电动汽车用二次电池及关键材料技术

Secondary batteries and key materials for electric vehicle technology

吴锋

Feng Wu

北京理工大学

Institute of Beijing Technology

2010. 8. 30

吴锋教授简介 Prof. Feng Wu

吴锋，北京理工大学化工与环境学院教授委员会主任，中国电池工业协会副理事长、国家973绿色二次电池项目首席科学家、“863”计划重大专项“节能与新能源汽车”咨询评审专家。曾任“863”功能材料专家组成员、副组长，“863”新材料领域专家委员会委员、常委，国家科技部镍氢电池专家组组长、“863”电动汽车重大专项总体组成员（动力电池责任专家）等，从1988年起，先后参与规划和组织了中国镍氢电池、锂离子电池、动力电池及相关材料的研究与产业化开发。

Prof. Feng WU is the Chairman of the professor committee in School of Chemical Engineering & Environment Science, Beijing Institute of Technology (the Chief Professor). Vice President of China Battery Industry Association, and the Chief Scientist of National 973 Program (green secondary batteries).

Prof. Feng WU used to be the associate group leader of the National 863 expert council for Functional Materials, the commissioner and the standing committee member of the National 863 expert council for advanced Materials, the group leader of the Ni-MH battery expert committee of the Ministry of Science and Technology, the member of the National 863 expert committee of electric vehicle (general scientist of power batteries). Since 1988, he used to participate and organize the R&D of Ni-MH batteries LIBs and key materials in China,

能源与环境问题已成为全人类面临的重大难题
Energy and Environmental Problems are the Big Issues

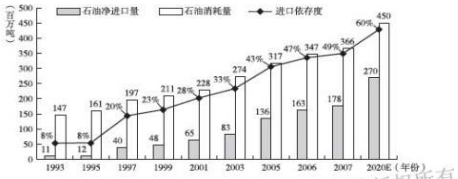


图5 我国的石油依存度变化（1993～2007）

资料来源：相应年份的《中国统计年鉴》。

社会科学文献出版社版权所有

国内外机构对中国石油对外依存度预测结果比较表

单位：%

预测机构	2010 年	2020 年
中国能源研究所	46～52	55～62
国际能源机构（IEA）	60	76
美国能源信息署（EAI）	49.7	65.5
欧佩克（OPEC）	45	52

资料来源：吴磊：《中国石油安全》，中国社会科学出版社 2003 年版，第 126 页。

Humanity's Top Ten Problems for next 50 years

1. ENERGY
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

2003	6.3	Billion People
2050	8-10	Billion People

The top ten problems mankind will face during the next 50 years according to Nobel laureate Richard Smalley.

由于化石燃料有限从而引起：

后续资源不足；生态环境恶化；地区冲突加剧，……

Problems caused by the fossil fuels:

Non-sustainable development, Environmental deterioration , Region conflict ……

建立洁净可再生的新能源体系是人类社会的必然选择！

To establish a clean and renewable energy system is an inevitable choice of human beings.

发展电动汽车是汽车技术进步和产品升级的必然选择
It is an inevitable choice to develop EV & HEV

- 中国正在成为世界汽车生产和消费大国，面临节能减排的重大挑战。
- **China is becoming a great power for the manufacturing and consuming of global automobiles, and facing a challenge of energy saving and emission reduction.**

- 欧洲和日本2020年汽车CO_2排放目标分别为95g/km和115.5g/km；中国2020年对应的CO_2排放将降至120g/km以内。
- **The targets of Europe and Japan for CO_2 emission are 95g/km and115.5g/km respectively. Correspondingly, it is less than 120g/km for China.**

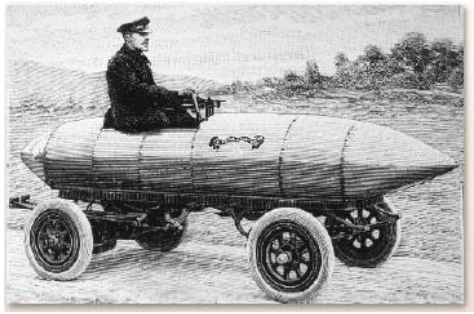
- 低碳经济促使汽车CO_2减排目标法规日趋严格，从技术经济综合评价看，汽车动力混合化/电气化势在必行。
- **Towards a Low-carbon Economy, the hybridization and electrification of automobile power is to be imperative.**

二次电池一直是电动汽车发展的主要技术瓶颈

Secondary batteries is always the major bottle-neck for electric vehicles

从电动汽车“几起几落 - 几落几起”的历程可以看出， 二次电池是电动汽车和新型清洁交通工具发展的主要技术瓶颈。

Electric vehicles have been developed for more than a century. Their “up and down” history indicates that the secondary batteries is the major bottle-neck for novel clean electric vehicles.



1899，比利时“不满足”牌电动汽车问世（铅酸电池）
1899, a Belgian EV (lead-acid battery)

1996-2000，通用EV1（铅酸电池）
1996-2000, EV1 of GE (lead-acid battery)

1997, 2004，2009，丰田第一、第二、第三代混合动力车-Prius（镍氢电池）
1997, 2004, 2009, the first, second and third generation of Toyota Prius HEV (MN-Ni battery)

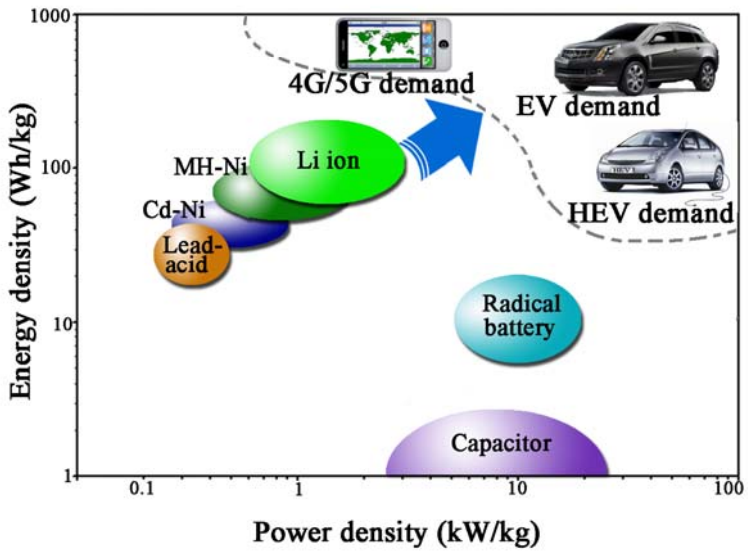
2009，美国菲斯克公司Plug-in电动车（锂离子电池）
2009, a Plug-in HEV of Fisker Automotive, USA (LIB)

- 电动汽车的应用需求需要二次电池具有高能量密度和高功率密度

  High energy density and high power density of secondary batteries are required for electric vehicle applications.

- 基于新材料和新体系的探索可实现二次电池技术的突破

  Breakthroughs in secondary battery technology can be brought by exploring new materials and battery system.



Energy density and power density of various secondary batteries

- 中国电动汽车与动力电池发展概况
An overview on the development of EVs and Power Batteries of China

1987-1990年：国家科技部在“863”计划中列入储氢材料与镍氢电池子课题

1991-1995年：国家科技部在“863”计划中列入锂离子电池子课题

1996-2000年：国家科技部在“863”计划中将镍氢电池列为重大项目

1996-2000年：国家科技部在“863”计划中将锂离子电池列为重点项目

2000-2005年：国家科技部启动实施“863”电动汽车重大专项

2002-2008年：国家科技部启动实施“973”绿色二次电池相关基础研究项目

2006-2011年：国家科技部启动实施“863”节能与新能源汽车重大专项

2009-2013年：国家科技部启动实施“973”新型二次电池及相关能源材料基础研究项目

2009年：　国家科技部、财政部启动“十城千辆”规模化示范运行

2010年：　国家科技部、工信部规划启动电动汽车相关重大专项

1987-1990, MOST, sub-project for hydrogen-storage materials and MH-Ni batteries in “863” program

1991-1995, MOST, sub-project for lithium ion batteries in “863” program

1996-2000, MOST, key project for MH-Ni batteries in “863” program

1996-2000, MOST, key project for lithium ion batteries in “863” program

2000-2005, MOST, important and special project for EVs in “863” program

2002-2008, MOST, basic research on green secondary batteries in “973” program

2006-2011, MOST, key project for energy saving and emission reduction in “863” program

2009-2013, MOST, basic research for novel secondary batteries and relative energy material in “973” program

2009, MOST & MOF, demonstrative operation for “Ten cities-thousand EVs”

2010, MOST & MOIIT, planning the startup of other important and special projects for EVs

Supported by 973 and 863 Programs in China

1 高能量密度电池及关键材料
High energy density batteries and key materials

2 高功率密度电池及关键材料
High power batteries and key materials

3 电池安全性
Battery safety

4 电池回收再生与环境影响
Battery recovery, regeneration and environmental effect

5 电池检测技术与能量回收
Battery testing and energy recovery

National electric vehicle key project layout: Three vertical and Three parallel aspects

电动汽车“三纵三横”技术体系

“十 五”863计划《电动汽车》重大科技专项

十一五863计划《节能与新能源汽车》重大项目

十二五计划

燃料电池汽车 Fuel cell cars	混合动力汽车 HEVs	纯电动汽车 EVs
燃料电池整车技术 Entire car	混合动力整车技术 Entire car	纯电动车整车技术 Entire car
整车标定和匹配 System matching	整车标定和匹配 System matching	整车标定和匹配 System matching
燃料电池发动机 FC engine	发动机和传动 Engine and drive	
	机电耦合技术 coupling	

多能源动力总成控制系统 (Multi-power controlling system)

电机驱动系统和控制单元 (Driving system and controlloing units)

DC/DC变换器

ISA/ISG技术

动力电池和电池组管理系统 (mamagement sysytems for power battery)

动力电池在中国的发展
The development of Power Batteries in China

2009年底中国车用锂离子动力电池和镍氢动力电池的年生产能力分别超过9亿瓦时和1.4亿瓦时，2010年底有望进一步提升到40亿瓦时和3.6亿瓦时以上。

At the end of 2009, the off-take potentials of LIB and MH-Ni batteries exceed 9 hundred million Wh and 1.4 hundred million Wh. And will promoted to 40 hundred million Wh and 3.6 hundred million Wh at the end of 2010.

按每辆装30kwh（约合A级车续驶里程200公里）电池计，2010年底可满足约15万辆电动汽车装车需求。

Meet the demand of 150 thousand EVS at the end of 2010 (each car30kwh, approximately for 200km)

中国锂离子电池及材料生产现状
The actual state of LIB and the key materials in China

目前全球锂电供应主要由中、日、韩所垄断，三者合计市场占有率超过95%,中国锂电产品正由低端市场向高端发展。中国锂电池企业近年来发展迅速，比亚迪、深圳比克、ATL公司和天津力神4家公司的销量均已进入全球前十名。在3G手机和笔记本电脑用锂电池方面，中国锂电企业的市场份额正在不断加大；在电动工具、电动自行车、电动汽车用锂离子电池等方面，中国企业也在积极开拓市场。

So far, the global LIB supply is mainly occupied by China, Japan and Korea, who are sharing more than 95% of the market. China's LIB products are from the low end to high-end development. And the sales of BYD, BAK, ATL, and Tianjin Lishen are all in top 10 in the world. In addition, the lot of China in 3G mobile phone and laptop is increasing. Furthermore, Chinese corporations are actively exploiting the market of electric vehicles, electric bikes, and power batteries.

中国锂离子电池及材料生产现状
The actual state of LIB and the key materials in China

- 中国锂离子电池正极材料生产企业主要有北京当升科技、湖南瑞翔、中信国安盟固利、天津巴莫、衫衫新材料等。负极材料生产企业主要有深圳贝特瑞、杉杉科技等。电解液生产企业主要有张家港国泰华荣、广州天赐、汕头金光、天津金牛等合计约占20%份额，部分从国外进口。中国锂离子电池隔膜材料目前主要从美国、日本进口。

- **The major corporations for LIB cathode include Beijing Easpring Co., Ltd., Hunan Reshine New Material Co., Ltd., CITIC GUOAN Mengguli, Tianjin B&M Science and Technology Joint-Stock Co., Ltd, Shanshan, etc. Those for anode materials include BTR, Shanshan technolgy, etc. Those for electrolyte inculde Zhangjiagang Guotai Huarong, Guangzhou Tinci Materials Technology Co., Ltd., Tianjin Jinniu, etc., which are sharing about 20% of the market. In addtion, partial of the electrolyte is imported from USA and Japan. The membranes for LIB are mainly imported from USA and Japan.**

1 高比能电池及关键材料 High energy density batteries and key materials

目前的锂离子电池能量密度约为120 - 150Wh/kg，充电后续驶里程约200-300公里

At present, the energy density of LIB is 120 - 150Wh/kg, and

与传统燃油车相比缺乏优势

Not superior to traditional cars

当高比能电池能量密度大于300 Wh/kg时，充电后续驶里程有可能高于600公里

When the energy density of batteries is larger than 300 Wh/kg, and the duration distance of electric vehicles may extended to 600 km.

可望逐步、部分地替代传统燃油车

Potential alternatives

多电子高比能二次电池新体系 Multi-electron sencondary batteries

$$w = \frac{n \cdot F \cdot E^{0}}{\sum M_i}$$

Electron number
反应电子数

Energy density
能量密度

Molecular mass
化学式量

基于轻元素化合物的多电子反应有望实现二次电池能量密度的跨越式提升。

The multi-electron reactions based on lightweight elements are a promising way for super-high energy density.

非水溶液体系的多电子反应材料：硫正极材料

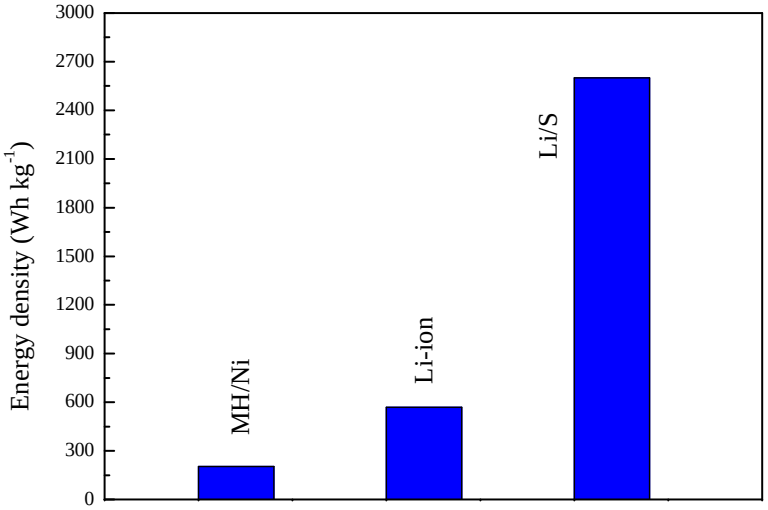
Multi-electron materials in non-aqueous electrolyte: Sulfur cathode

优势：

硫是轻元素正极材料。基于2电子反应，硫正极具有高的理论容量(1672 mAh/g)，其相应锂-硫电池的理论能量密度可达2600Wh/kg。

Advantage:

Sulfur is a light-weight element as cathode materials, which can react with metallic lithium to form Li_2S with two-electron reaction, leading to the high theoretical capacity of 1672 mAh/g and the high theoretical energy density of 2600 Wh/kg in lithium/sulfur battery.



Theoretical energy density of different batteries based on anode and cathode active materials.

多电子高比能二次电池新体系

Multi-electron sencondary batteries

提出并验证了一批多电子反应体系，涉及多种反应类型：

Put forward some multi-electron reaction systems with various types:

水溶液体系： 金属硼化物负极（晶态VB_2、TiB_2；6～11e）；

metal borides (crystal VB_2 and TiB_2；6～11e)

Aqueous systems: 储氢合金（ CoB_x, La_2Mg_{17}/Ni, 2e ）；αNi$(OH)_2$正极（ 2e ）；

Hydrogen-storage alloys (CoB_x, La_2Mg_{17}/Ni, 2e); αNi$(OH)_2$ cathode（ 2e ）

非水体系： 金属硅(锡)化物（ $FeSi_x$, SnNi 4e ）；硫碳复合材料（ S-C, 2e ）；

Non-aqueous systems: metal silicide (tin compound)（ FeSix, SnNi 4e ）; sulfur-carbon composite materials（ S-C, 2e ）

基于多电子反应理论研制的二次电池能量密度达到 350Wh/kg

The energy density of the prototype based on the multi-electron reaction theory is 350Wh/kg

2 高功率密度电池及关键材料

High power batteries and key materials

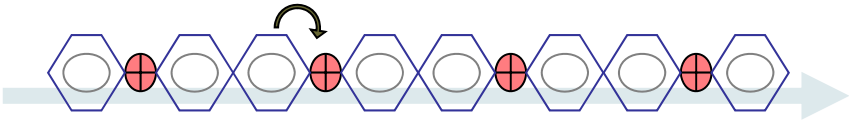
提高二次电池功率密度的途径：快速电极反应

Way to increase power density of secondary batteries: Fast electrode reaction

未来电池体系 **Future battery system**

自由基聚合物

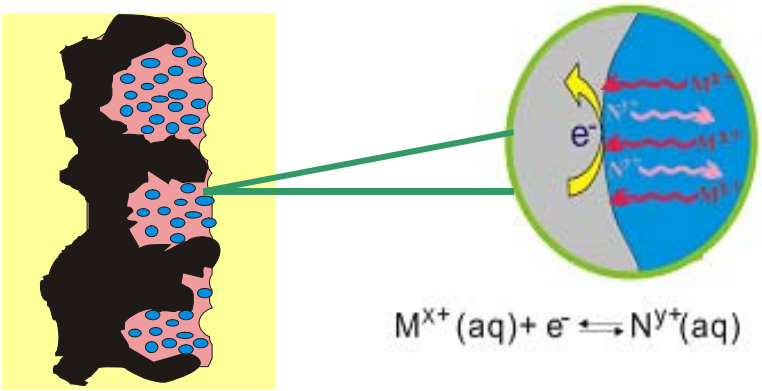
Radical polymer



薄液层储能体系

Thin liquid system

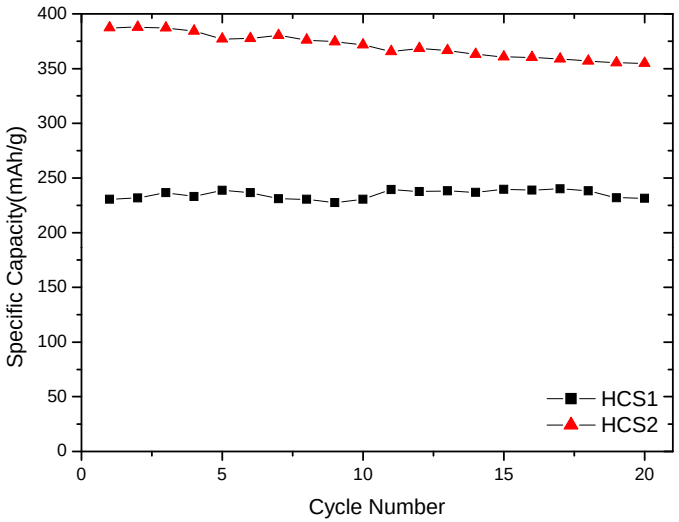
for energy storage



高功率锂离子动力电池
High power LIB

探索制备**高性能纳米微孔硬碳球嵌锂负极材料**，改善锂离子动力电池高功率性能。

A high performance micro-porous hard carbon sphere improves the high rate performances of LIB.



胶束法制备多孔硬碳材料

The porous hard carbon originated from a micelle method

高性能镍氢动力电池
High performance MH-Ni batteries

在AB_5 和$AB_{3.5}$两种电极材料对比研究的基础上，探索采用$AB_{3.5}$电极活性材料、覆钴（高价）复合氧化镍电极材料、复合电解质和大分子卟啉类添加剂等，研制开发出高性能宽温带、高功率镍氢动力电池。

Use $AB_{3.5}$ type hydrogen-storage materials, Co-coated composite nickel cathode, composite electrolyte, and functional additives, develop high power MH-Ni batteries with a wide temperate zone.

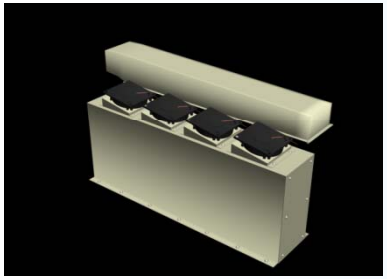
研制出具有自主知识产权的高功率（ > 1250W/kg ）镍氢动力电池和高功率（ > 1800W/kg ）锂离子动力电池

High power MH-Ni battery （ > 1260W/kg ）and high power LIB （ 1800W > /kg ）with proprietary rights

单车试验运行已完成10万公里的考核

Demonstrative operation for 100 thousand kilometers (an independent car)

8Ah/336V 电池组



8Ah/144V 电池组

研制生产的电池组已应用于东风电动、奇瑞、长安、长春一汽、沈阳华晨等公司的混合动力车。

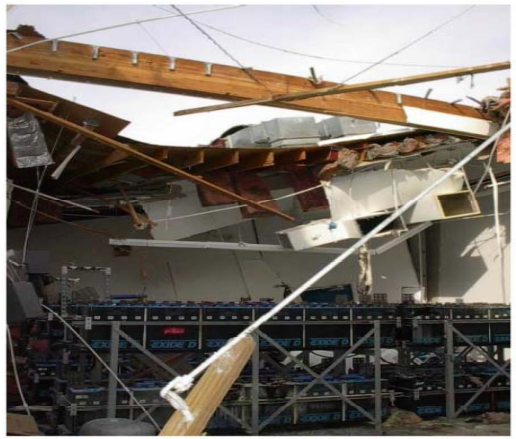
battery packages have been applied for HEV

装车试验运行

3 电池安全性 Battery safety

目前制约高能量与高功率锂离子电池应用拓展的主要问题是 **安全可靠性**。

The key issue restricting high energy and high power LIB is Safety.



锂离子电池生产企业电池爆炸

Detonation of a LIB manufactory

Figure 1--Fire Damaged PHEV Prius

电池燃烧损坏的PHEV

A destroyed PHEV

手机锂离子电池爆炸

Detonation of LIB in a mobile phone

笔记本电脑锂离子电池燃烧

Burn-up of a notebook

动力电池安全性研究进展
Progress in the safety

- 如何解决 … 性问题？
- H … nic
- … 题？
- How … away ?
- 如何改善动力锂离子电池 … 使用的安全可靠性问题？
- How to improve the safety of LIB in a wide temperate

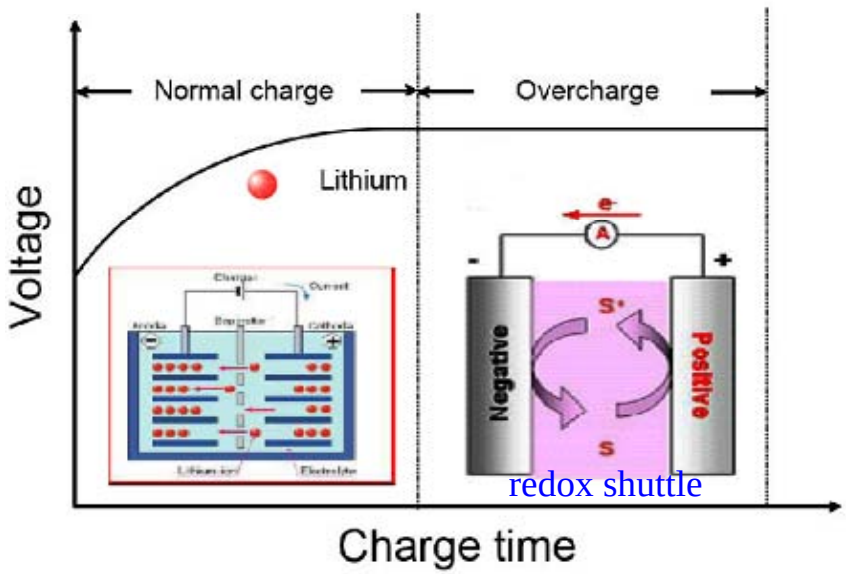
针对上述问题，应该从电池结构、电池材料、反应机制、制备工艺等多方面入手，发展了系列化的锂离子电池安全材料和技术。

A series techniques and additives for improving the battery safety have been developed for the battery construction and reaction mechanisms

氧化还原电对电压钳制
Overcharge tolerances by redox shuttles

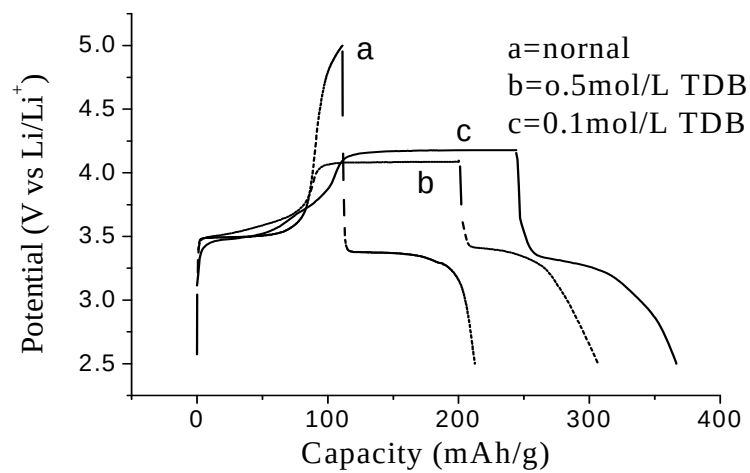
利用可逆氧化还原分子作为电解液添加剂。当电池过充电时，还原态分子在正极上氧化成氧化态分子, 随之氧化态分子扩散至负极又还原成还原态分子，如此内循环使充电电压钳制在安全值。

Once overcharged, the redox shuttle is oxidized on the positive electrode, while the oxidized species diffuses back to the negative electrode and are reduced to its original state, locking the charging voltage in acceptable region.



典型分子：二甲氧基苯

Shuttle molecule: 4-tertbutyl-1,2-dimethoxybenzen (TDB) (soluble, stable and electrochemically reversible)



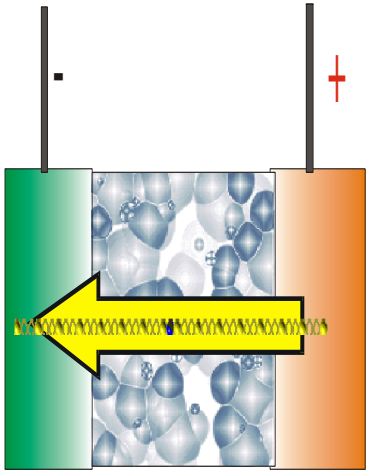
TDB对磷酸铁锂电池的过充电电压具有控制作用，且不影响正常的充放电

The TDB shuttle molecules provide feasible overcharge protection, and have indiscernible detrimental influences on the normal performances of Li/$LiFePO_4$ cells.

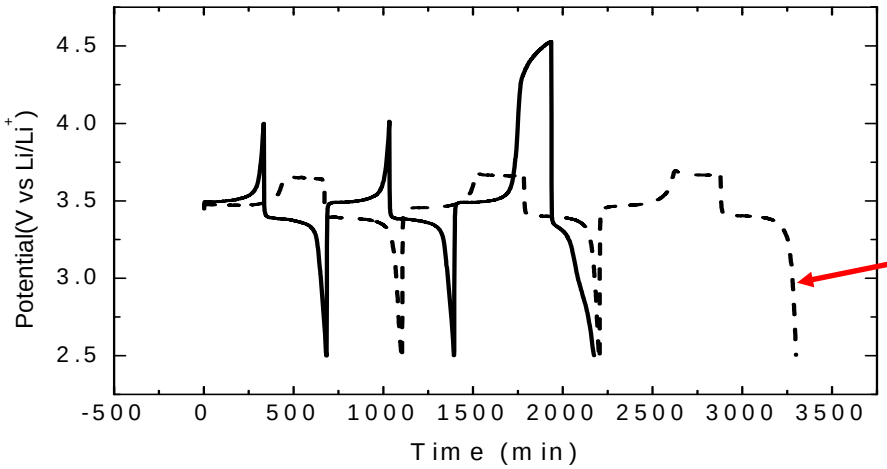
电压敏感隔膜
Switchable Separator

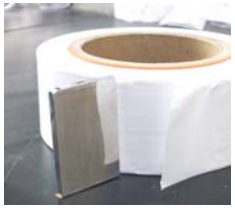
采用活性聚合物作为隔膜材料，在正常充放电电压区间呈绝缘态，只允许离子传导；而当充电电压达到控制值时，聚合物被氧化掺杂成为电子导电态，使电池内部形成短路，实现自激发内部保护。

Filled with electrochemically active polymers, the separator can transform from an isolating state to a conducting state at defined charging voltage, so as to bypass the overcharging current.



电压敏感隔膜
Switchable Separator





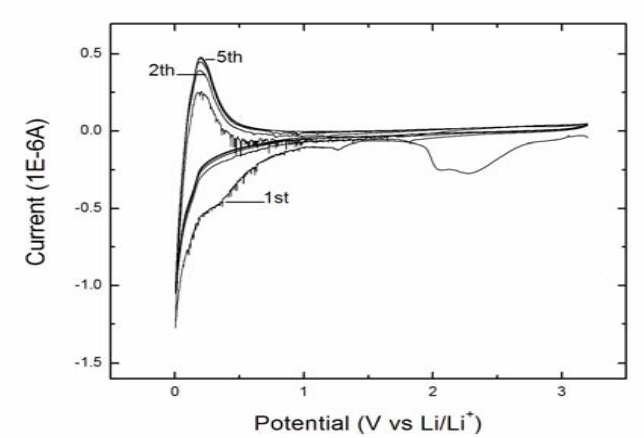
采用三苯胺修饰电活性隔膜，磷酸铁锂电池可实现电池内部保护，以维持电压在安全的范围(~3.75V)。

The electroactive membrane modified with triphenylamine (PTPan) could produce an resistive internal short circuit to maintain the voltage at the safety value of ~3.75V for Li/$LiFePO_4$ cells.

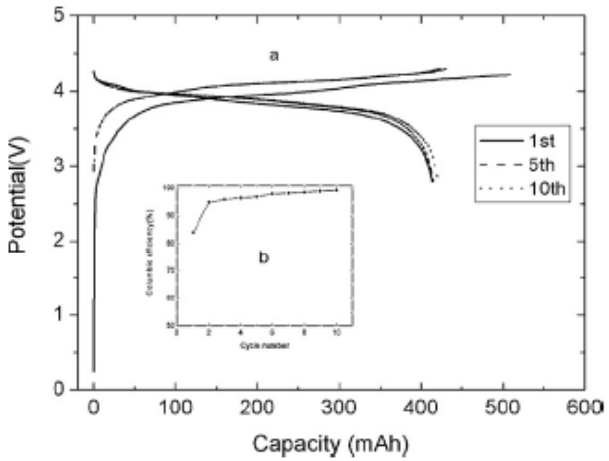
阻燃电解液添加剂
Nonflammable electrolyte solvent

为进一步抑制有机电解液的易燃性，需探索阻燃性电解液，其中磷酸脂电解液的主要问题是在石墨负极的电化学兼容性。

To further suppress the electrolyte flammability, the development of nonflammable electrolytes is necessary. Organic phosphates are strong fire-retardant and good solvents, but incompatible with graphite anode.



Graphite in DMMP +1M $LiClO_4$ + 10% Cl-EC.



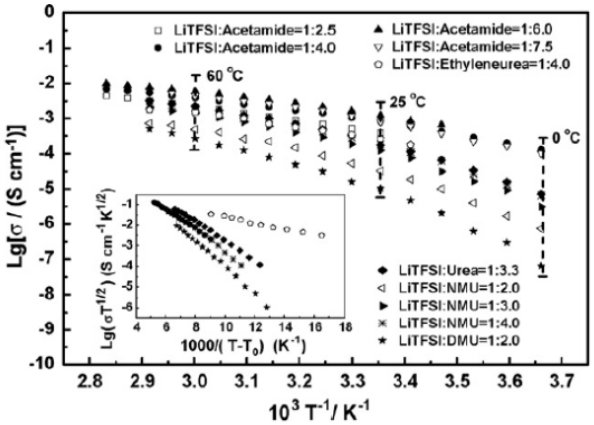
Commercial C/$LiCoO_2$ cell at 20℃, 1M $LiClO_4$ DMMP with 10% Cl-EC.

在甲基磷酸二甲酯溶液(含氯乙烯碳酸酯)中，石墨负极表现出良好可逆性，表明甲基磷酸二甲酯具有良好电化学兼容性。石墨/钴酸锂电池的充放电性质与碳酸脂无异，显示锂电池的高安全性。

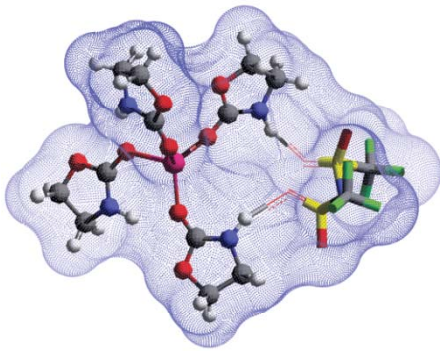
In the presence of chloro-ethylene carbonate (Cl-EC), the nonflammable dimethyl methyl phosphite (DMMP can be used as an electrolyte solvent for constructing safer Li-ion batteries.

改善锂离子电池安全性能的新型电解质材料 - 离子液体

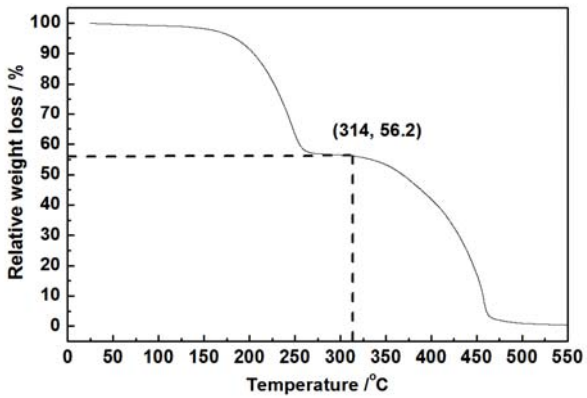
novel electrolyte materials for improving the safety of lithium ion battery– ionic liquids



Ionic conductivity



Molecular structure of of IR



TG curve of IR

应用离子液体作为新型功能电解质材料，可提高电池工作电压，获得更高的比能量；另一方面结合其不易燃、不挥发等物化特性，应用于锂离子电池可改善体系的安全性和高温特性。

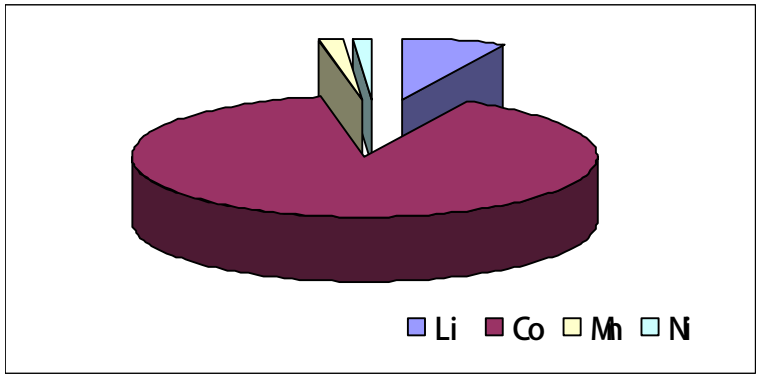
With ionic liquid as the electrolytes, the lithium ion battery can be charged to a higher voltage and therefore a higher capacity can be obtained. With high performance, such as noninflammable, negligible vapor pressure and high thermal stability, ionic liquid is considered to be a promising electrolyte candidate for lithium ion batteries with high safety and stability.

4 电池回收再生与环境影响

Battery recovery, regeneration and environmental effect

- 电动汽车电池的大量应用将面临资源与环境影响。
  Huge use of secondary batteries in electric vehicles will have great impact on battery material resources and environment.

- 需探索电池材料的绿色回收再生技术。
  “Green” technology of recovery and regeneration of battery materials should be explored.

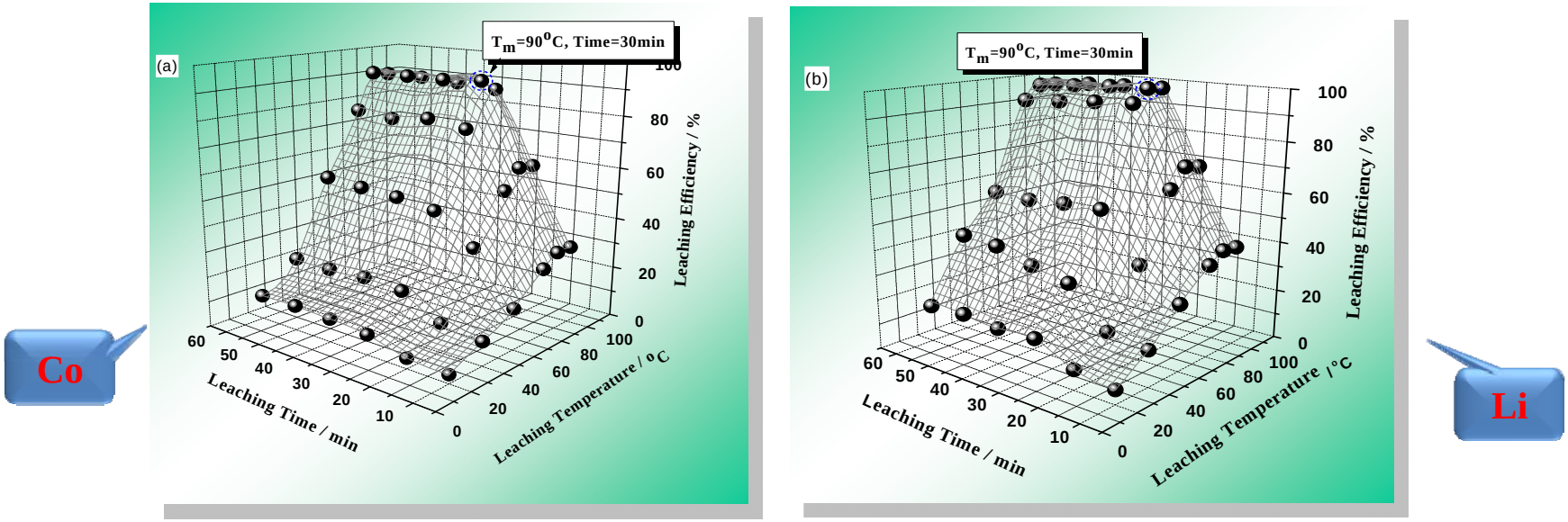


天然有机酸对钴酸锂的回收

Recovery of spent $LiCoO_2$ using natural organic acid

采用天然有机酸中易降解的柠檬酸和苹果酸对废旧电池的钴酸锂进行回收处理，将$LiCoO_2$材料中Co和Li转化相应的柠檬酸盐和苹果酸盐，金属钴离子浸出率在90%以上，锂离子的浸出率接近100%。

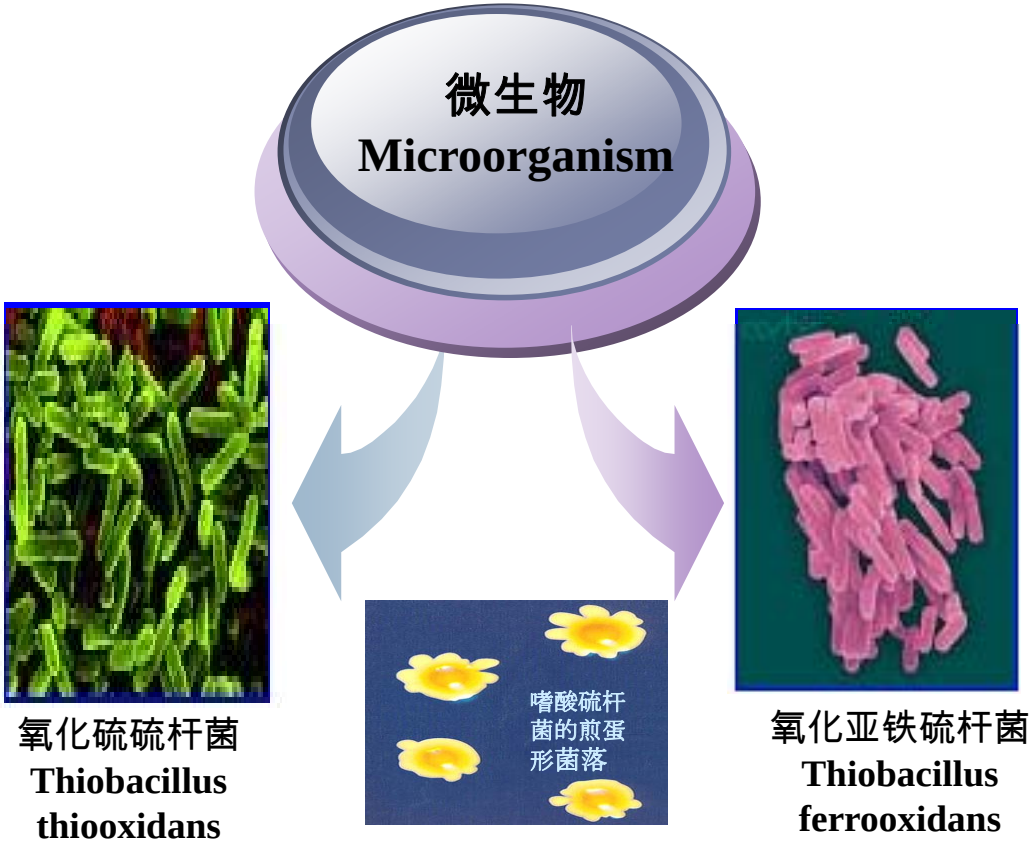
Citric acid and DL-malic acid are introduced as leaching for the recovery of cobalt and lithium from spent LIBs. When Citric acid and DL-malic acid are used, an effective recovery of Li and Co as their respective citrates is possible. The results showed that the conditions for achieving a recovery of more than 90% Co and nearly 100% Li are achieved.



Effect of leaching temperature and time on the leaching efficiency of $LiCoO_2$ with citric acid

生物淋滤技术用于电池材料的回收
Bioleaching for recovery of spent battery materials

提出生物淋滤--液膜萃取回收废旧电池中贵金属的资源化处理新思路，即通过自养型嗜酸硫杆菌将废旧电池中贵金属选择地溶解，再借助选择性液膜萃取回收，最终达到回收有用金属的目的。

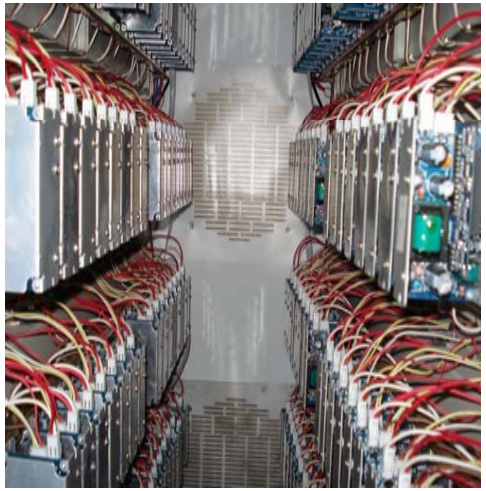


Bioleaching-liquid extraction method has been proposed and the Acidithiobacillus ferrooxidans (At.f) and Acidithiobacillus thiooxidans (At.t) were used in bio-dissolution experiments for spent batteries. Valuable metals will be selectively dissolved and then recovered using selective liquid membrane extraction. Finally the purpose of recovery for valuable metals can be achieved.

5 电池检测技术与能量回收 Battery testing and energy recovery

电池放电能量回收
Recovery of battery energy during discharging

电池放电能量回收利用技术与电池研究和生产中的节能减排密切相关。结合数字化技术，高频开关电源技术及计算机控制技术，并使所设计的充放电源拓扑结构达到高控制精度，实现动力锂离子电池检测、化成过程中放电能量的回收，可节能50%以上。·

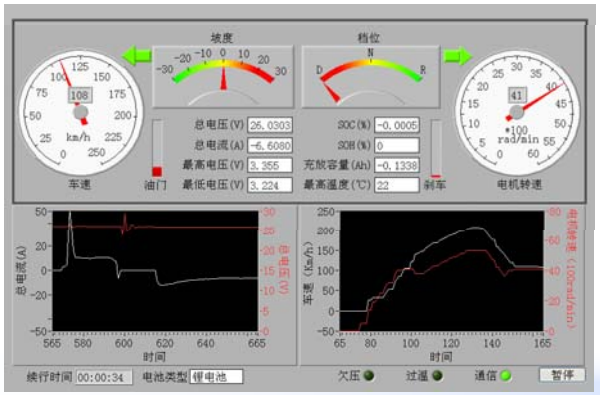


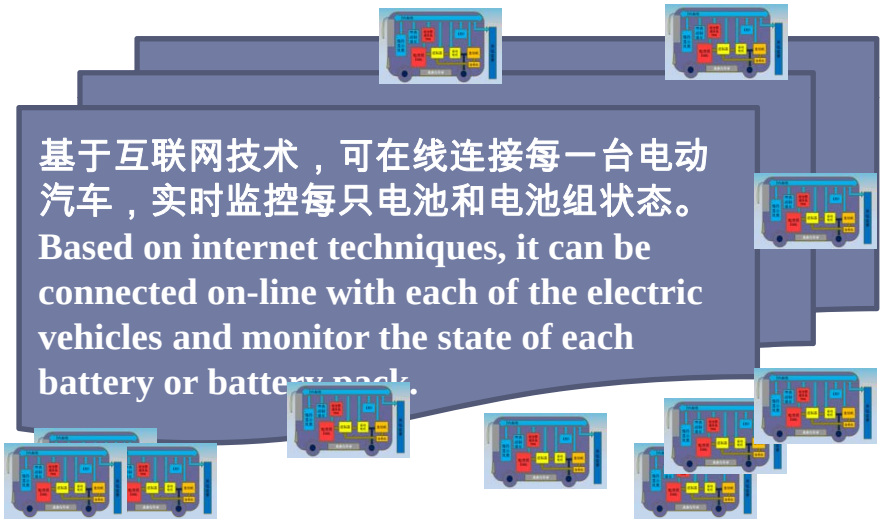
The technology of batteries discharge energy recycle has deep connection with the saving energy and reducing environment pollution during the process of battery researches and production. With the digital technology, the switch power supply technology and the computer-control technology，The topology structure we designed has a high control precision, so that The technology of discharge energy recycle of li-ion power batteries has come to realization, and over 50% energy can be recycled.

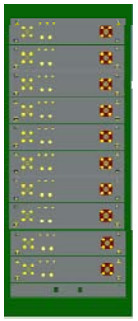
电动汽车电池仿真系统
Electric vehicle battery simulation system

可实现电动车运行实测数据的仿真，分析电池的性能。结合互联网技术，实现在线数据共享。

The on-line data simulation of the electric vehicle motion and the battery performance analysis can be realized. With the help of internet techniques, the on-line data can be shared.

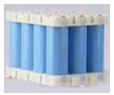






Battery system

Battery pack



Batteries

中国动力电池亟待解决的问题
Problem demanding prompt solution

动力电池突破技术
Breakthrough of Power Battries

电池 | 模块 | 控制 | 检测 | 标准

- 进一步
- 进一步
- 进一步
- 进一步
- 探索新型材料，提高性能，降低成本

- 安全性的测试与
- 循环寿命的测试
- 日历寿命的测试

- 动力电池单体系列化及规
- 动力电池安全性；
- 动力电池循环耐久性；
- 动力电池系统（含管理系统）

- 镍氢动力电池(MH-Ni)
- 锂离子动力电池(LIB)

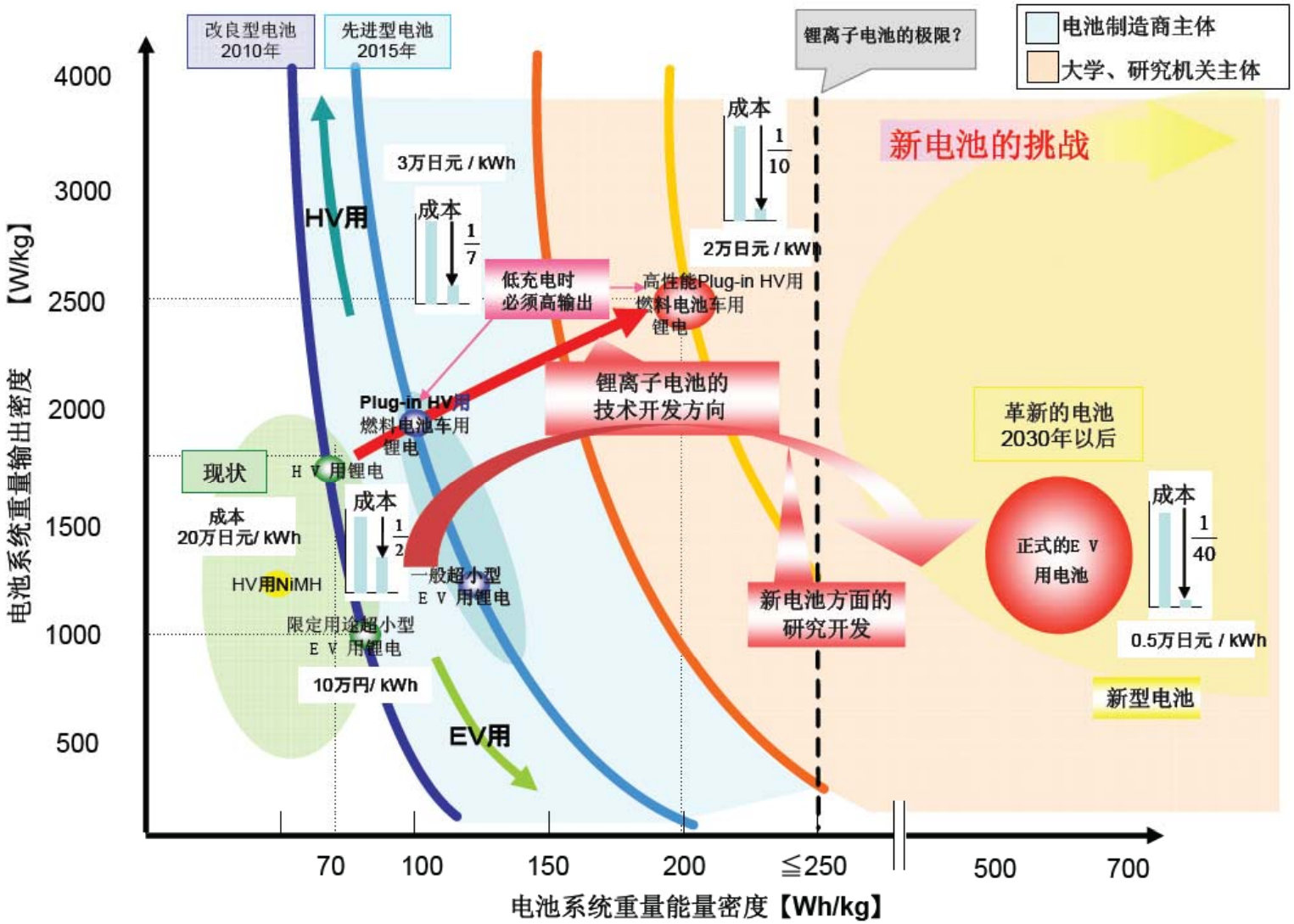
- 单体和模块(Battery and package)
- 系统(system)

- HEV
- PHEV

- 高功率型(High Power)
- 高能量型(High energy)

也系
应性等

日本NEDO锂离子电池计划目标
The targets of NEDO Japan



Viewpoints

- 锂离子动力电池是EV和PHEV较为理想的动力电源，进一步提高其安全性能，降低电池、材料和管理系统成本，将会得到日益广泛的应用。
- **LIB is an ideal power battery for EV and HEV. It will be popular used on condition that improving the safety and reducing the cost.**
- 镍氢动力电池作为当今HEV的主流动力电池，已有二百万辆HEV的销售业绩，在今后相当长的时间内仍将是HEV的主要动力电池之一。
- **As the major power battery for the present HEV, which has a sale record more than 2 million, MH-Ni battery will still serve as one of the major power batteries.**
- 中国锂和稀土资源丰富，有利于锂离子和镍氢动力电池及相关材料产业的发展。
- **The abundance of Chinese lithium and rare earth resources is a impetus for the development of power batteries and relative industry.**
- 新一代绿色二次电池的问世和发展，将为电动汽车提供更高性价比的电源。
- **The coming out green secondary batteries will give high cost performance power supply for EV and HEV.**

Viewpoints

有人说电池是被“打包了的能源”，我觉得电动汽车就像是把“汽车插上了翅膀”，电动汽车、动力电池及相关材料产业的腾飞，在全球将产生更为丰富多彩的创新和就业机会，为生活在21世纪的人们带来了新的憧憬和希望。中美两国有值得称颂的合作历史，有令人羡慕的资源和市场，只要我们真诚合作，就可以谱写出惠及子孙的新篇章。让历史记住北京，记住芝加哥，让我们同心携手，共创辉煌！

As the others say that the battery is a package of energy, I would say that the electric vehicles will be the new concept vehicle with wings, which development can make the related industries fly. This will bring us a colorful world with new innovations, new hopes, new life style and new jobs. (just like the container brings great changes for the belt line as well as the whole society). Sino-US cooperation will benefit both great countries, where the huge market and nature resources are admired, especially benefit our next generation. Beijing and Chicago will be remembered in the history.

We wish US-China sincere and successful cooperation in future!

Thank you for your attention!