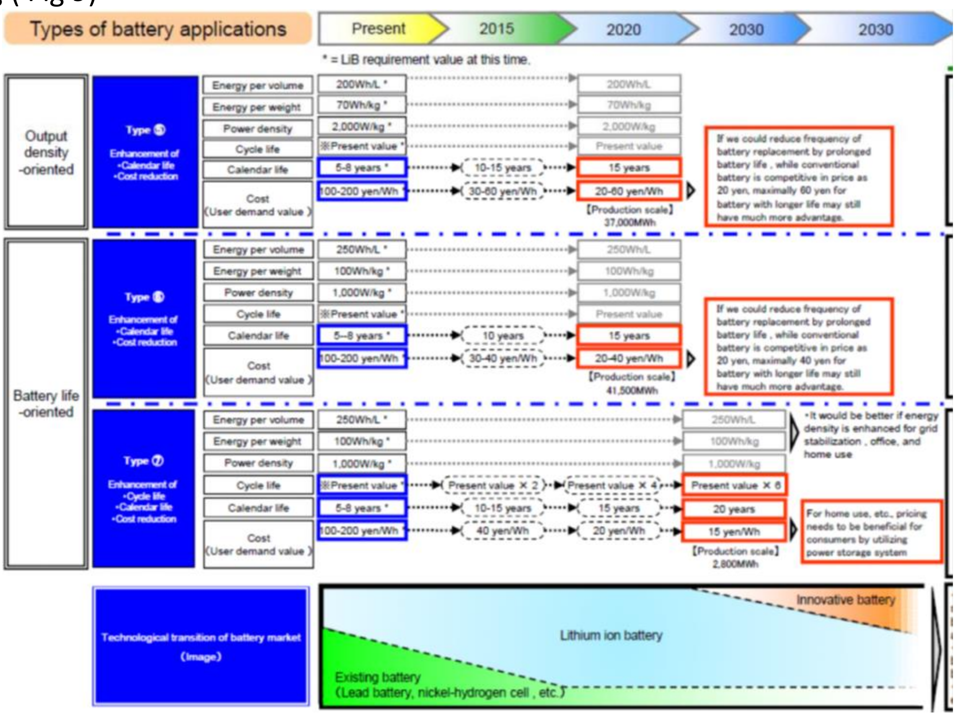
National R&D programs are a relatively small proportion of the total investment in battery R&D worldwide; a single battery manufacturer can invest the equivalent of an entire country's R&D budget. This is true even in the US where the government budget for battery R&D was $76 million in 2010; by comparison GS Yuasa (a Japanese battery manufacturer) invested $76 million in 2011.

Industry funded R&D is highly secretive and often a new technology (R&D stream) is only known about in press releases before mass manufacture, or through patent applications. A large proportion of world battery R&D is carried out in this way by companies such as: Panasonic/Sanyo, Samsung, Sony, Toshiba, LG Chem, Mitsubishi, Hitachi, Toyota, GS Yuasa, Lishen, BYD and 3M. Due to their secretive nature, the R&D spent on automotive batteries for the majority of these companies remains difficult to estimate.

The USA and Japan have announced funded programs for battery development.

3.1.1. Japan

NEDO has published in 2010 the description of technical performance and cost objectives for the Li-ion batteries. Typical expectations for the energy batteries are the improvement of life duration to 15 years and reduction of cost by more than 50% (200-400 $/Wh for EV batteries). EV batteries are expected to reach 250 Wh/kg (Fig 9)



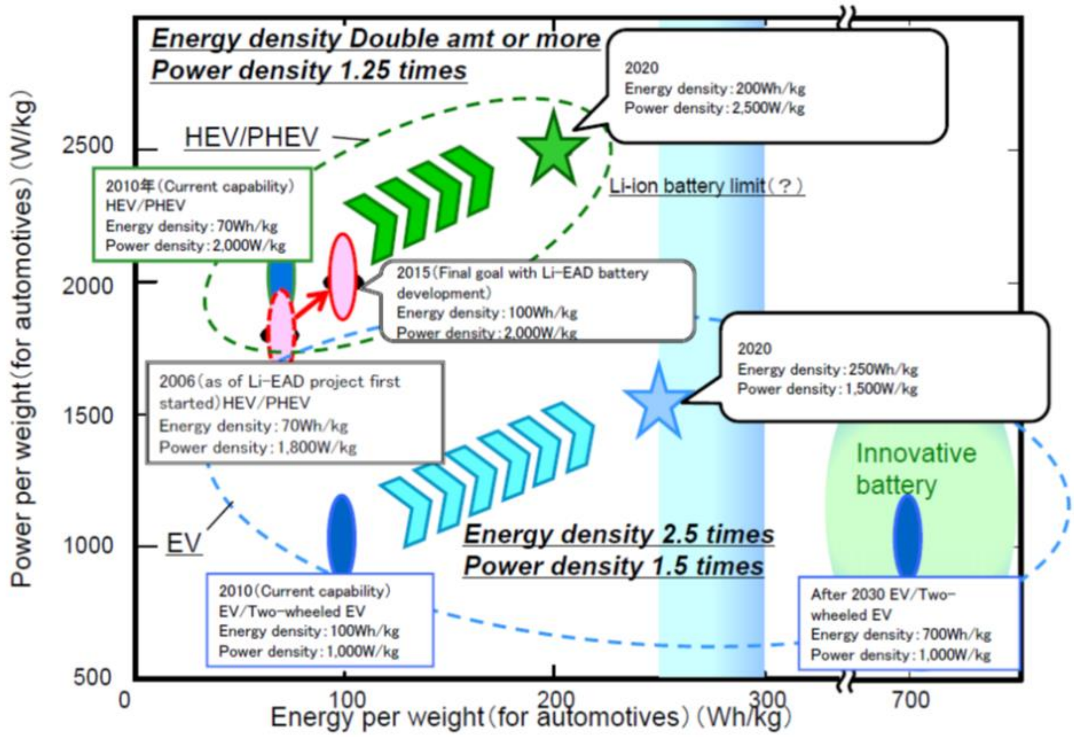


Fig. 9: Source: French Embassy in Japan

To reach these objectives, the NEDO has set-up several programs, with a global funding of 7,7 billion yens.

Outline of NEDO's Program :

Project	Main Target	Period	Budget in FY 2011
Research and Development Initiative for Scientific Innovation of New Generation Batteries (RISING)	Analysis of Battery Reaction Mechanism - Guideline to develop new material for LiB - New Materials for Post LiB	2009-2015	3,000
Development of High-performance Battery System for Next-generation Vehicles	Battery Module for PHEV - New Materials for LiB limitation, Post LiB	2007-2011	2,479
Speedy Innovation of Li ion And next Generation battery material's Evaluation R&D -	Battery Material's Evaluation y Cell Optimization	2010-2014	250
Electric Energy Storage System for Grid-connection	Low Cost, Long Life, Safety System	2011 2015	2 000
Total		In Million JPY	7,729

Japanese companies, such as Toyota, are transposing these objectives on their own roadmap (Fig.10).

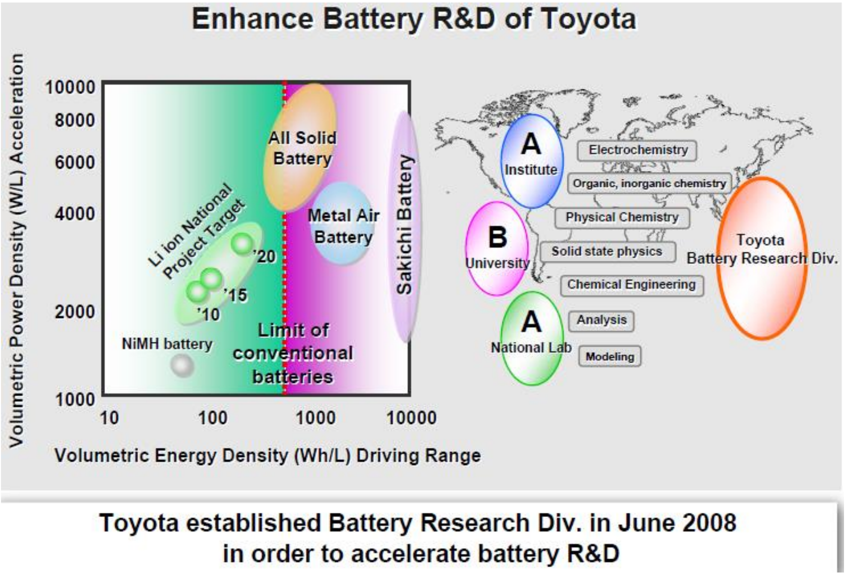


Fig. 10 : Source Toyota

3.1.2. USA

Several programs are supported by the Department of Energy (DOE) : see for example the chart describing the funding for the DOE "EV Everywhere Grand Challenge", 2012-2022, Fig.11.

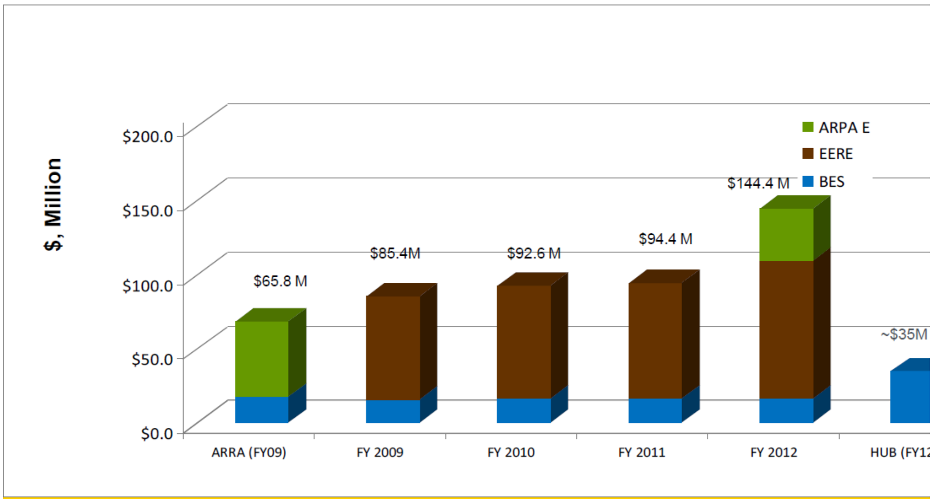


Fig. 11 : source DOE 2012

- Office of Science/Basic Energy Sciences (BES): Fundamental research to understand, predict, and control matter and energy at electronic, atomic, and molecular levels.
- Advanced Research Projects Agency – Energy (ARPA–E): High-risk transformational research with potential for significant commercial impact.
- EERE Vehicle Technologies (VTP): Applied battery R&D to enable a large market penetration of hybrid and electric vehicles.

The DOE program is covering a broad range of technical developments, from active material research to battery system development.
The typical values of performances expected are in the same range as the Japanese ones. Cell Targets performances at 200-300 Wh/kg with 10+ calendar year life and $300/kWh pack cost HEV.
Battery Pack Targets at $100-150/kWh for electric vehicles (Fig.12).

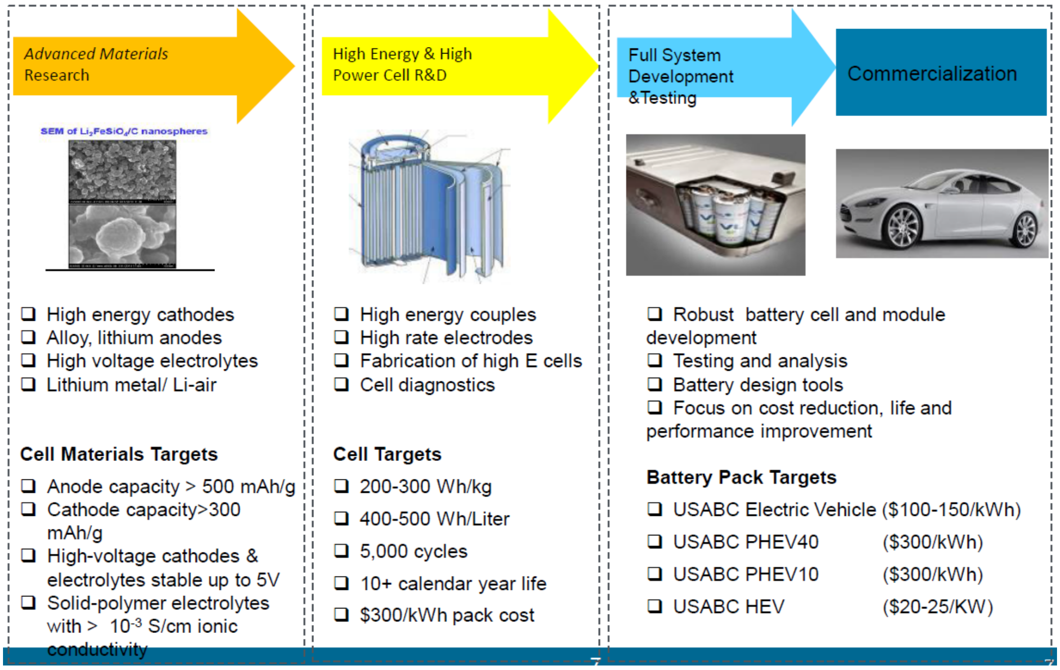


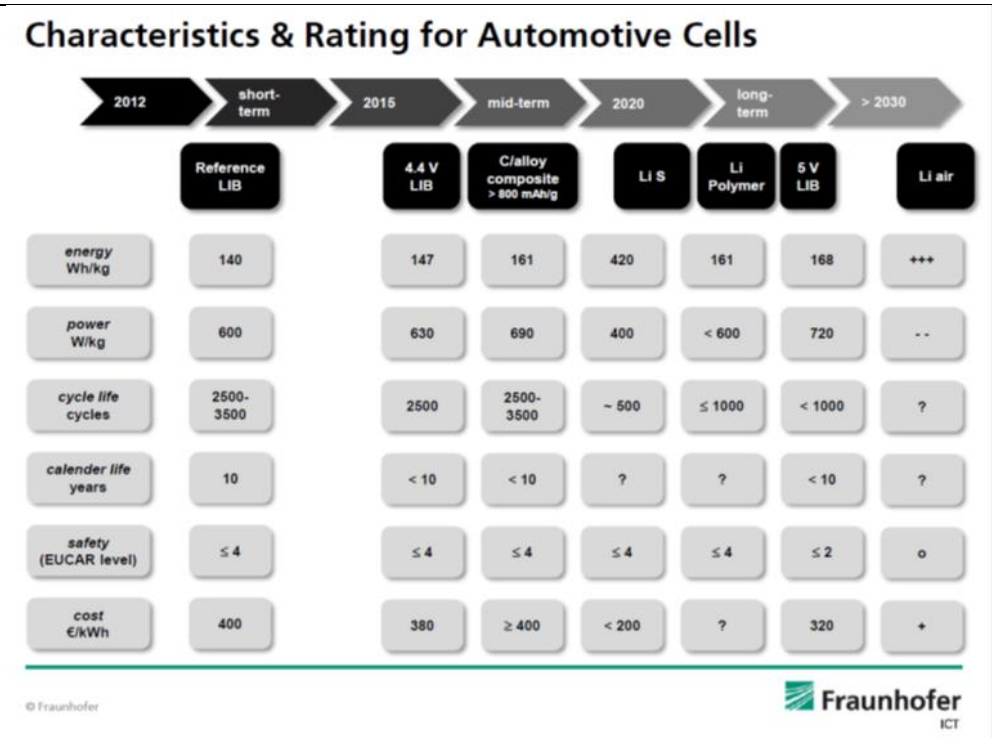
Fig.12. Source DOE 2012

3.1.3. Europe

There are to our knowledge no identified European funding schemes with a clear target description as presented for the USA and Japan. Nevertheless, several organizations are structuring the road map for the electro-mobility, including the energy storage systems. In particular, the European Green Car Initiative is following the R&D programs including Batteries (Ref.10). The objectives were set based on workshop and studies, with objectives resumed in the table here below: joint EC/EPoSS/ERTRAC Expert Workshop 2009/ Dr. Gereon Meyer:

Batteriesfor EVs	today	2012	2016	2020
Energy Density(cells)	140Wh/kg(200 for laptop batteries)	220Wh/kg(140-300)	300 Wh/kg(150-500)	450 Wh/kg(250-700)>1000 (LiO2)
Lifetime(calendar life)	7 yrs.(lack of reliable data for EV)	9 yrs(8-10)	11 yrs.(10-12)	17 yrs.(10-20 yrs)
Cost(cells)	700 Euro/kWh	500 Euro/kWh(350-600)	400 Euro/ kWh(250-500)	250 Euro /kWh(200-300)100 (LiO2)

More recently, the Fraunhofer- institute has published a study of energy storage for electro-mobility, describing a technical roadmap for the Li-ion batteries. The objectives in 2020 seems relatively coherent with the USA and Japan roadmaps, although less ambitious in costs (Fig.13).



	Reference LIB	4.4 V LIB	C/alloy composite > 800 mAh/g	Li S	Li Polymer	5 V LIB	Li air
energy Wh/kg	140	147	161	420	161	168	+++
power W/kg	600	630	690	400	< 600	720	- -
cycle life cycles	2500-3500	2500	2500-3500	~ 500	≤ 1000	< 1000	?
calender life years	10	< 10	< 10	?	?	< 10	?
safety (EUCAR level)	≤ 4	≤ 4	≤ 4	≤ 4	≤ 4	≤ 2	o
cost €/kWh	400	380	≥ 400	< 200	?	320	+

Fig.13 : Source Fraunhoffer

Finally, Element Energy has published in 2012 a report for the Committee on Climate Change , on "Cost and performance of EV battery". This report is summarizing several studies and models to anticipate the performances and cost of the Li-ion EV battery in 2020. The model indicates a cost reduction of 50% at pack level, reaching 330$/kWh, for an energy density of 150 Wh/kg (Fig.14). Once again, these objectives are close to the one of the US and Japanese programs, although less ambitious in the cost reduction prevision. This study will be used several times as a reference for this document (Ref.8).

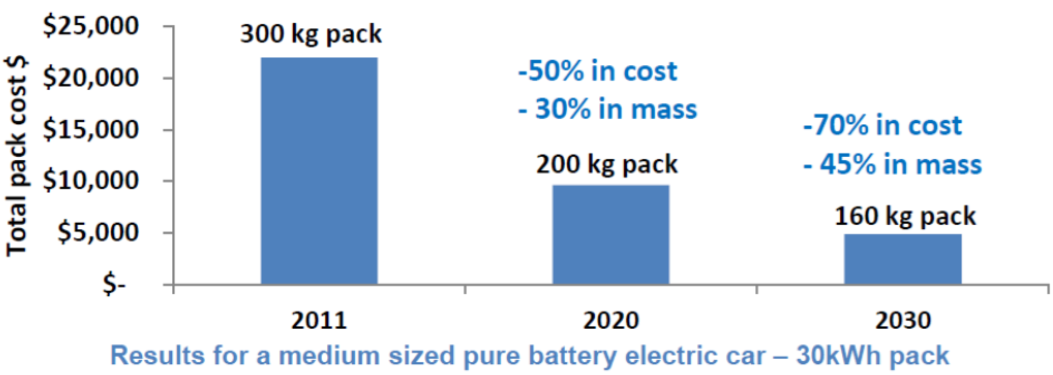


Fig.14 : Source Element Energy

3. 2. Fields of innovation

3.2.1. Active Materials

Concerning the active materials, all roadmaps are integrating the on-going research programs on new materials worldwide.

Many similarities can be found between the roadmap from the DOE, and the one from Fraunhofer Institute (Fig 15 and 16):

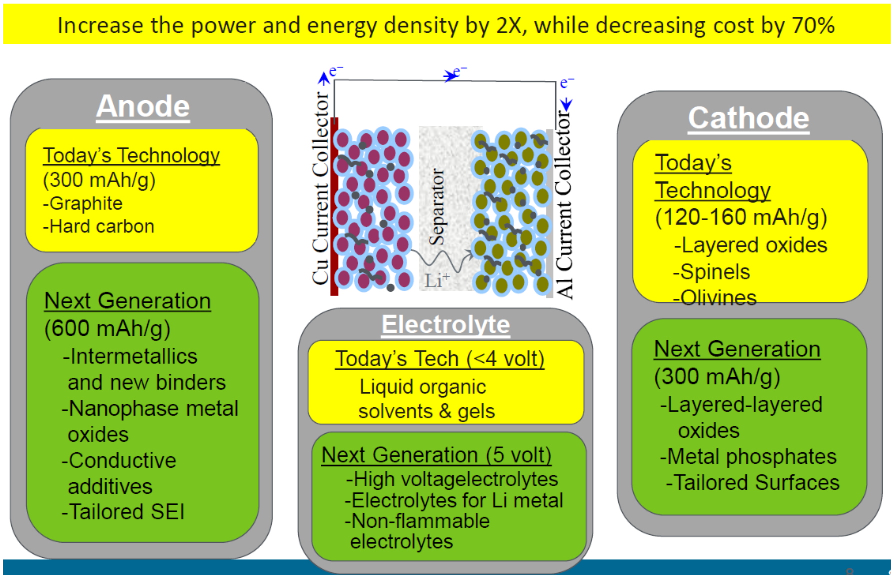


Fig.15: New battery components of interest: list from DOE

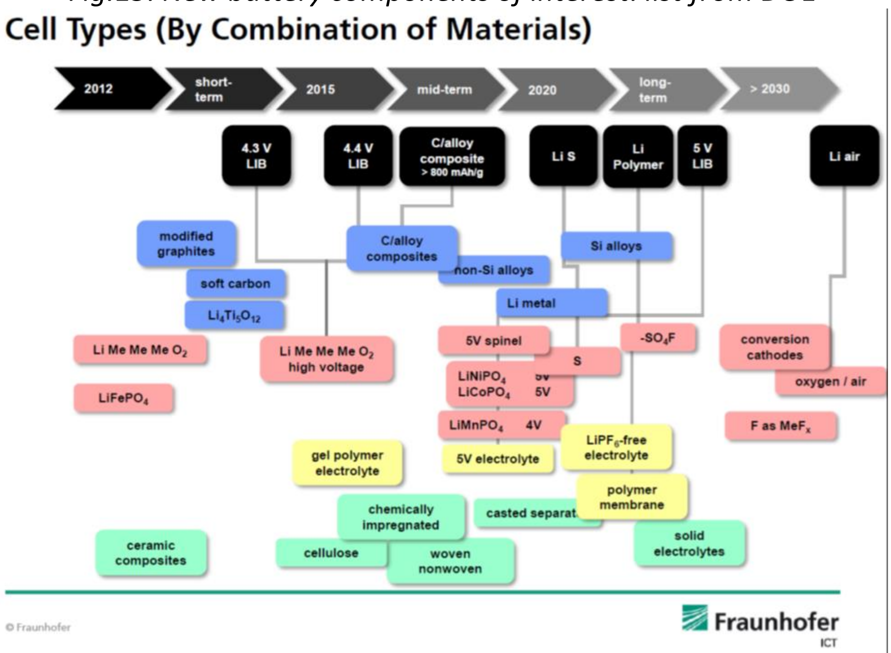


Fig. 16: List of battery components of interest from Fraunhofer:

European proposal

A top down approach can give confidence that a performance improvement program will be successful: the chart on the performance progress over years (see introduction) proves the constant progression of battery performances. Nevertheless, we have to remember that such a progression has been obtained in specific conditions: a huge development of the communication industry, creating a large market and associated investments. We have to take care that similar conditions will push for investment in the e-mobility industry.

Based on an exhaustive study of the on-going technical developments, the list of candidate materials proposed either by Fraunhofer or Element Energy allows the construction of a bottom-up approach.

This list should not be limitative: depending on manufacturer's objectives and background, the selected subject to be passed from Research to Development may change. Some of the expected performance improvements are described below, based on Element Energy analysis:

Cathodes properties : metal oxyde	**Current NMC**	**Adv. NMC potential**	
Theoretical capacity (mAh/g)	280	300	
Reversible capacity (mAh/g)	140	200	
Voltage vs Li/Li+ (V)	3.7	3.7	
Cathode properties : Phosphates/sulfates	**Current LFP**	**LMP potential**	**Li(M)SO4F potential**
Theoretical capacity (mAh/g)	170	170	170
Reversible capacity (mAh/g)	130	150	150
Voltage vs Li/Li+ (V)	3.4	4	5

Anodes properties	**LTO**	**Graphite**	**Silicon**
Type	Intercalation	Intercalation	Alloying
Theoretical capacity mAh/g	175	330	4200
Voltage vs Li/Li+ (V)	1.5	0.1	0.1
Current collector	Aluminium	Copper	Copper
Main drawbacks	Low voltage & low energy density cell	Safety issues	Volume expansion (up to 300%), poor cycling ability
Development status	New product, in series car in 2012	Commonly used	Si/C alloys used in some consumer cells

It is worth noting that not all chemistries included in the roadmap would be suitable for both BEV and PHEV.

For example, today's composite cathodes (layered-layered like Li(M)SO4 F) show poor power capability and are thus unlikely candidates for PHEV cells.

As a result of these detailed objectives per material, and the maturity of the different research programs, a roadmap of the technical performance can be anticipated (Fig. 17):

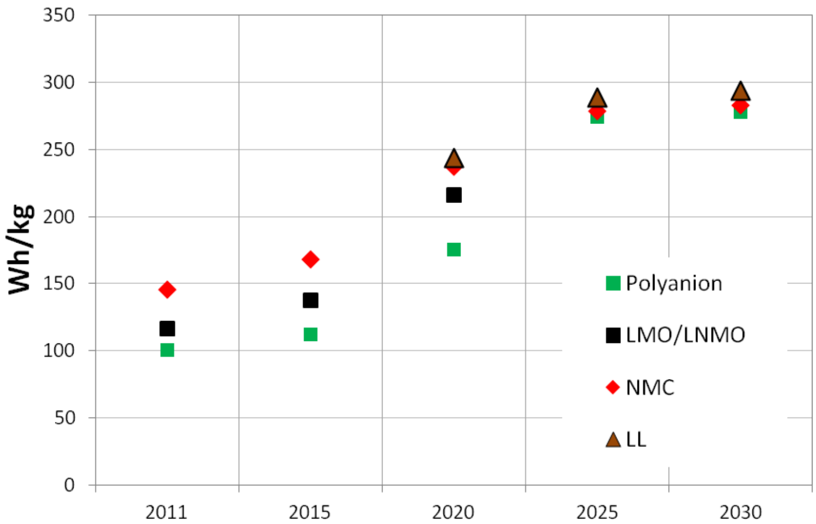


Fig 17: road map of technical performance for active materials. Source Element Energy

In Europe , the R&D work on these new materials is integrated in a quite well organized infrastructure:

- Universities have created Research poles to support these materials studies (for example the European network ALISTORE-ERI).
- Research Institutes like Fraunhofer in Germany or CEA in France are very active the field of Battery materials.
- The Industry is involved through direct internal work and associated programs (using private or National and European funding - see ref. 7: list of European program FP7 in the Project Portfolio of European Green Car Initiative PPP: AMELIE, APPLES, ESTRELIA, EUROLIION, GREENLIION)

Some specific measures may be taken to ensure the key European objectives are taken in account:

- Raw materials Initiative: In the list of materials cited, no critical new metals are identified with scarcity risks. Li and Co are already used, newcomers may be Silicium, Tin , Manganese/ Iron phosphate or Sulphate: all materials seem to be abundant.
- Recycling efficiency and local recycling: this will be considered in the specific “recycling” paragraph.

Conclusion: In the field of new materials research, a lot of studies are ongoing. This gives some visibility on a roadmap with quantified goals for Europe. The existing infrastructure associates Industry, Research Institutes (such as Fraunhofer in Germany, CEA in France) and Universities networks. These programs are often supported by European Funding schemes.

3.2.2. Cells technologies and processes

The cell design and technology are key contributors to obtain the best service from the active material used. They are selected to fit the product application, thus creating performances differences between “energy optimized” products, used in the pure electric vehicles and “power optimized” products, used in hybrid vehicles.

As an example is described below the thickness of the electrodes as a limiting factor: for a given chemistry, the electrodes have a maximum thickness, limited by their capability to provide the power requirement of the application. High power products, such as the one requested by the HEV application, have to integrate thinner electrodes, requiring more conductive substrate, and limiting the amount of active material. In typical high energy cells, the active material represents 60 to 70% of the weight, but only 20 to 30% in very high power cells. Consequently, the HEV batteries present a lower specific energy (Wh/kg) and a higher cost (€/Wh) (Fig.18).

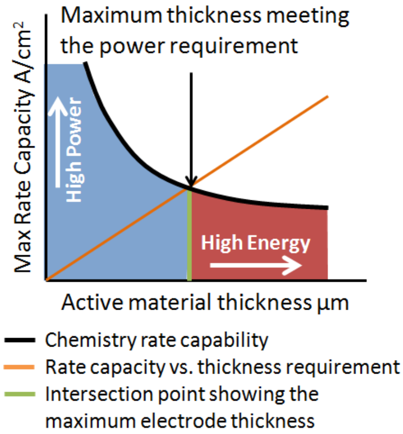


Fig. 18 Source « Element Energy », March 1012

Another area of cell technology development is the type of cell enclosure: it is generally considered that the "pouch cell" design (using a flexible film of polymer and Aluminum, closed with a polymer glue) is offering technical advantages versus the traditional "hard case" design (Aluminum welded can, prismatic or cylindrical). There are known weaknesses of "pouch cell" technology: lack of tightness over long duration, and fragility to mechanical stress. These weaknesses are being progressively reduced with technology developments, ensuring now better life duration (more than 10 years) and integration in systems for mechanical protection. This technology is now widely used in Asia with relatively large cells for the electronic tablets market.

Manufacturing Processes are also of key importance for cost and performance optimization. The DOE in the USA program emphasized a specific roadmap in this field (Fig. 19):

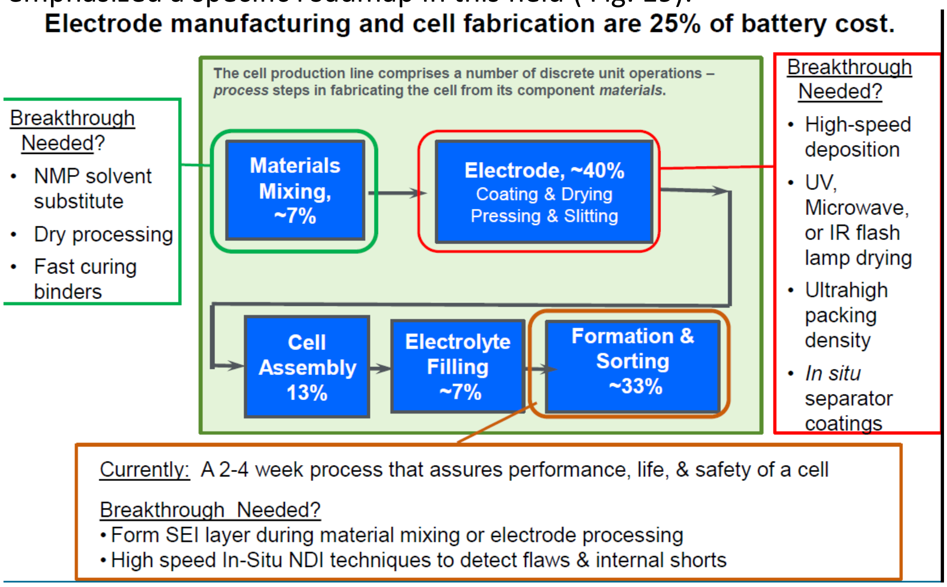


Fig.19 source DOE 2012

Future Trends:

All Li-ion chemistries will continue to develop in portable, automotive and industrial applications.
Technological advances in cathodes, anodes and electrolytes have the potential to greatly improve battery capacity by reducing the amount of both active and non-active material needed per kWH.
R&D efforts into these improvements are being driven by the consumer electronics market for smaller cells. It has to be noted that most of these are made in the Asian countries, where are the battery suppliers for this market.

In Europe, these cell technology topics are generally integrated in industrials programs, due to their nature: they are often associated with the industrial manufacturing process and equipment. Universities have a more limited access to this field. Among the few Process development programs running in Europe, we can describe the program ELIBAMA, launched in 2011: The ELIBAMA (European Li-Ion Battery Advanced MAnufacturing) project aims at enhancing and accelerating the creation of a strong European automotive battery industry structured around industrial companies already committed to mass production of Li-ion cells and batteries for EVs. This project is part of the European 7th Framework Program and of the European Green Cars Initiative (http://elibama.eu/).

Nevertheless, compared to the large R&D investments made in Asia in this field, and the limited size of the Battery industry in Europe, we consider that this part of the battery technology in Europe has a limited support.

Conclusion: In the field of cells technologies R&D, the dominant position of the Asian Battery Industry for the telecom and PC market support their leadership in R&D investment. Progress objectives have been decided in Europe, mainly supported by the industry. Due to the nature of the work, the Universities have a limited involvement in this subject.
Design and Eco-design of Electrodes, electrolyte and cells for automotive application, and more generally for e-mobility will require significant effort in order for Europe to remain competitive.

3.2.3. Battery Systems

Battery performance requirements depend on the vehicle application. Two important factors determine battery performance: energy, which can be thought of as driving range, and power, which can be thought of as acceleration. The power-to-energy (P/E) ratio shows how much power per unit of energy is required for the application (DOE, 2007). The Fig. 20 shows how deeply batteries are charged (state of charge) when they are used in different applications:

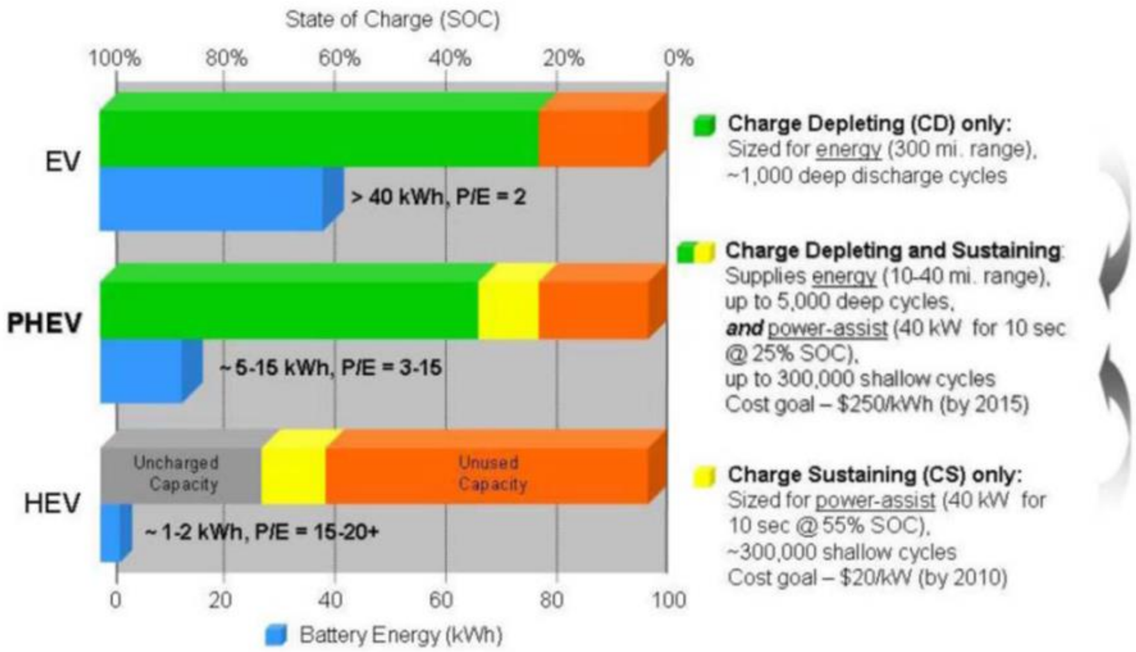


Fig. 20 : Source CGGC

- **HEVs**: Most HEVs use batteries to store energy captured during braking and use this energy to boost a vehicle's acceleration. The battery in an HEV is required to store only a small amount of energy, since it is recharged frequently during driving. Batteries for HEVs have a "shallow cycle,"—which means they do not fully charge—and they are designed for a 300,000-cycle lifetime. Because of these cycle characteristics, HEV batteries need more power than energy, resulting in high P/E values ranging from 15 to 20. The battery capacity is relatively small, just 1-2 kilowatt-hours (kWh) (DOE, 2007).
- **PHEVs**: PHEVs are hybrid vehicles with large-capacity batteries that can be charged from the electric grid. With their larger battery capacity, 5 to 15 kWh (DOE, 2007), PHEVs use only their electric motor and stored battery power to travel for short distances, meaning that PHEVs do not consume any liquid fossil fuels for short trips if the batteries are fully charged (Hori, 1998). After battery-stored energy is depleted, the battery works as an HEV battery for power assisting. Thus, a PHEV battery needs both energy and power performance, resulting in a medium P/E range of 3-15. In other words, PHEV batteries require both shallow cycle durability—similar to HEVs—and deep cycle durability.
- **EVs**: EVs only use an electric motor powered by batteries to power the vehicle. Batteries for EVs need more energy capacity because of longer driving ranges, so EVs have the lowest P/E factor. The battery gets fully charged and discharged (deep cycles) and requires 1,000-cycle durability. The battery size of EVs is larger than that for PHEVs or HEVs. For example, the Nissan Leaf has a 24-kWh capacity (Nissan USA, 2010). Lithium-ion battery packs for compact EVs will use 1,800 to 2,000 cells (METI, 2009b).

These large differences in battery performances and functions are generating a large field of innovation for the systems technologies:

The Battery Management System (BMS):
The battery management system can be compared to the cells li-ion chemistry and cells technology for the innovation potential: new developments can bring significant improvement in performance and safety, while reducing the cost. The electric energy management for the e-mobility has created at least two new fields of technical innovation:

- The power electronics for mobile systems: Up to recent years, the power electronic components were mainly used in stationary applications. The e-mobility creates the need of small, light and mechanically resistant components adapted to the power and voltage of electric vehicles.
- The battery control and management electronics: New generation of electronics are being developed, based on new IC components, integrating more functionality in less space. Reducing the number of components also increases the reliability of the systems.

The Battery mechanical integration:
This part is highly dependent on the options selected by the OEM integrating the battery: Design, modularity, new technologies usage are often decided by the OEM according the objectives and design options of the vehicle. Parameters such has vehicle weight balance, geometry of battery interface, safety protections integration and maintenance options depends on the global vehicle design.
Nevertheless, innovation in this field can also provide significant performances improvement and cost reduction, as described in the table below

Pack production	Cell materials	Pack components
Cheaper as fewer cells to handle and test per kWh on the production line. Greater active material Wh/kg (mAh/g and/or voltage) also means less cell material to handle in the plant.	A greater active material Wh/kg means less material to purchase per kWh. This translates in a cost reduction *if the material cost per kg does not increase when mAh/g and/or V increase.*	Fewer cells to connect and monitor: cost reduction in BMS, wiring harness and interconnectors. Smaller pack volume reduces the housing cost

Battery Integration in EV/HEV has just started in Europe with dedicated vehicle platforms (for example ZOE from Renault): still a lot of progress is expected. As this field of innovation is perceived as a competitive area by the automotive manufacturers, the R&D is mainly driven by the automotive and electronic industry.

We can worry about the point that a lack of shared vision of the roadmap objectives, particularly with the battery industry, may hinder the Battery industry development in Europe. Most FP7 European funded programs about vehicle integration, such as E-Future, MAENAD, POLLUX, PMOB, WIDEMOB, or others, have no Battery Manufacturers in the partnership.

Conclusion: The battery technology development is for a large part in the hands of the OEM's. Benefitting of the relative strengths of the European automotive industry, a competitive development effort can be expected for the battery system technologies. A stronger cooperation with the battery industry may improve the efficiency of these developments.

3.2.4. Recycling

Due to the chemistry of the new generation of Li-ion batteries, no need for new recycling technology development is expected. Nevertheless, processes will have to be adapted for recycling of the Electric Vehicle batteries, due to their dimensions and energy content (safety). The programs should support the European initiatives:

1. The Raw Materials Initiative

   The recycling of materials used in batteries is a critical element of the life cycle of a rechargeable battery. The recovery of materials is operated by more energy efficient processes than the production of primary materials.

12. The Resource Efficiency policy

   The Resource Efficiency policy should not only consider the optimization of the recovery of valuable resources in Europe but it should also integrate the future of the European Industry. Indeed the recovery of raw materials in an efficient manner in Europe should in priority feed the European Manufacturing Industry. In this respect the EU legislation should consider that the EU Industry cannot be placed in a less competitive position than its partners at a global scale.

To increase the efficiency of material collection for recycling, a number of regulatory instruments are already applicable, such as the Eco-design Directive, the Directive on End-of-Life Vehicles, the Directive on Waste Electric and Electronic Equipment, the Batteries Directive and the Waste Framework Directive. The interface between these legislations is a challenge (Fig 20).

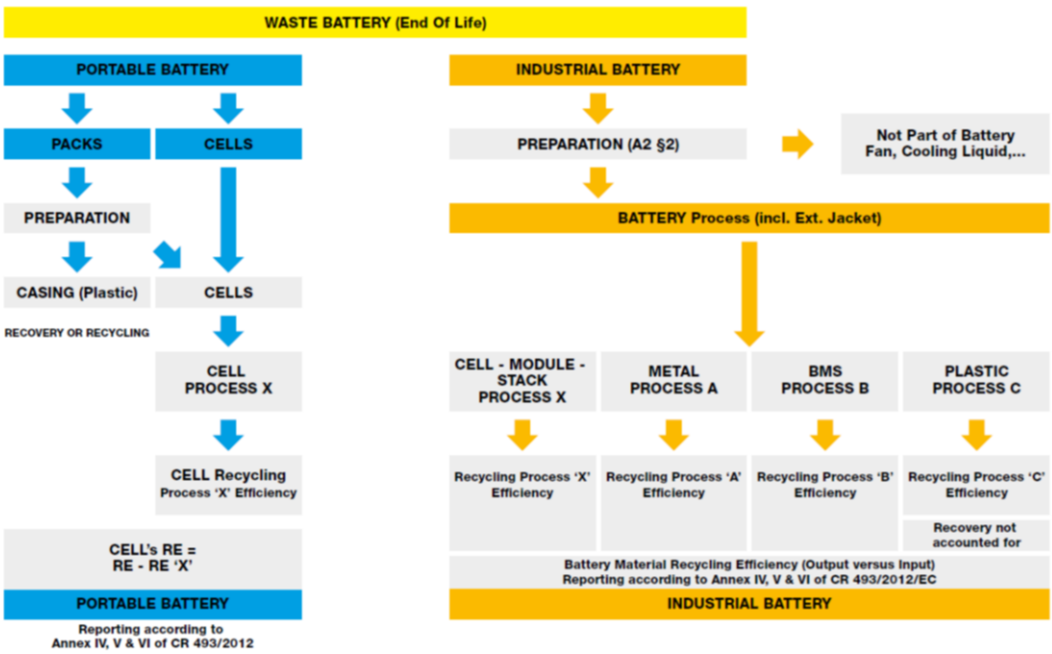


Fig. 21 recycling efficiency Source Recharge

Although Lithium supplies are theoretically able to cope with projected demand across applications by 2030, there are several advantages in European companies reducing their dependency on exported materials, with 70% of global lithium deposits located in three South American countries. Developed recycling and reuse schemes will also protect against future price fluctuations and could realize potential for second-life applications.

Certain car and battery manufacturers have already begun to implement schemes for the recycling of used EV and HEV batteries. Several pilot projects across Europe, Japan and the USA have also been implemented to further explore possibilities of Li-Ion battery recycling. For example, RECHARGE member Umicore has in 2011 opened an industrial-scale recycling facility for end-of-life rechargeable batteries in its Hoboken plant (Belgium). After developing and putting into operation the world's first recycling process enabling metal recovery from used Li-ion, Li-polymer and NiMH batteries with minimal environmental impact, Umicore opened this facility to cope with the expected growth in demand for EV and HEV vehicles in coming decades.

At regulatory level, the recycling objectives provided in the Battery Directive are common to "other batteries": a recycling efficiency of 50% in weight is the target. These objectives have not been specifically adapted to Li-ion batteries, and the possible "close loop" which can be set-up for the components of this battery technology. Establishing recycling qualitative and quantitative objectives, based on scientific calculation and real value chain would be helpful both for the recyclers and the car manufacturers.

Conclusion: processes have been developed, allowing close loop recycling of the present Li-ion products, but the processes have to be adapted for recycling of the Electric Vehicle batteries. Current recycling cost has a strong economic impact that could jeopardize the electric Vehicle business model and future. Treatment cost reduction is required that include further technical development (treated volume increase will not be sufficient to eliminate the possible negative value linked to this operation). In addition, establishing recycling qualitative and quantitative objectives, based on scientific calculation would be helpful both for the recyclers and the car manufacturers.

3.3. Technical Roadmap Conclusion

Globally, significant efforts are organized in the European structure for the technical development of the Li-ion batteries, roadmaps and objectives clearly described for the materials development.

A weaker position is observed in the cell technology development: main developments are in Asia with portable industry. Due to the nature of the work, the Universities have a limited involvement in this subject.

Design and Eco-design of Electrodes, electrolyte and cells for automotive application, and more generally for e-mobility will require significant effort in order for Europe to remain competitive.

In the engineering of battery systems and their integration in vehicles (largely linked to the automotive companies individual development plans), a stronger vertical cooperation with the battery industry may improve the efficiency of the e-vehicle development, in a more integrated approach that may be supported by governments public initiatives.

4. Industrial roadmap

4.1. Volumes

The objective of this part is to describe the battery industry industrial roadmap required to support the e-mobility development.
The evaluation of the expected number and type of vehicles is one of the key assumptions of this roadmap. Depending on this, the associated battery volume can be calculated. But the performance and cost roadmap of the batteries themselves can have a significant impact on the success of the e-mobility development, due to the relative cost of the battery in the vehicles. There is then a need of global models associating the cost roadmap for batteries with different assumptions on e-mobility development. Several of these have been published in the recent years. An extensive review over fifteen of the most referenced battery cost models has been presented in Element energy report. EPRI38 (Electric Power Research Institute) in 2010 undertook a similar review of seven of the most used models with an in-depth review of two of the bottom up models. The conclusions of this study and its grading criteria were used to inform the larger, more general, review of existing models undertaken in Element Energy study.

Three methods are used in these models:

1) Bottom-up
This method is based on a detailed set of inputs, uses a specified manufacturing process (with associated costs) and specifies a design of a battery pack. The EPRI study concluded this was the most informative and useful model format, with assumptions generally more explicit and better documented than the 'top down'
2) Top-down
This is the preferred method used by financial institutions. From a starting reference year, learning rates are applied to the different battery cost components, using historical learning rates or primary analysis with industry consultation. This kind of analysis is very good for identifying overall patterns of developments in industries, but often does not have the explanatory power to identify the origin of changes, or fundamentals which might constrain such changes in the future.

3) Hybrid
This uses a combination of the two models, starting from a bottom-up model but with industry informed trajectories on costs and performance improving the validity of the results through time.

To ensure that no important models were overlooked in the review the following process was used:

- A search of all the major battery research programs and institutions worldwide,
- Consultation with battery industry experts and private discussions with manufacturers,
- A recent publications search including conference proceedings and merit reviews.

A summary of a selection of reviewed models is shown in Fig.22:

	Time dimension	Allows performance changes?	Shows key drivers?	High level outputs	Detailed outputs	Bottom up model?	Level of access to inputs	Detail of process	Production volume effect
ANL	No	Yes	Yes	Yes	High	Yes	High	High	Yes
DLR	No	Yes	Yes	Yes	Low	Yes	Moderate	Moderate	-
TIAX	No	Yes	No	Yes	Moderate	Yes	Moderate	Moderate	-
Roland Berger	Yes (2020+)	No	Yes	Yes	Moderate	No	Moderate	Low	No
Avicenne	Yes (2020)	No	Yes	Yes	Moderate	Yes	Low	Low	-
Boston Consulting	Yes (2020)	-	No	Yes	Moderate	No	Low	Low	-
CARB	No	No	Yes	Yes	Low	No	High	High	Yes
Deutsche Bank	Yes (2020)	No	No	Yes	High	No	Low	Low	Yes

Fig.22: models comparison table

Significant differences can be observed when comparing the models, with as an example the aforementioned model results for 2020 (ANL) and long term (Roland Berger) (Fig. 23). The ANL cost is significantly lower, mainly because highly optimized manufacturing is assumed, along with very low pack component costs (BMS, housing etc). Cell manufacturers interviewed for this work view the ANL results as too optimistic for 2020 but recognize the approach in terms of cell design and link between production cost and volume is sound.

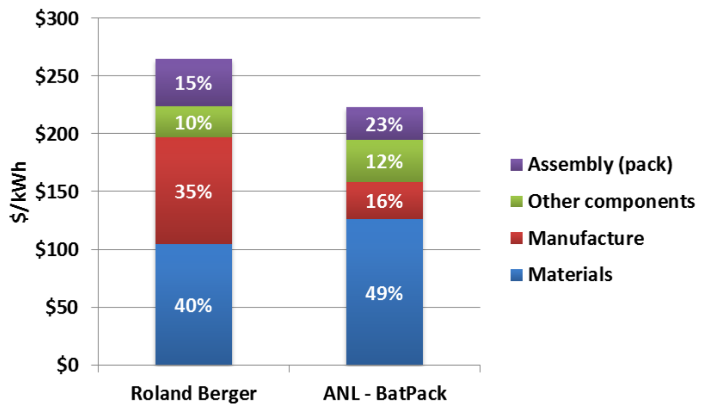


Fig 23: models costs comparison. Source:Element Energy study (2012)

Finally, Element Energy has proposed his own model, based on a bottom-up approach for the years 2012-2030. It is based on the following assumptions:

Standardization and manufacturing of large cells

At the core of the model is the assumption that some degree of standardization in large cell manufacturing will emerge in the coming decade, in line with the transport roadmap that envisages policy support that stimulates electric vehicle uptake.

It is assumed that manufacturing improvements will make standardized quality large cells achievable, at high production yields, by 2015. The adjective 'quality' refers here to the high standard of consistency, safety and life that automotive packs require.

EV uptake and production volumes

In the model, three cost areas are affected by standardization and learnings brought by cumulative production: cell material costs, cell production (plant capacity and CAPEX), packing costs.

The production costs are based on the methodology developed by ANL for their BatPaC model. It reproduces the relationships between volume (e.g. quantity of material handled, number of cells produced) and manufacturing cost. The ANL BatPaC plant costs are used as the lower bound of our CAPEX plant costs; it assumes a highly optimized plant, producing one type of cell, operating after a large adoption of EVs.

This lower bound manufacturing cost, corresponding to a consolidated EV market, is assumed to be reached by 2025 in the base case. This would correspond to a global EV uptake following the same trajectory as HEVs since 2000, thanks to policy support in developed countries, to reach around 1% of global sales by 2020 (~4million cumulative sales).

Material improvement

It is expected that the current R&D on cell materials will deliver increased energy density and bring new, cheaper materials into cells. Several R&D scenarios have been developed around this theme, presented in section 3.1.

In the baseline scenario, lithium-ion cells answering the automotive market needs (safety, power, life) exceed 200Wh/kg by 2020.

Scenarios

The baseline technology roadmap together with the central EV uptake constitutes the base case of the lithium-ion battery model. The central EV uptake scenario represents a successful trajectory for EVs, i.e. their uptake, supported by policy, increases steadily and advances in materials bring high energy density cells.

Two other scenarios have been developed to represent alternative narratives. A more conservative scenario ('Niche EV') sees slower material improvements and no EV uptake beyond niche or localized markets while the third scenario is very optimistic ('EV push'). In the 'Niche EV' scenario, progress on materials is made, and cell production costs do decrease over time, despite the globally low uptake of EVs. It is assumed other emerging large cell markets (e.g. grid back up) will grow and contribute to innovation and cost reduction. Cost and performance of EV batteries The 'EV push' scenario corresponds to quick EV uptake and material improvements, bringing the production costs to their optimized level as early as 2020.

The table below summarizes the scenarios.

Table 5-3 Main model assumptions and scenarios **Scenario**	**R&D path**	**EV uptake**
Niche EV	**Slow R&D** This is a conservative scenario. Some scientific challenges do not get overcome (5V electrolyte, capacity cathode >200mAh/g). Overall little/slow material improvement, silicon blend anode from 2025. Cells at 200Wh/kg by 2020 and 260Wh/kg by 2030.	**Low uptake** Lack of strong policy support and no rapid improvement in cost/performance of EVs means EVs stay a niche product for at least a decade (<1% global sales by 2020). This corresponds to 3 million cumulative sales by 2020. Learning brought by cumulative production drives the cell production cost (CAPEX) down. The low EV uptake means the production cost are not optimized before 2030.
Baseline case **Steady EV**	**Baseline R&D** Baseline scenario. Existing materials improve and new materials get developed. 5V cells become possible. Silicon blend anode from 2020. Cells at 250Wh/kg by 2020 and 290Wh/kg by 2030.	**Baseline uptake** Plug-in vehicle uptake follows the same path as hybrid vehicles since 2000, thanks to policy support in developed countries. This corresponds to 4 million cumulative sales by 2020. Learning brought by cumulative production means production costs are optimized by 2025.
EV push	**Fast R&D** This is an aggressive/optimistic scenario. Faster introduction of the baseline R&D. Material breakthrough introduced as soon as 2015. Cells at 280Wh/kg by 2020 and 300Wh/kg by 2030.	**Stretch uptake** In line with the CCC central scenario of uptake in the UK – this corresponds to a strong global policy push, delivering over 5% EV uptake at global level by 2020. This corresponds to 16 million cumulative sales by 2020. The fast uptake means production costs are optimized by 2020.

These scenarios present a growth of market share compatible with most of the published previsions in this field: as a reference, the base scenario with a cumulative volume of 4 million EV in 2020 is very close to the Avicenne prevision (Fig 24):

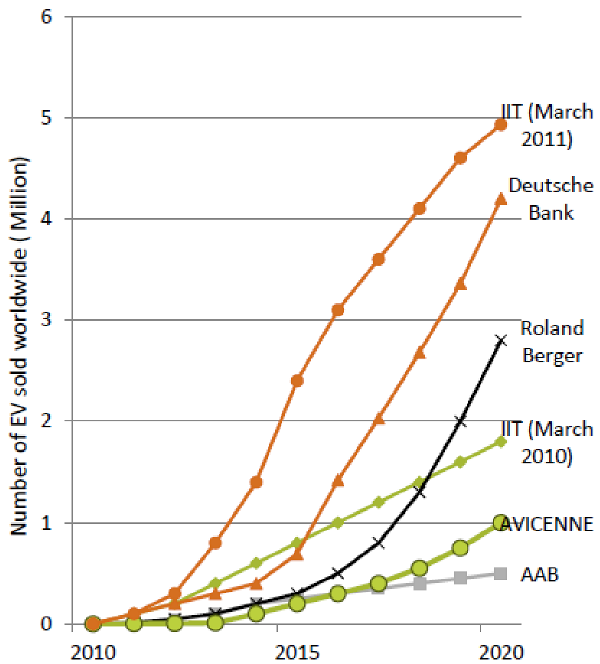


Fig 24 : markets previsions comparison . Source Avicenne 2012

4.2. Cost impact

Some results of these models are shown in the Fig. 25:

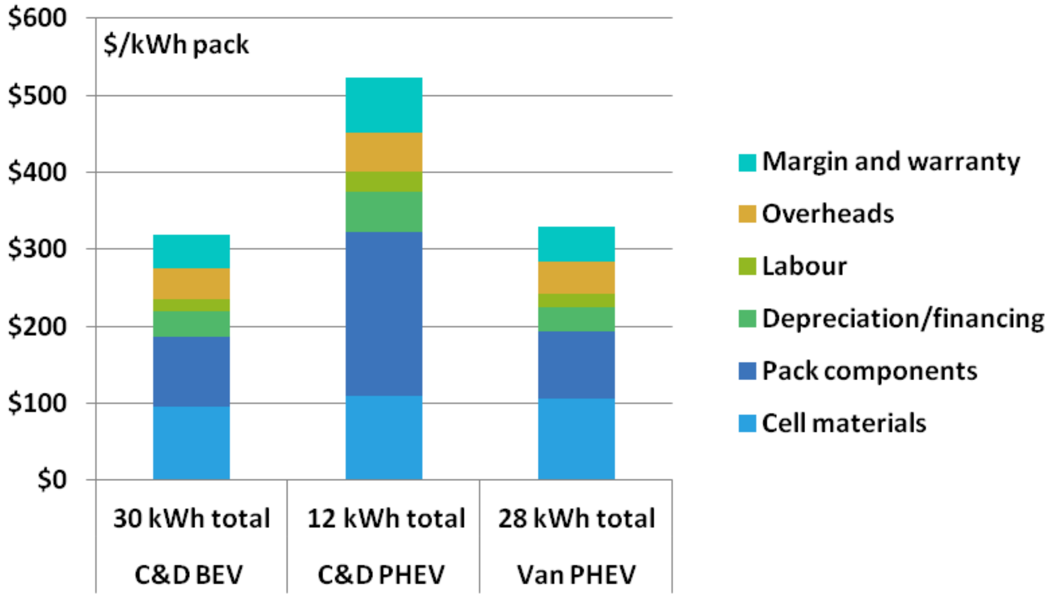


Fig 25. Pack cost ($/kWh) comparison in 2020 for BEV and PHEV applications (Element Energy 2012)

The result is relatively coherent with the objectives of the worldwide programs described in the introduction: the cost of the lithium-ion batteries for EV can decrease close to #300$/kWh in 2020, without unrealistic assumptions on the technical progress and manufacturing technology.

Further cost reduction on the contrary requires the development of more innovative technologies, not available today. The cost calculated with this model is coherent with many roadmap objectives (here below at cell level). It can be noted once again that the USA objective in cost reduction is the more ambitious, and not in agreement with our reference model (Fig 26 and 27).

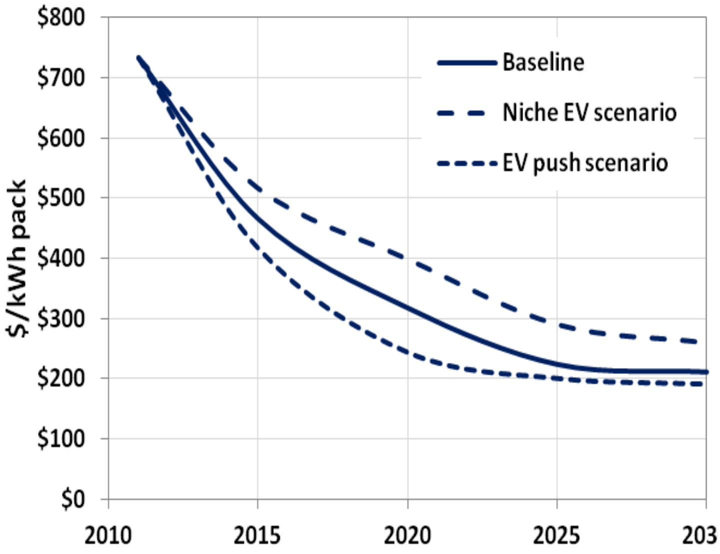


Fig 26: Element Energy Study (2012)

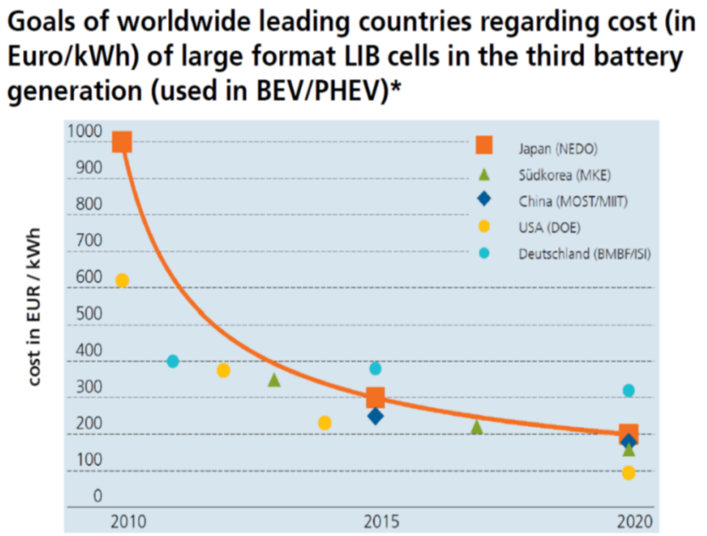
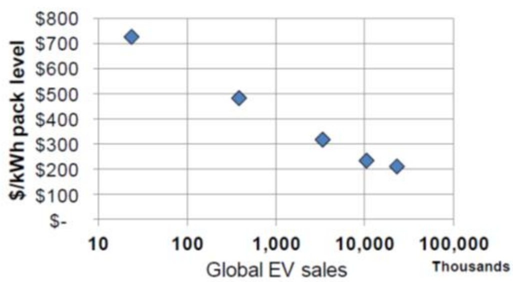


Fig27: Fraunhofer review, Nice 2012

It is important to observe that the larger part of the cost reduction is expected to come from the automation of manufacturing, associated with the investment of the manufacturing plant, and the components cost reduction due to volume effect. This is reflected in the Fig 28. It explains why the cost objective is so dependent on the manufacturing volume assumptions.

Learning rates applicable to components and effect at pack level

Pack component	Rate applied	Comments
BMS	90%	Fairly repetitive electronics
Power electronics	90%	If standardised parts are used
Wiring harnesses	85%	Very manual operation
Cell interconnections	85%	Very manual operation
Internal cell support	97%	Dominated by machine and raw materials
Housing	91%	Dominated by machine and raw materials



Learning rates

- Learning rate to apply to each pack component estimated according to typical learning rates observed across industries
- Indicative overall learning rate of 90% for pack components (a doubling of cumulative production reduces the cost by 10%)
- Cell production costs also benefit from chemistry improvements, resulting in overall 87% learning rate for whole pack (graph).

Source: Element Energy analysis for the Committee on Climate Change (2012) elementenergy | 15

Fig 28 : pack cost reduction with volume manufacturing

4.3. Investment

The size of the investments is defined in the models.
It is based:

- on the calculated quantity of batteries required for anticipated market: this is presented in Avicenne Fig. 29, and
- on the cost of the highly automated plants, based on the real projects investments - see graph Element Energy Fig. 30.

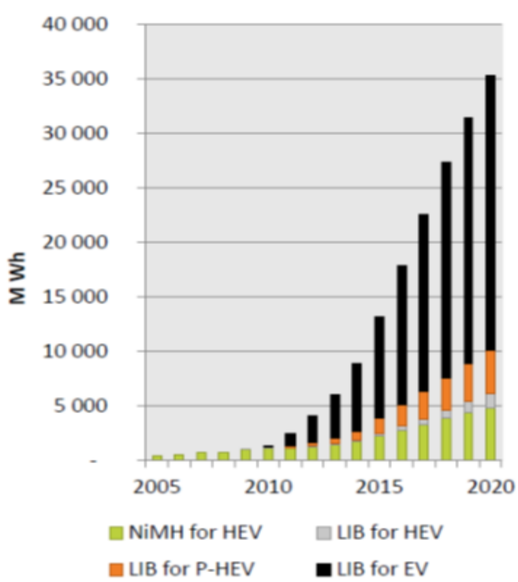


Fig. 29 Avicenne (Nice 2012)

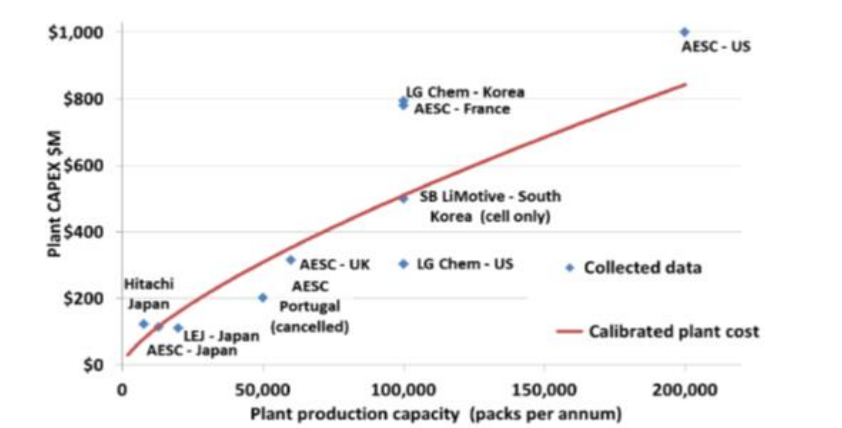


Figure 8-11 Investment costs ($million) of current and planned battery manufacturing plants dedicated to the automotive market. Publically available data collected by Element Energy

Fig. 30. Element energy study (2012)Packs of 20 kWh

This data, presented for the worldwide global market, have been recalculated for Europe, assuming the electrification of vehicles in Europe is on the same ratio than on the global vehicles market (12 M vehicles in Europe, versus 70 millions worldwide).
According this hypothesis, the total investment corresponding to the prevision for Europe s represented Fig 31.

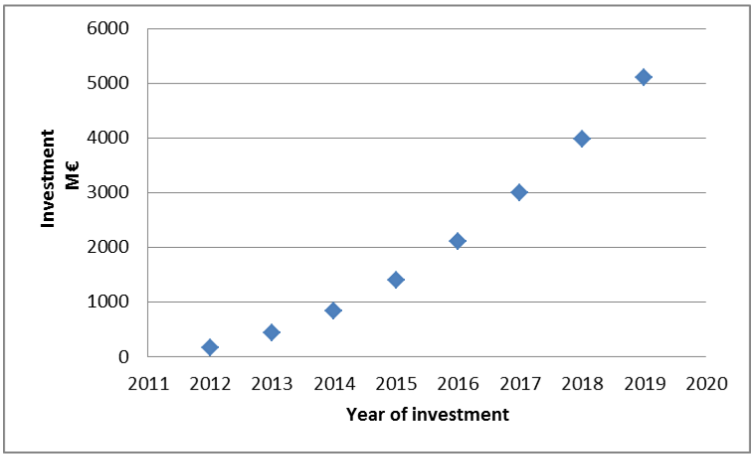
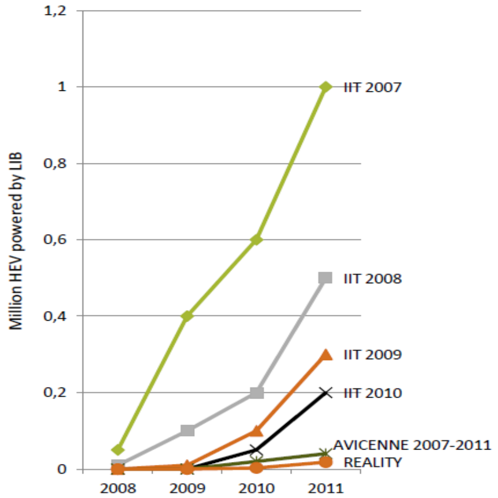


Fig 31 Cumulated investment in battery manufacturing for Europe (Source Recharge)

The cumulated value represents a huge investment of 5.000 Million Euro, but the main issue may be at the starting point of the curve: the uncertainty of the business roadmap and the overcapacity at short term (see below) may delay the decision to launch investment when required.

Present status on manufacturing capabilities.

The uptake of the EV and HEV has been slow worldwide compared to the previsions, and particularly in Europe (Fig 32). In the USA, the DOE has granted large subsidies to batteries manufacturers, and large battery manufacturing plants have invested. As a consequence, there is for the moment an overcapacity in Li-ion battery production worldwide (Fig 33):



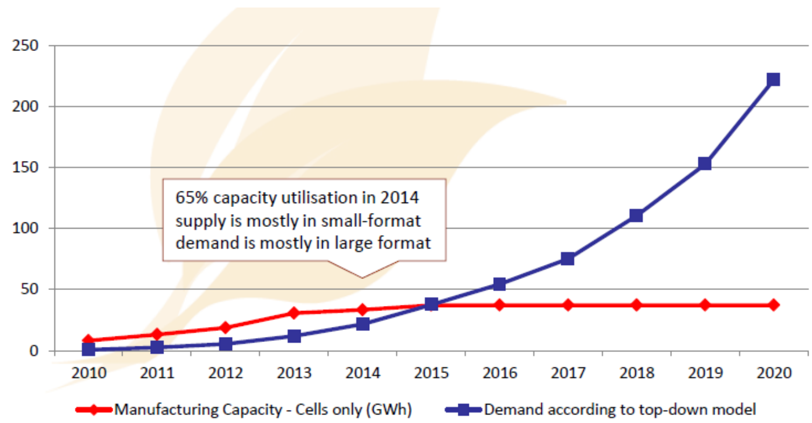


Fig 32. Source: Avicenne, Batteries 2012 Nice

Fig.33 : Natureo Finance (Batteries 2012, Nice)

Today in Europe, according the known investments from Saft, Litec and Batscap (Bolloré), the total investment for cell manufacturing capability is limited to less than 5% of the investment anticipated in the world before 2015. In the meantime, the large Li-ion manufacturers, particularly in Korea and Japan, are investing large manufacturing capacities, based on the portable market growth. There is no similar situation in Europe, most of this market being Asian, with limited access for European competition.

In spite its limited size, this European manufacturing capacity is not fully used in 2013, and is facing a competitive situation due to the worldwide overcapacity.

Due to the Battery manufacturers location in Asia, the main suppliers in the value chain of Li-ion batteries are located in Asia also, as indicated in the Fig 33b.

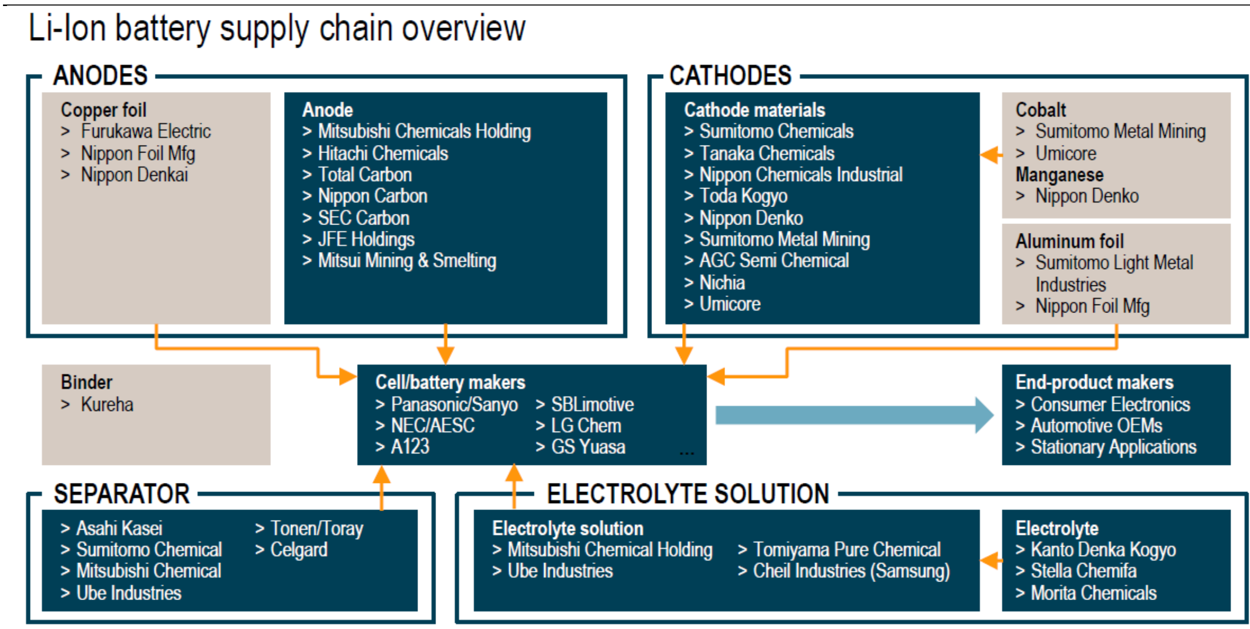


Fig 33b. Battery suppliers - Source Roland Berger

There is a risk that investment in battery manufacturing is difficult in Europe for the coming years, if no improvement is proposed for the business model (see paragraph 5). We can then worry that the development of manufacturing capacity in Europe becomes late, at least for cell manufacturing in the coming years.

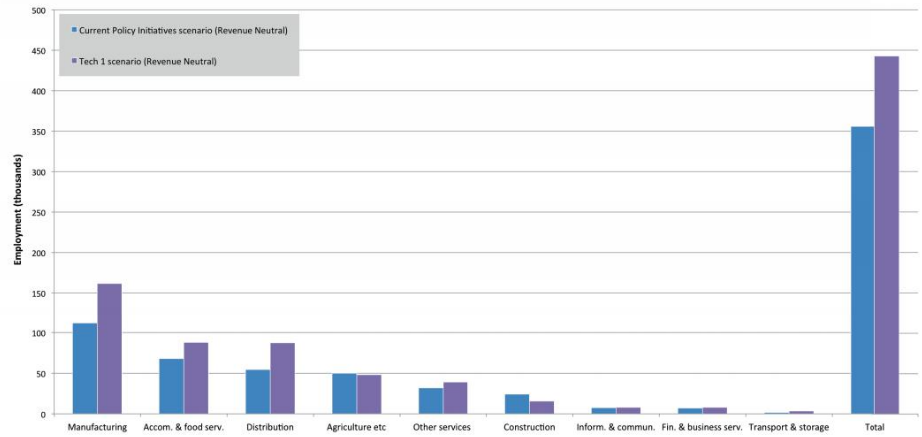
4.4. Employment

Employment consequences :
On 19 March 2013, RICARDO-AEA presented the key findings of the technical and macro-economic study "An economic assessment of low carbon vehicles"
(*http://www.ricardoaea.com/cms/assets/MediaRelease/ Economic-Assessment-Vehicles-FINAL2.pdf*).
Focusing on light-duty vehicles – cars and vans, the study shows that a shift to low-carbon cars generates positive direct and indirect employment impacts.
The report, published by Cambridge Econometrics and Ricardo-AEA is based on a research project convened by the European Climate Foundation.
Its aim was to analyze the economic impacts of decarbonizing light duty vehicles. As part of the study, the impacts of the European Commission's proposed 2020 CO_2 regulation for cars and vans have been assessed.

Key findings
The analysis showed that a shift to low-carbon vehicles would increase spending on vehicle technology, therefore generating positive direct employment impacts, but potentially adding €1,000-€1,100 to the capital cost of the average new car in 2020.
However, these additional technology costs would be offset by fuel savings of around €400 per year, indicating a break-even point for drivers of approximately three years.

At the EU level, the cost of running and maintaining the European car fleet would become €33-35 billion lower each year than in a “do nothing scenario” by 2030, leading to positive economic impacts including indirect employment gains.

Employment impact
Results include both direct impacts from increased spending on vehicle technology and indirect impacts that result from lower fuel bills across the economy (Fig 34).



Source: Cambridge Econometrics

Fig 34. Employment repartition Source Ricardo AEA

This study shows the benefit on the employment in Europe of the integration of the e-mobility: up to 300. 000 employments. The more significant part is in the Manufacturing.

4.5. Industrial roadfmap conclusion.

Roadmaps for possible market development and associated industrial investment are clear.

The European Battery industry is starting from a low level of local manufacturing in Europe.
The global associated industries (from specialized components suppliers to recycling industry), has relatively low manufacturing capabilities in Europe compared to the expected development.

Following the prevision on EV/HEV market development, investment will be needed from 2014.
It appears that the industrialization of Li-ion batteries is expensive: 5.000 Millions € investment required in battery manufacturing to follow the road map to 2020. It represents a considerable burden for the Battery Industry, which makes the decision for investment difficult without a clear business model.

In Europe, the Battery Industry level of investment is still low, particularly compared to the Asian competitors, backed by the growing market of portable equipment. It appears of the upmost importance to build strong business cases with the E-mobility market if we want to build a competitive Battery Industry in Europe.

At stake are the global consequences on the employment: the e-mobiliy deployment may bring up to 300. 000 new jobs.

5. Business Roadmap

5.1. Investment Risks

a) A first type of risk to be considered is the one from the market acceptance side.

Conclusion from Element Energy: "These cost predictions indicate that electric drivetrains will, for ca. 20 years, cost a premium to produce. It is highly debatable whether the mass market and late adopters will accept a price premium for such a long period of time. To sustain the uptake required, it would seem necessary to have either regulations focusing on OEMs (i.e. fleet average emissions targets favoring some EV production) or incentives (such as grants to reduce the cost difference to consumers).

If the combination of regulation/incentives were not in place over the time period – then the predictions given in this document may be very optimistic. While material improvements are more likely to emerge (because there are other, larger markets for these high performance cells), the production of large format cells, and the learning rate improvement in packing costs, will not emerge if EV uptake stalls.

As indicated on the Fig.35, the price of the Electric vehicles is still higher than the one of the ICE vehicles: this is the fundamental reason for the market acceptance risk.

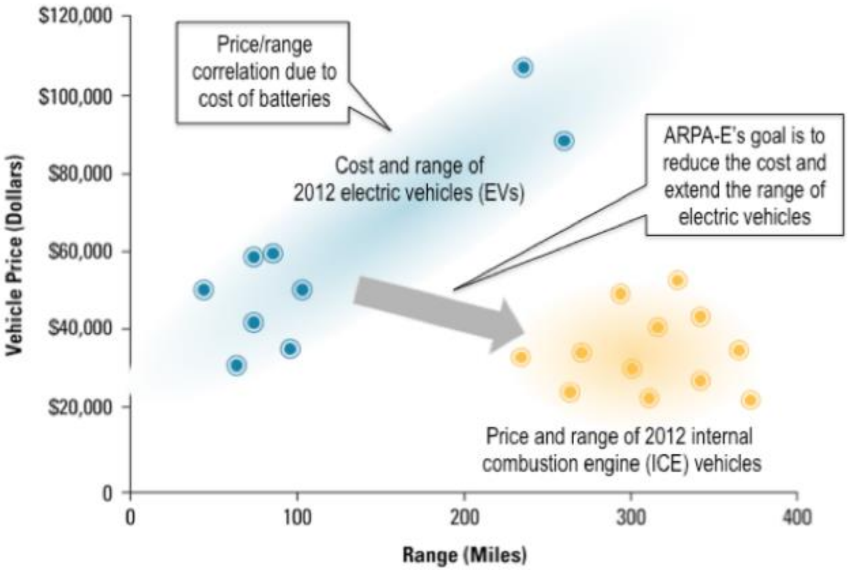


Fig 35 : Vehicles price comparision (Source DOE 2012)

b) A second type of risk is the technical one: has the technology enough maturity to avoid any late reject from the market, or will another technology become the better competitor?

It is clear that this risk has disappeared in Li-ion technology for portable applications, based on the large industrial use in these markets. For the large systems requested in the E-mobility, the remaining question may be the management of the safety. This is addressed by industrial and technical means, but some doubts are relayed in the media and may impact the consumers.

c) The risk of low price market leading to risk of business losses has to be addressed as well.
It is linked to the first risk described, at least in the first years. After the initial phase, there is still the risk of large investment pay-back delay.

What could be the ways to reduce these risks?
Some ideas have been proposed here and there, at different level of maturity.
For example, changing the selling model of electric vehicles, with rented batteries instead of sold, or looking for a second use of the e-mobility batteries.
In this field, the DOE has listed some points of impact of the EV Everywhere program:

- Non-economic drivers/psychological factors of PEV consumer adoption?
- Pack-level battery innovation?
- Beyond Li-ion battery technology?
- Disruptive approaches to fast-charge/battery-swap?
- Innovations for grid stability for fast charge?
- Autonomous vehicle control to enable ultra-lightweight PEV's?
- New vehicle ownership/usage models?
- New non-rare earth magnet/motor designs?
- Workplace Charging Challenge?

Renault has been looking for the ways to improve the battery COST PERFORMANCE. (Fig 36)

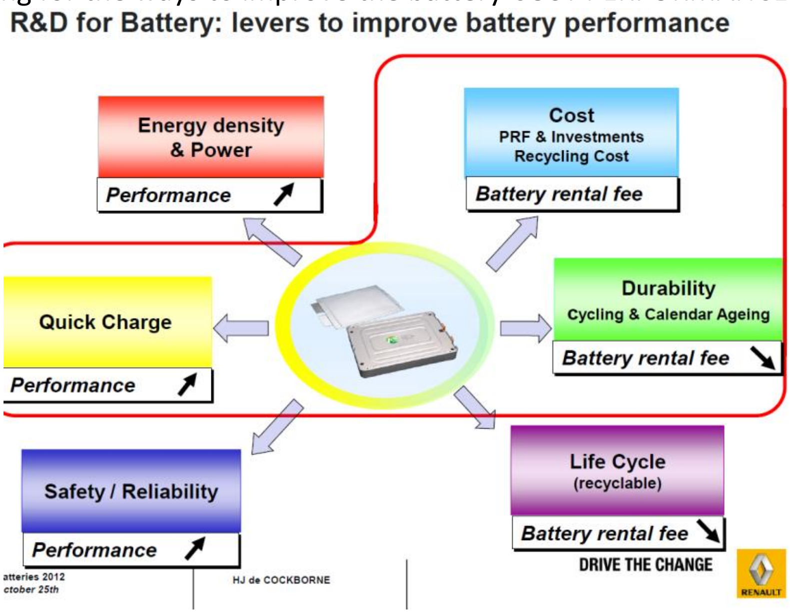


Fig 36: Battery cost/performance improvement (Source Renault 2012)

Nevertheless, in the present time market, most of these innovative approaches have a limited impact on the global Business model.

5.2. Business Models

The requirements to support a successful investment are stringent.
A list of critical conditions has been proposed by Natureo Finance to support key investment decisions (Nice, Batteries 2012):

A. Strong technology at the cell, battery and pack level
- Cell design controls key characteristics: energy, power, cycle life, safety and cost as well as many other parameters.
- Battery design required for cell safety and performance and configuring solutions for complex applications such as vehicles or grid services.

B. Strong client base and market access
- Sales channels and partners in the right markets
- Knowledge of opportunities and time to develop appropriate products

C. Strong manufacturing process experience and capacity
- Mastery over processes has profound effect on quality, safety and cost
- Capacity to fulfill requirements of large production runs
- Mastery over multiple cell chemistries

D. Strong financial backing
- In context of high Capex, working capital requirements
- Required until cost/price situation balanced out
- Few companies have these capabilities

This last point of Financial Backing is particularly critical in the present situation of the Battery Industry competition: Capacity utilization is low (unabsorbed manufacturing costs) and Cell industry is underwater (prices are under cost in some markets). As a result, the global Battery Industry profits are decreasing (Fig 37).

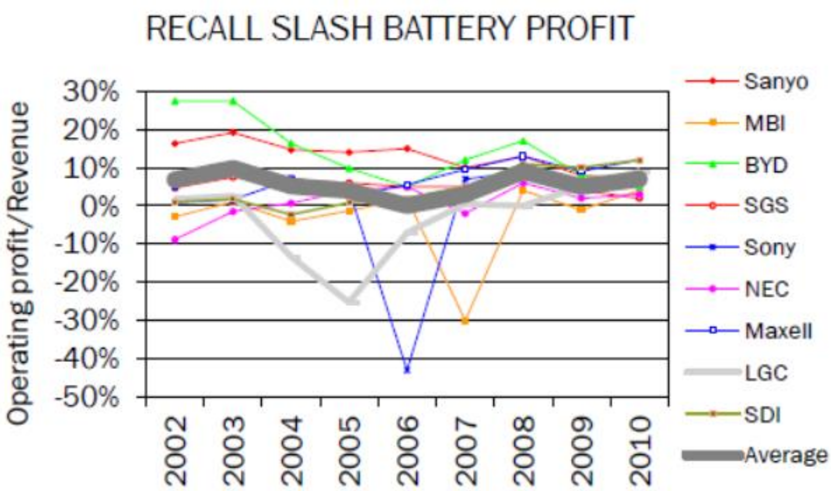


Fig. 37 Avicenne Batteries 2012 Nice

The capability of the European Battery Industry to fulfill these critical conditions has to be considered:

A. Strong technology
The relative strength and weaknesses of the European industry in this field have been resented in paragraph 3.

B. Manufacturing capability
The roadmaps have been presented in paragraph. 4. This is already a weak point for the European industry.

C. Market access
In this domain, the supply chain structure can make a difference: integration, JV, single suppliers/ multi-suppliers structures.

- NRI (Batteries 2012, Nice) has proposed comparing the status of the two options: vertical integration (car manufacturers have a JV with a battery manufacturer) or horizontal (car manufacturers look for standardized products from several suppliers).
- According to NRI, at the present time, the EV battery business is moving from the phase of the R&D investment to the phase of production investment, which is much more capital consuming for the industry. This represents the highest risk phase for the investors and the companies' financial health.
- Because the EV-market the volumes have not increased in 2012 as anticipated, then the battery suppliers have got losses (example: A123 bankrupcy in 2012). Nevertheless, it is too early according NRI to decide if the model of JV will remain better.
- In this field, the model of joint venture between Battery industry and Automotive industry has not been largely applied in Europe. It is not clear if the European automotive industry will prefer this model, or an horizontal model of standard supply of batteries

D. Strong financial backing
The size of the Battery manufacturers in Europe is today clearly too small to face the large investment requested. The same type of discussion on Associations or JV, as presented on the market access subject, is applicable.

5.3. Business Roadmap conclusion.

- **The business roadmap** for the development of the Battery Industry in Europe is not clear:

The cost benefits brought by high production volume of battery packs are highly dependent on the uptake of EVs. According the cost comparisons between EV-HEV and ICE vehicles, this is uncertain and will depend on incentives and regulation. The capital investment is high, but due to the large worldwide competition pressure on prices, the return on investment may be long for the industry.

- To support these risks there is a need for the Battery industry to have a clear market access and a strong financial backing. In this field, the model of joint venture between Battery industry and Automotive industry has not been largely applied in Europe. It is not clear if the European automotive industry will prefer this model, or an horizontal model of standard supply of batteries.

- In addition, the Battery industry in Europe is in a difficult situation of (supposed) temporary overproduction of Li-ion batteries, although the production capabilities are quite limited compared to the expected market of the e-mobility, or the existing market of portable appliances. In this context, there is a high risk that the Battery industry can't make investment decision in Europe until the market becomes a reality, with imported battery systems or cells.

- This may have negative consequences on the employment development in Europe at short term. On the longer term, it is expected that the E-mobility industry may need local manufacturing of the cells and batteries for a volume market. But in such conditions, the control of capital investment for battery manufacturing will probably be in Non-European based companies.

- Finally, there is the risk that the industrial development of the cell manufacturing in Europe is delayed, as well as the investment in the components manufacturing and recycling industry.

6. Conclusions

This analysis of the status of the Battery Industry, associated with the projected road map for the E-mobility raises questions about the possible success of the Industry development for this Market in Europe.

RECHARGE is proposing a list of areas of support to this development, presented in the conclusions of the executive summary.

References:

1. ANL, Modelling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles, 2011
2. Avicenne, The worldwide battery market 2011-2025, Batteries 2012 conference, Nice, October 2012
3. Boston Consulting, Batteries for electric cars, 2010
4. Roland Berger, Technology and market drivers for stationary and automotive battery systems, Batteries 2012 conference, Nice, October 2012
5. CARB, Status and Prospects for Zero Emissions Vehicle Technology, 2007
6. CGGC, Lithium ion batteries for electric vehicles, October 2010
7. Deutsche bank, ElectricCarsPluggedIn2, 2009
8. Element Energy "Cost and performance of EV batteries", Final report for The Committee on Climate Change, 21/03/2012
9. EPRI, Large-Format Lithium-Ion Battery Costs Analysis - Critical Review of Existing models 2011.
10. the European Green Car Initiative (www.green-cars-initiative.eu), 2012 report.
11. Fraunhofer ICT: What does the future hold for Battery technology, Batteries 2012 conference, Nice, October 2012
12. French embassy in Japan, Etat de la R&D dans le domaine des batteries pour véhicules électriques au Japon, October 2010
13. ICCT: European vehicle market statistics, 2011
14. Natureo Finance, Lithium Battery Trends: identifying Winning Players, Batteries 2012 conference, Nice, October 2012.
15. NRI: trends of electrified vehicle and implications for the Battery Business, IMLB conference, Korea 2012
16. Renault :How to develop Electric Vehicle as a mass market product, Batteries 2012 conference, Nice, October 2012
17. RICARDO-AEA: an economic assessment of low carbon vehicles, Cambridge econometrics, March 2013.
18. Toyota Motors Europe: Toyota's perspective on sustainable mobility, Batteries 2012 conference, Nice, October 2012