materials valley

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materials for a better life

ELEKTROCHEMISCHE ENERGIE-SPEICHER- UND WANDLERSYSTEME

16:20 Uhr **Übersicht über Batterie Typen aus Sicht eines Batterie-Materialien Herstellers**
Dr. Marcel Meeus, Umicore AG & Co. KG, Olen, Belgien

HEV/PHEV/EV Roadmap battery developments

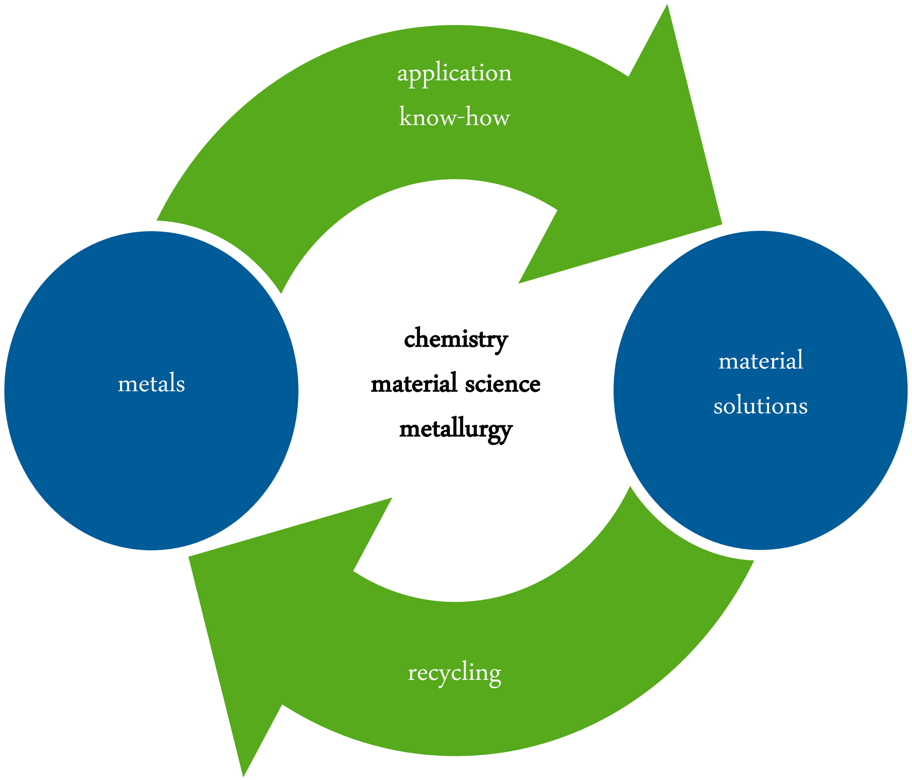
Agenda

1. Umicore materials supplier to the battery industry
2. Generic insight battery technologies, opportunities and challenges
3. Further advances to increase performances and reduce cost
4. Pace of technology evolution
5. Some specifics for HEV/EV
6. Conclusions
7. Glossary

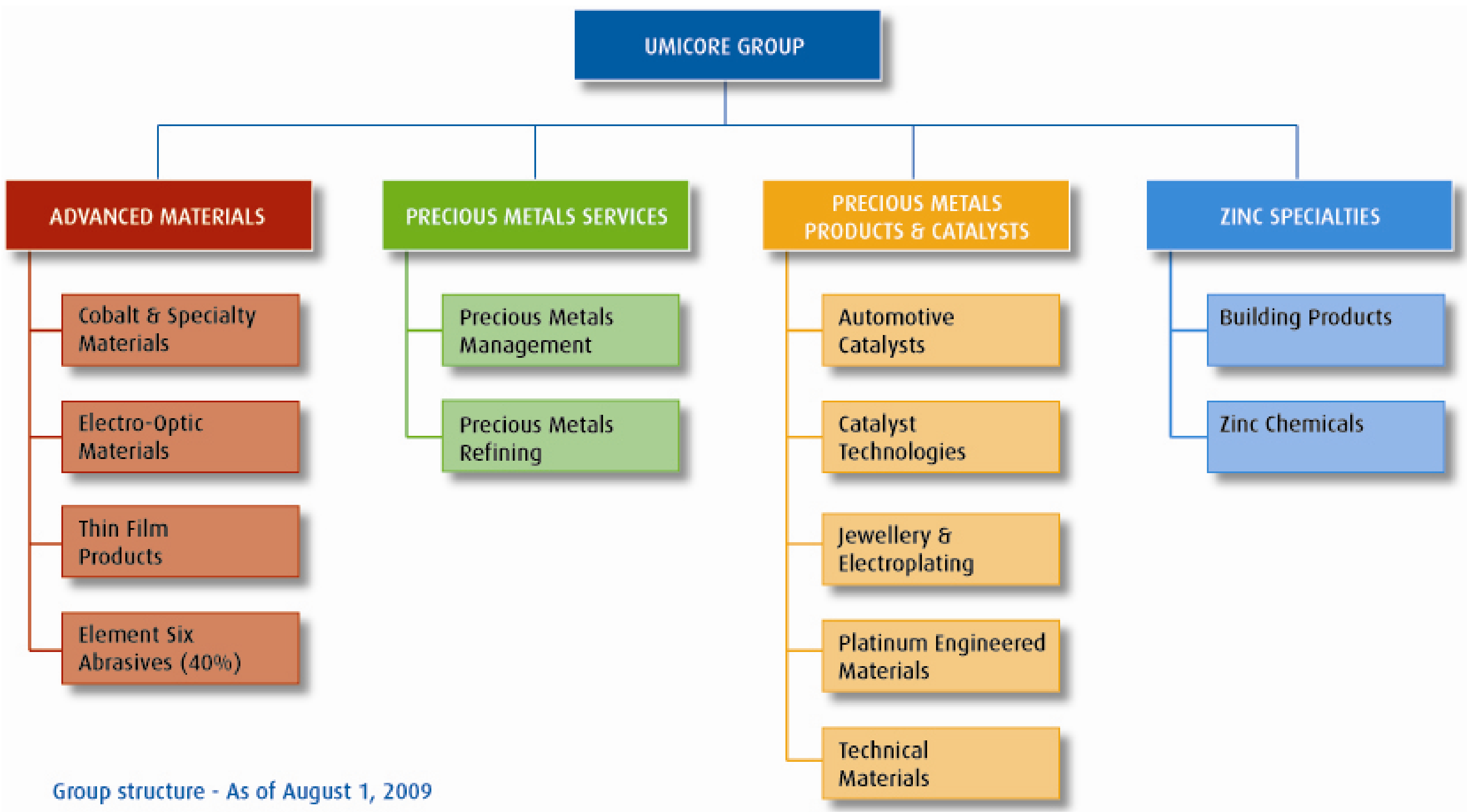
Umicore today – a materials technology group

“Less is more”

Metal related materials can be efficiently and infinitely recycled, which makes them the basis for sustainable products and services



A decentralised, customer-focused organisation



Umicore is committed to all rechargeable battery systems (… and to Zn primary as well)

Overpelt (Belgium)

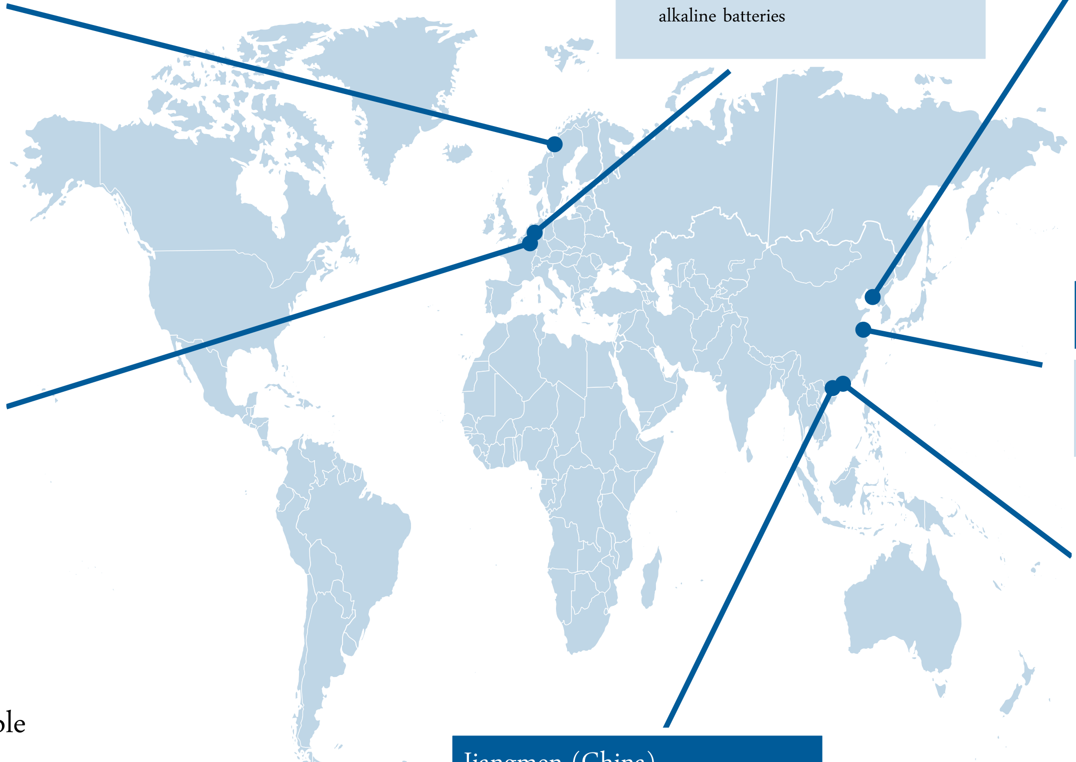
- Zn Powders for primary alkaline batteries

Hofors (Sweden)

- Battery recycling
- Pyrometallurgy
- Closed-loop

Cheonan (Korea)

- Cathode material production
- Application Lab
- Research & Technology
- Powder Technology



Shanghai (China)

- Zn Powders for primary alkaline batteries

Olen (Belgium)

- Headquarters
- R&D
- Precursor production
- Resources efficient

Jiangmen (China)

- JV (60%)
- Precursor production
- Cathode material production

Total workforce: >500 people

Jiangmen (China)

- JV (40%)
- Ni-hydroxide production
- Cost-efficient/high-volume

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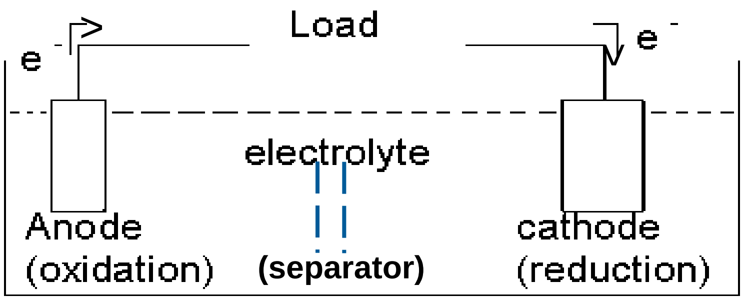
Electrochemical cell – basic components



- The anode (Greek anodos, way up) is the electrode at which oxidation takes place and electrons are fed into the external circuit. The cathode (Greek cathodos, way down) is the electrode at which reduction takes place and into which electrons are fed from the external circuit.
- In a primary cell, the anode is also the "negative" electrode and the cathode, the "positive" electrode. In a secondary cell on charge, the negative electrode becomes the cathode and the positive electrode, the anode.
- The electrolyte serves as a medium for completing the electrical circuit via the transport of ions.
- The reactants comprising the electrodes may be gaseous, liquid or solid, massive or porous. The electrolyte may be liquid or solid.

A wide portfolio of primary and rechargeable battery chemistries serves portable, automotive and stationary applications.

Wide portfolio of battery chemistries (non-exhaustive list)

Positive \ Negative	H_2	MH	Zn	Pb	Cd	Fe	Li	LiC_6	Al	Na
O_2	Fuel cell		KOH Zn/air				Organic Li/Air		KOH	
PbO_2				H_2SO_4 Pb/acid						
MnO_2			KOH $ZnCl_2$				organic			
NiOOH	KOH	KOH	KOH		KOH	KOH				
HgO			KOH							
AgO		KOH	KOH							
$LiCoO_2$								organic		
$LiNiO_2$								organic		
$LiMn_2O_4$								organic		
$LiNiMnCoO_2$								organic		
$LiFePO_4$								organic		
I,Br,S			aq.							
$(CF_x)_n$							organic			
S							Li/S			High t° Na/S

Green: Most important commercial cells (Fuel cell; Zn/air excluded; H_2SO_4 Pb/acid; KOH $ZnCl_2$; NiOOH with MH, Zn, Cd; HgO and AgO with Zn; LiC_6 organic cells)

Pink: New systems in development (KOH Zn/air; Organic Li/Air; Li/S; High t° Na/S)

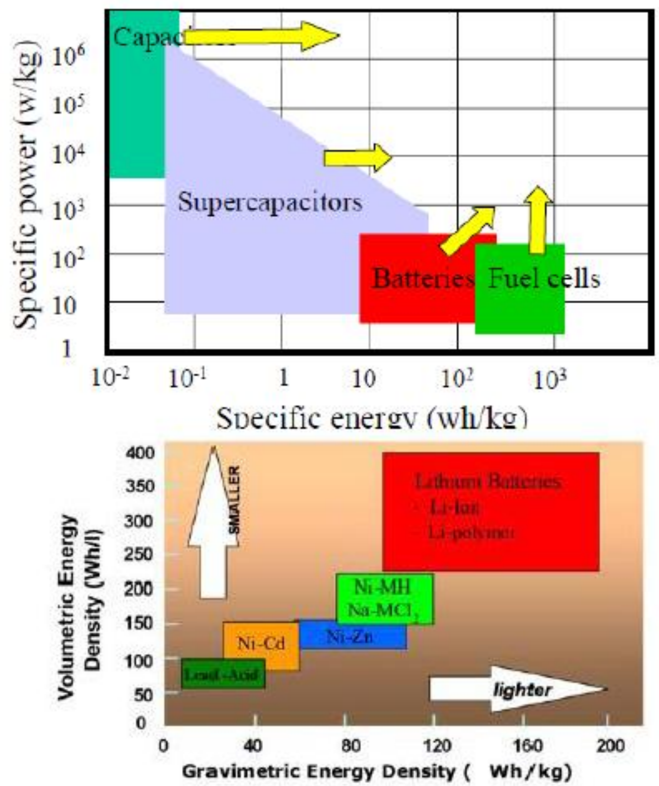
Overview of major rechargeable batteries

	NiCd	NiMH	Li-ion
Introduction	1956	1989	1992
Voltage	1.2V	1.2V	3.6-3.7V
Energy density	40Wh/kg 150Wh/L	80Wh/kg 300Wh/L	160Wh/kg 450Wh/L
Applications	Power tools Emergency lighting R/C toys	Cordless phones Household Replace alkaline	Portable electronics Power tools Gen #2 HEV
Umicore presence	Reducing	Moderate	Strong

Key Parameters

- Energy Density
- Power density
- Cycle life, Lifetime
- Charging rate
- Temperature stability
- Safety, Cost
- Manufacturability

Optimization strategy aligned with applications

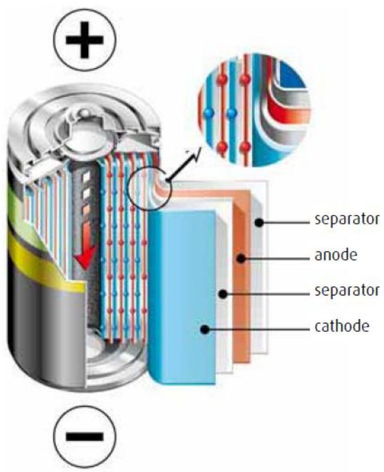


Basic Energy Workshop, Office of Science, DOE 2007

Trends

NiMH (1.2V)	→	Li-Ion (~3.6V)	→	Advanced Li-Ion (3.6V and more)	→	New Systems

Current Li-ion battery materials



- Anode (= negative)
  - graphite/carbon
- Separator
  - Ion permeable inert membrane
- Cathode (= positive)
  - Lithium cobaltite and new generation materials
- Electrolyte
  - Liquid or gel

Charge: Li-ions from cathode to anode

Discharge: Li-ions from anode to cathode

Li-Ion → Advanced Li-Ion

Continuous improvement to Advanced Li-ion systems

-> New cathode materials

LiCoO2

↓

NMC (1/3Ni, 1/3Mn, 1/3 Co or high Mn formulations)

or

NCA (Ni, Co, Al)

or

LMO (Mn spinel)

or

mixtures

or

LiFePO4

ongoing

-> 5V cathode materials in development

-> In combination with new electrolytes (**solid polymer** or **ionic liquids** ≥ 5V)

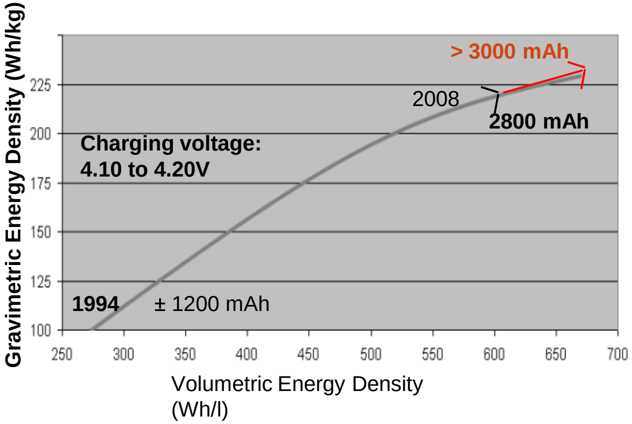
-> New anode materials

graphite (372 mAh/g)

0.1V

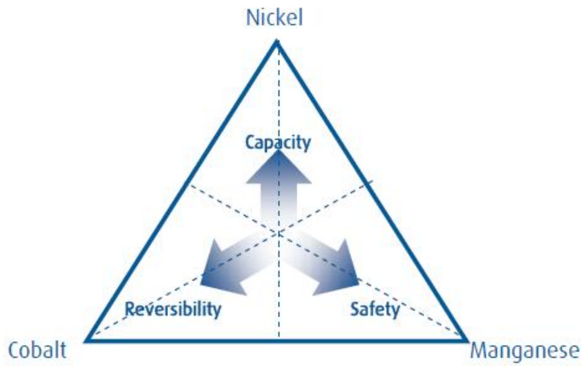
$Li_4Ti_5O_{12}$ commercial (1.5V)

Si,Sn/C… composite materials in development (1000-4000 mAh/g) (0.1V)



Cathode material evolution

- Mixed compounds (eg NMC: Ni/Co/Mn) for example Cellcore MX® introduced since 2005
- NMC compounds reduce cobalt use; first enters low-mid end
- Other materials for future generations of Li-ion technology

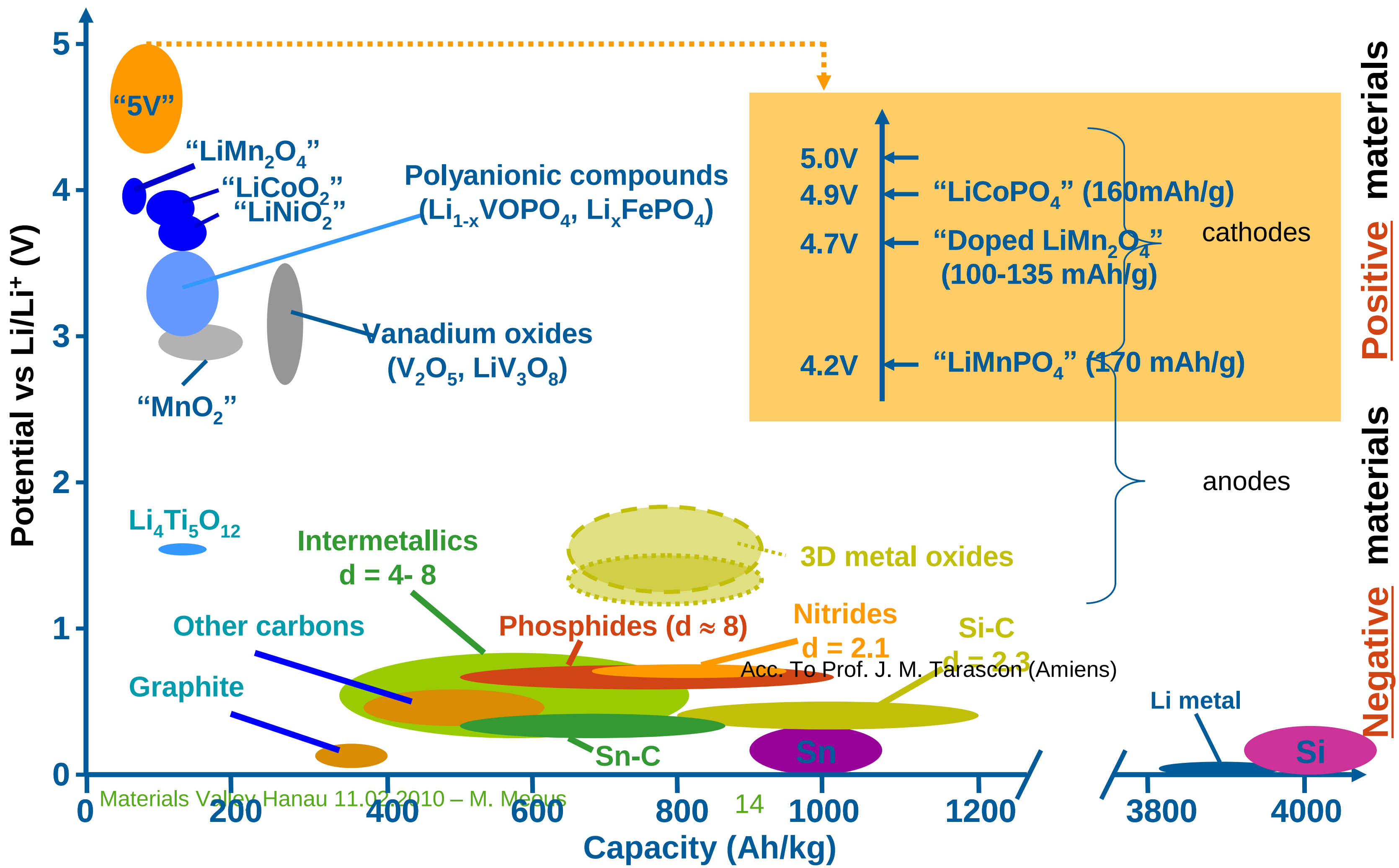


Some battery specifics ~ # cathodes (C anode)

	Cap. Cathode mAh/g	Cap. Batt.	Safety	Cyclability	Cost
$LiCoO_2$	160	++	++	++	+
$LiNiO_2$	170	+++	+	+	+
$LiNiMnCoO_2$	130-160	++	++	++	++
$LiMn_2O_4$	120	+	++++	+	+++
$LiFePO_4$	160	+	++++	++	+++

New chemistries anodes and cathodes

Various cathode and anode materials for LIB are studied to further improve capacities:



New chemistries anodes and cathodes

Cathodes -> more safety, higher potential, higher capacity

NANOTECHNOLOGIES

Anodes -> replacement of C by new materials with higher capacity (e.g. Sn and Si based intermetallics)

Problem to be overcome is swelling of the new materials

New rechargeable energy storage systems in development: Focus >> 400 Wh/kg, >> 1000 Wh/l

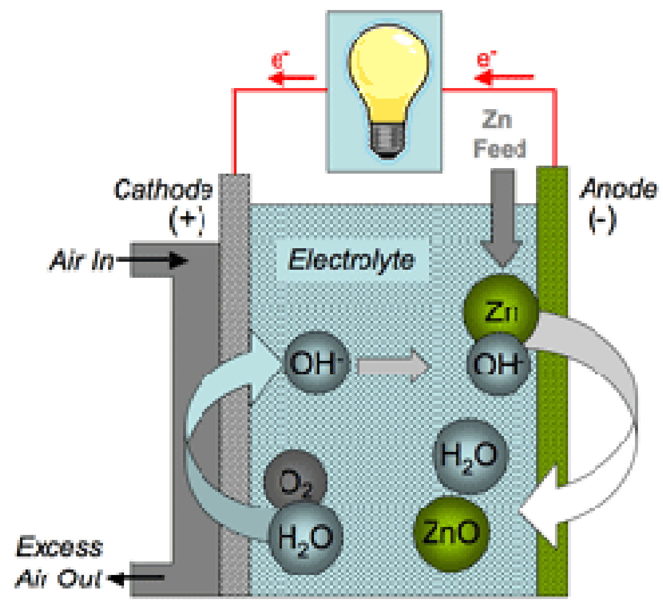
• Zn-Air

(1,6V, ± 500 Wh/kg, ± 1500 Wh/l practical values)

Electrolyte – Aqueous KOH
Negative – metal – Zinc
Positive – reversible air electrode – carbon with catalyst

- Power density is still uncertain. Carbon/carbon supercapacitors or a hybrid capacitor could be used for high pulse power.
- Electrical rechargeability still confronted with fundamental problems:shape change and dendrite formation. Solutions are still actively pursued

Zinc + Air = Energy

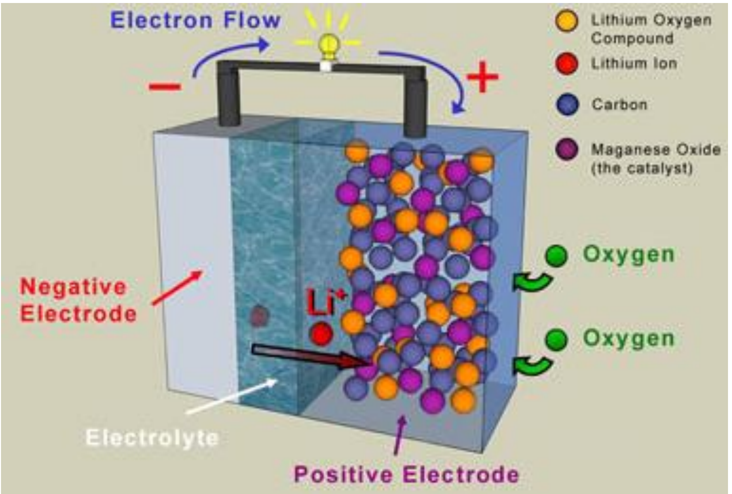


Ref. Powerair Corp.

New rechargeable energy storage systems in development: Focus >> 400 Wh/kg, >> 1000 Wh/l

Li-Air

(3,4V, ± 1300 Wh/kg)
practical values



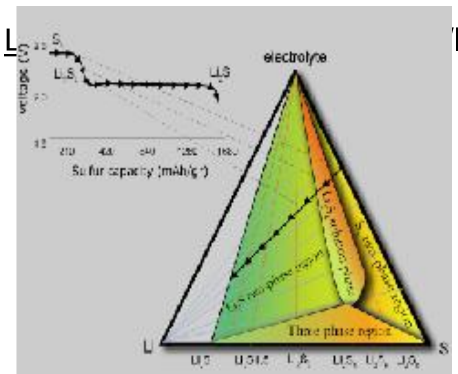
Univ. St. Andrews (P. Bruce)

<u>Battery of the future??</u>

Issues:

- Electrolyte choice/organic – aqueous
- Reversibility, cyclability
- Safety

Sulphur based batteries



PolyPlus Battery Company

Liquid cathode, safety ?, tolerant of overvoltages
Important players: Sion Power
Intellikraft Ltd.
Poly Plus Battery Cy …

High temperature system more developed for electricity storage for grid support (NGK Insulators Japan)

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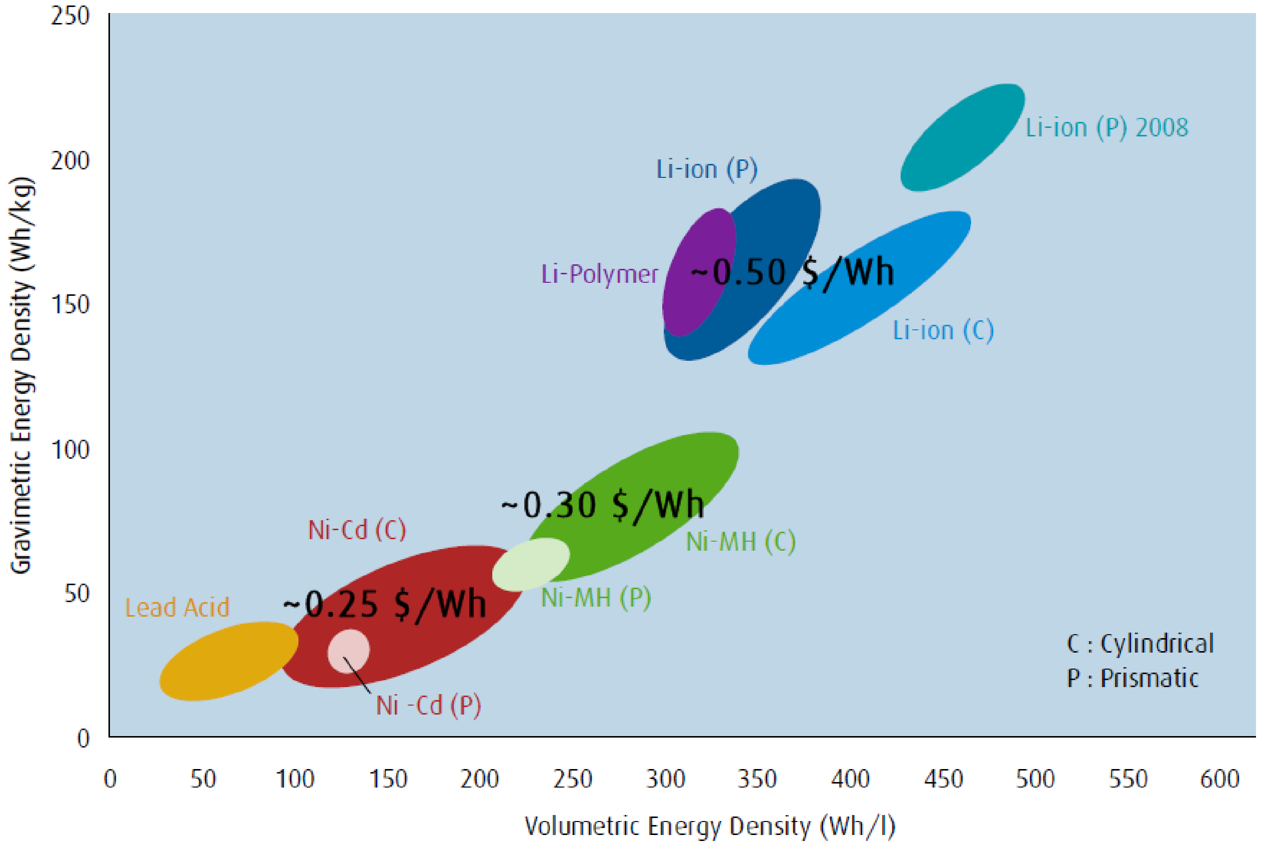
Further advances to increase performance and reduce cost



Focus Li-ion

Present average cost at cell manufacture level in $/kWh:

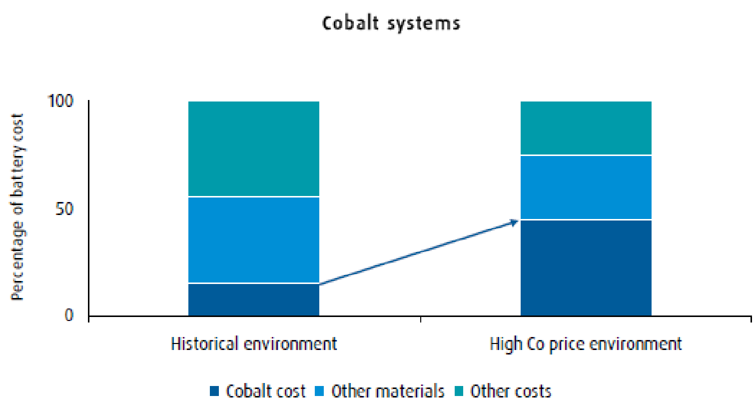
- Consumer electronics : 400 – 500
- HEV : 700 – 800 (pack price is 1000 – 1200)
- Target HEV : ≤ 250 (e.g. USABC targets)

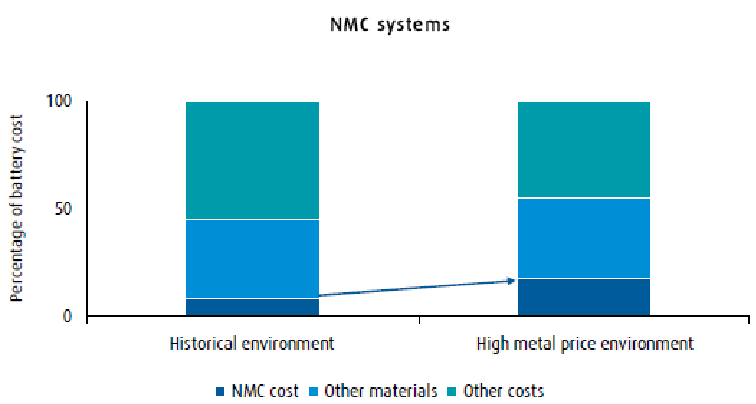
<u>How to achieve this?</u>

1. Increase cell/module capacity: advanced Li-Ion, new systems (see previous chapter)
2. Reduce material cost: $LiCoO_2$ -> cheaper materials (see previous chapter)
3. Automation and mass production (HEV/EV)

Current cost structure in Li-ion battery industry

- Two different models: Japan/Korea (automated) vs China (more manual)
- For the Japan/Korea model: materials > 50% of the total battery cost
- The pressure will remain on finding new materials that reduce/eliminate cobalt use





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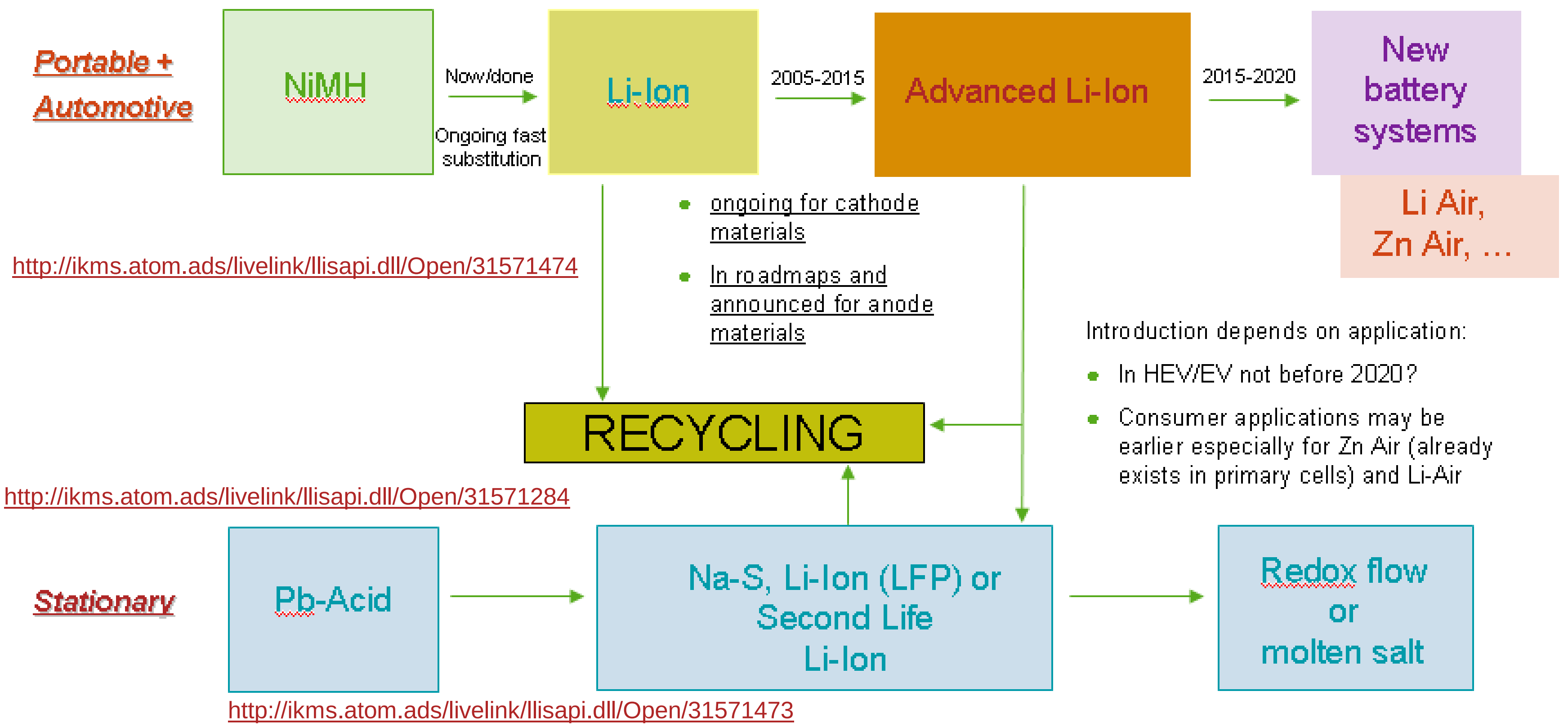
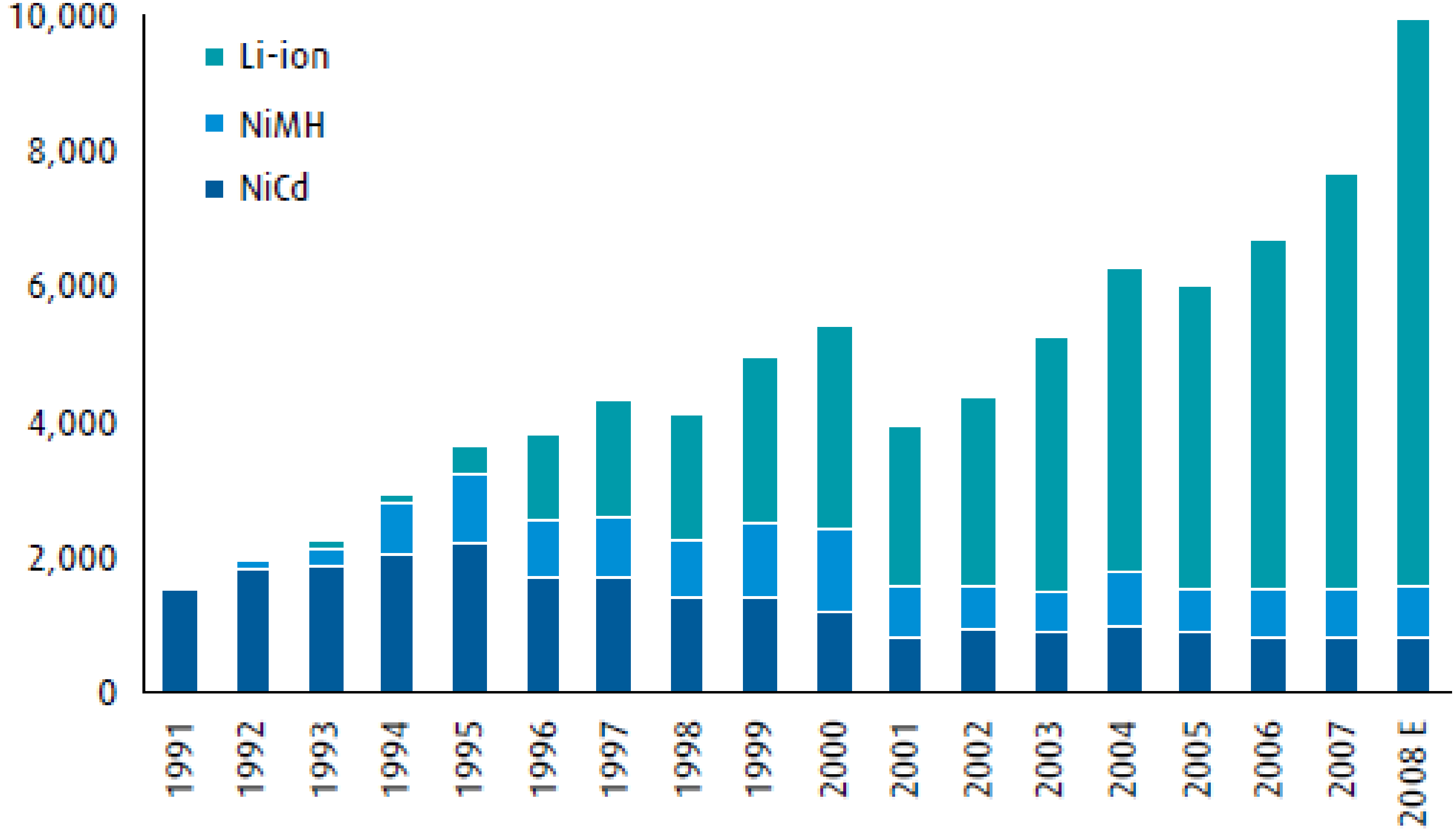
New technologies continuously change the battery landscape – timeline

Timeline for implementation of new technologies

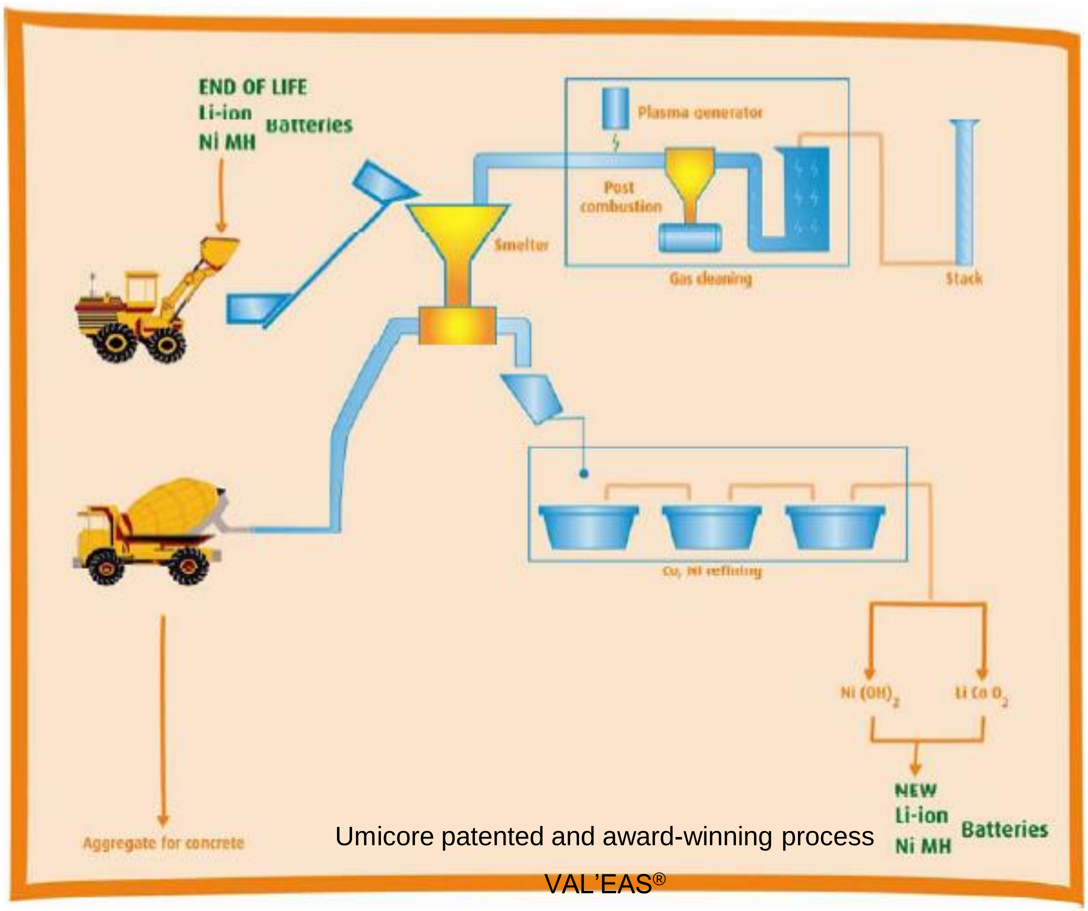


Rechargeable Battery Market value (in M$/yr)



Source : IIT + internal data (2008)

Critical step to Li-Ion and new battery systems further market development is to offer recycling capabilities



Umicore patented and award-winning process

VAL'EAS®

Possibilities for Umicore in stationary energy storage:

Overview: Stationary energy storage: partial fit for Li-ion battery technology

PV connected residential, commercial or small utility owned systems	Load leveling, management peak demand, Improvement power quality, smart grids, …

15 KWh — 1 MWh — Multi MWh range

<u>Li-Ion first life</u>	Na-S batteries
<u>Li-Ion second life</u>	Compressed air energy storage (CAES)
Na-S batteries	Pumped hydro …
	Others

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Rechargeable Battery Materials for Power applications (P)HEV/EV – Technology status - Summary

➢Various types of electrified vehicles:

- **Micro hybrids** (BMW, PSA start stop …): Pb-Acid or supercapacitor. No room for Li-ion before replacement of SLI Pb-Acid battery (~2020)
- **Mild hybrids** (S Class, BMW 7 series, Honda Insight …): First generation Li-ion implemented with need for **< 1.2kWh** energy on board. Very high power required (Power/Energy > 15).
- **Strong/Full hybrids** (Prius): Currently NiMH. Li-ion to be implemented with need for **1.5-2kWh** energy on board. Very high power required (Power/Energy ~10) also on charge (regenerative braking).
- **Plug-in Hybrid** (Volt, Prius GIII): 20-60km pure electric range with need for **9-16kWh** energy on board. High power required (Power/Energy ~5)
- **Pure electric** (IMiev, e-Smart …): 150km pure electric range min. with need for **16-35kWh** energy on board. Medium to high power required (Power/Energy ~3).

Reference

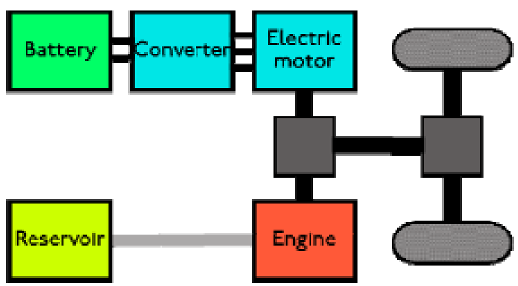
- 1l diesel: 9,9 kWh/l = 11,8 kWh/kg
- Li-Ion = 100 – 175 Wh/kg (or diesel 118 – 67 better, say 100)
- If efficiency of combustion engine is 5x lower than electric system, the Li-Ion battery is by factor 20 heavier.

Rechargeable Battery Materials for Power applications (P)HEV/EV – Technology status – Summary (2)

- Battery related challenges:
  - **Lifetime:** Warranty over 10y/150000kms for HEV/PHEV challenging
  - **Temperature management**: Extreme T to be avoided. Additional cooling/heating systems implemented
  - **Volumetric energy density** for pure EVs: 300km range would result in very big battery in the car.
  - **Safety:** Need for external safety devices (electronics, cooling system) adding to the cost/size of battery pack.
  - **Cost:** Current Li-ion cost is believed to be **~1000 USD/kWh**, target being **~250USD/kWh**

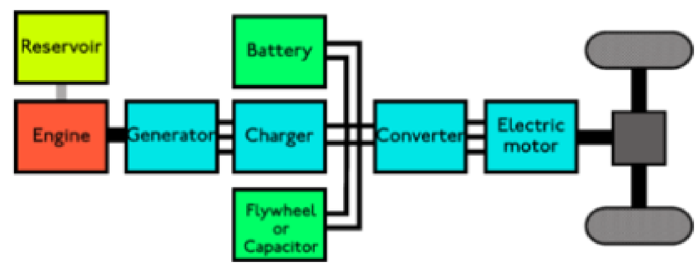
Developed propulsions are either hybrid, plug-in hybrid or fully electric. Hybrid propulsions can be classified according to the drive train design (parallel hybrids or serial hybrids)

Both – ICE as well as EM – used for traction



Parallel hybrid

ICE has no mechanical connection to the wheels – only used to drive generator

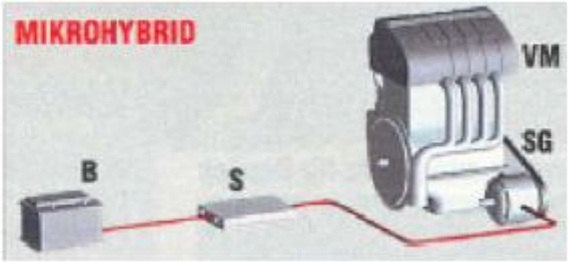


Serial hybrid

Hybrid propulsions can also be classified according to the installed electrical power:

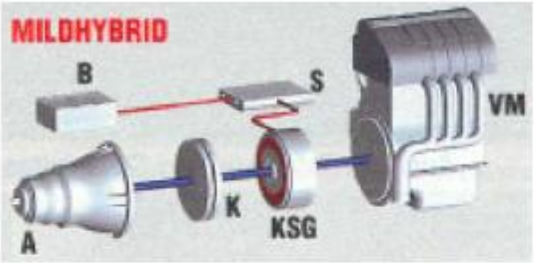
Micro Hybrid:

- PEM < 6 kW (electric motor not for direct driving)
- Voltage: 14V
- Start-Stop function
- Fuel economy: 3 – 6%
- Additional cost: 300 – 800€



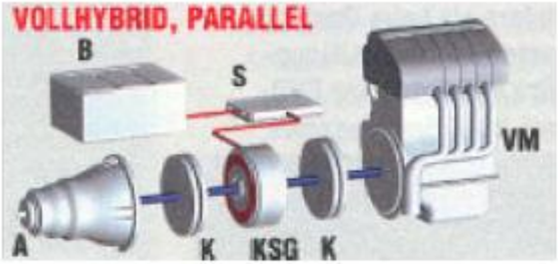
Mild Hybrid (mild/full have also 14V battery on board):

- P_{EM} ~6 – 20 kW
- Voltage: 42 – 150V
- Start-Stop function; boosting; recuperation
- Fuel economy: 10 – 20%
- Additional cost: 1000 – 2000€



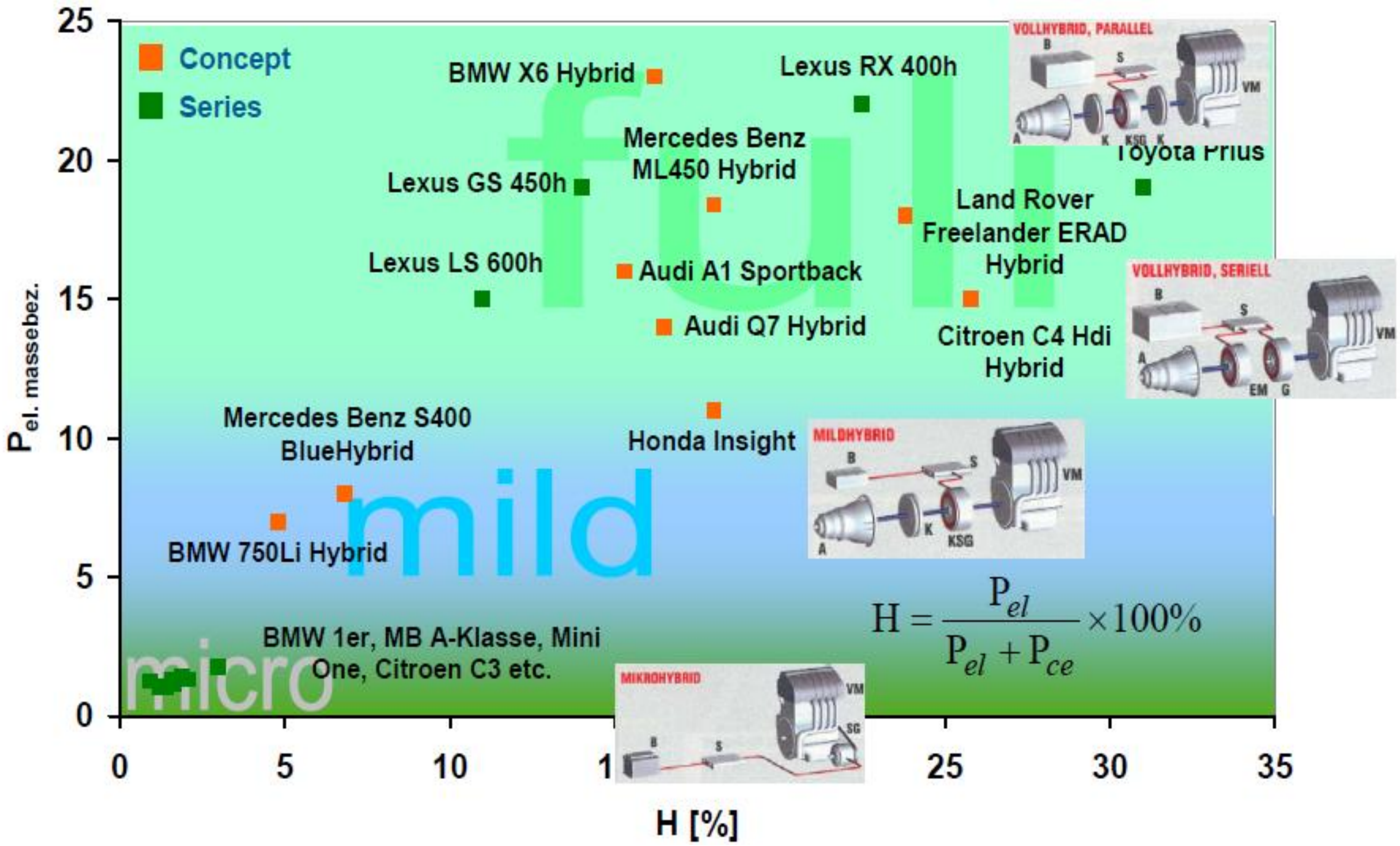
Full Hybrid:

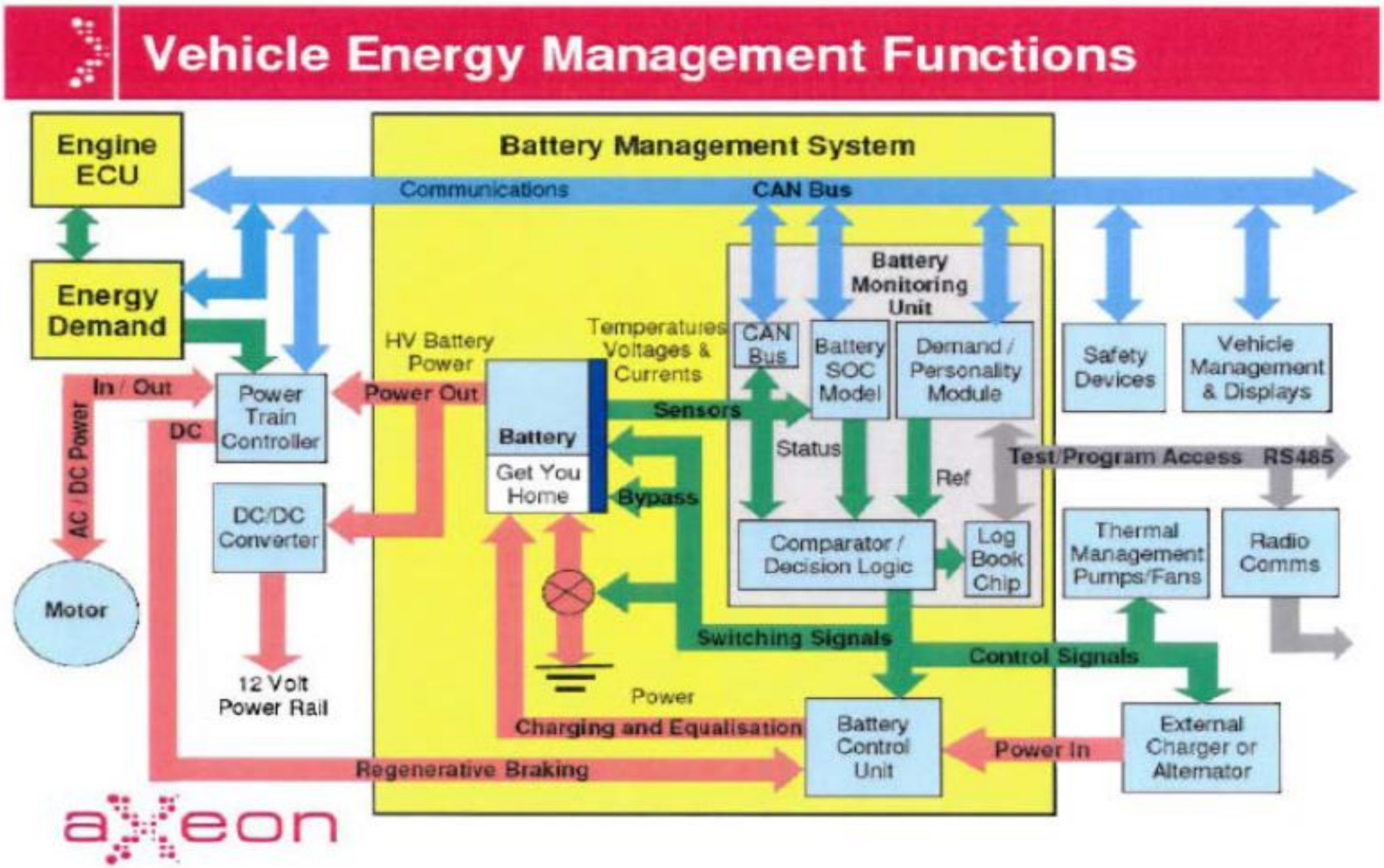
- P_{EM} > 40 kW
- Voltage: 150 – 600V
- Limiting factor is max. ampère (100?)
- Start-Stop function; boosting; recuperation; full electric driving
- Fuel economy: 30 – 40%
- Additional cost: 4000 – 8000€



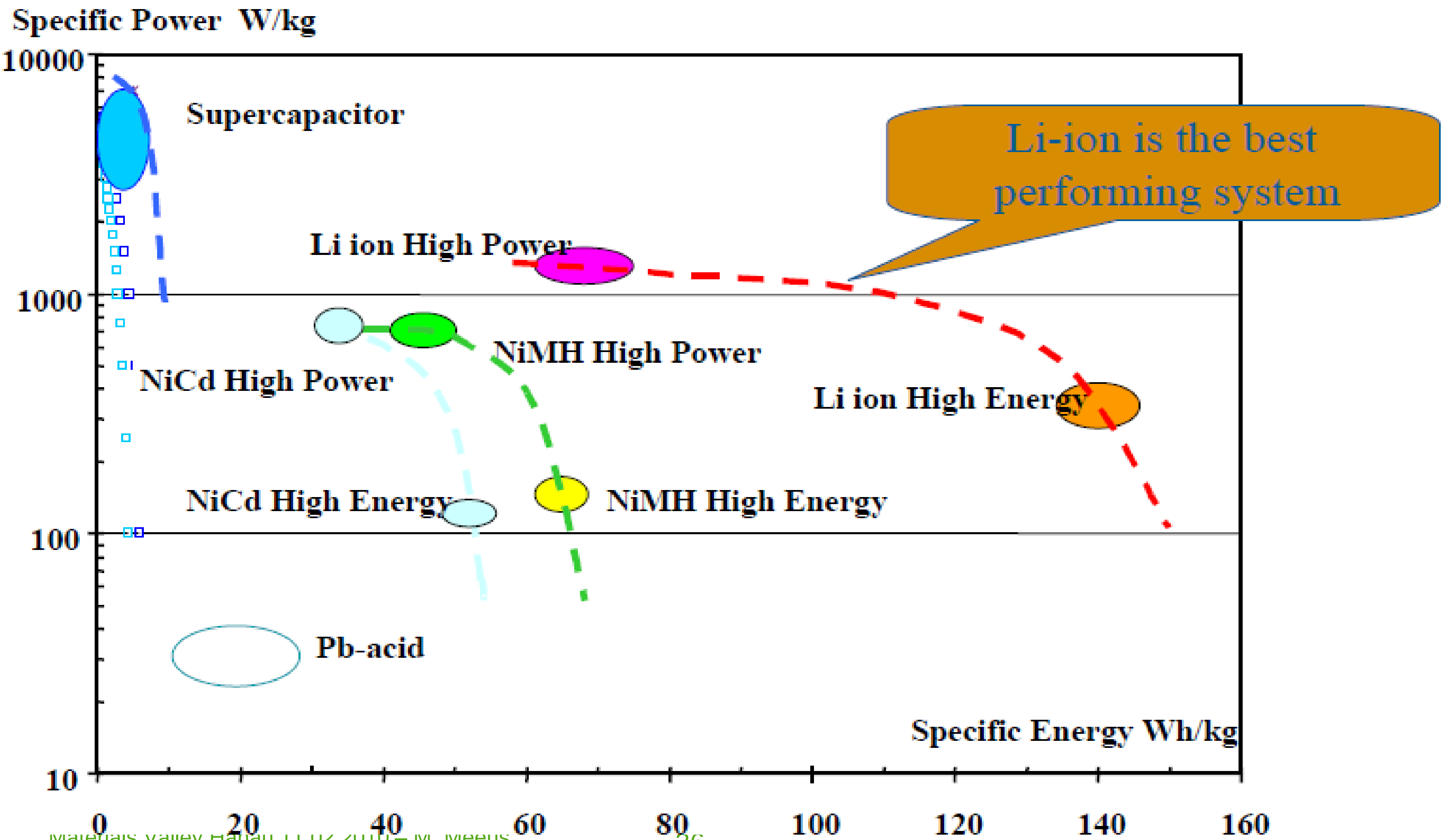
Ref.: VDA symposia “Innovative Fahrzeugantriebe 2008” Dresden

Today's market solutions

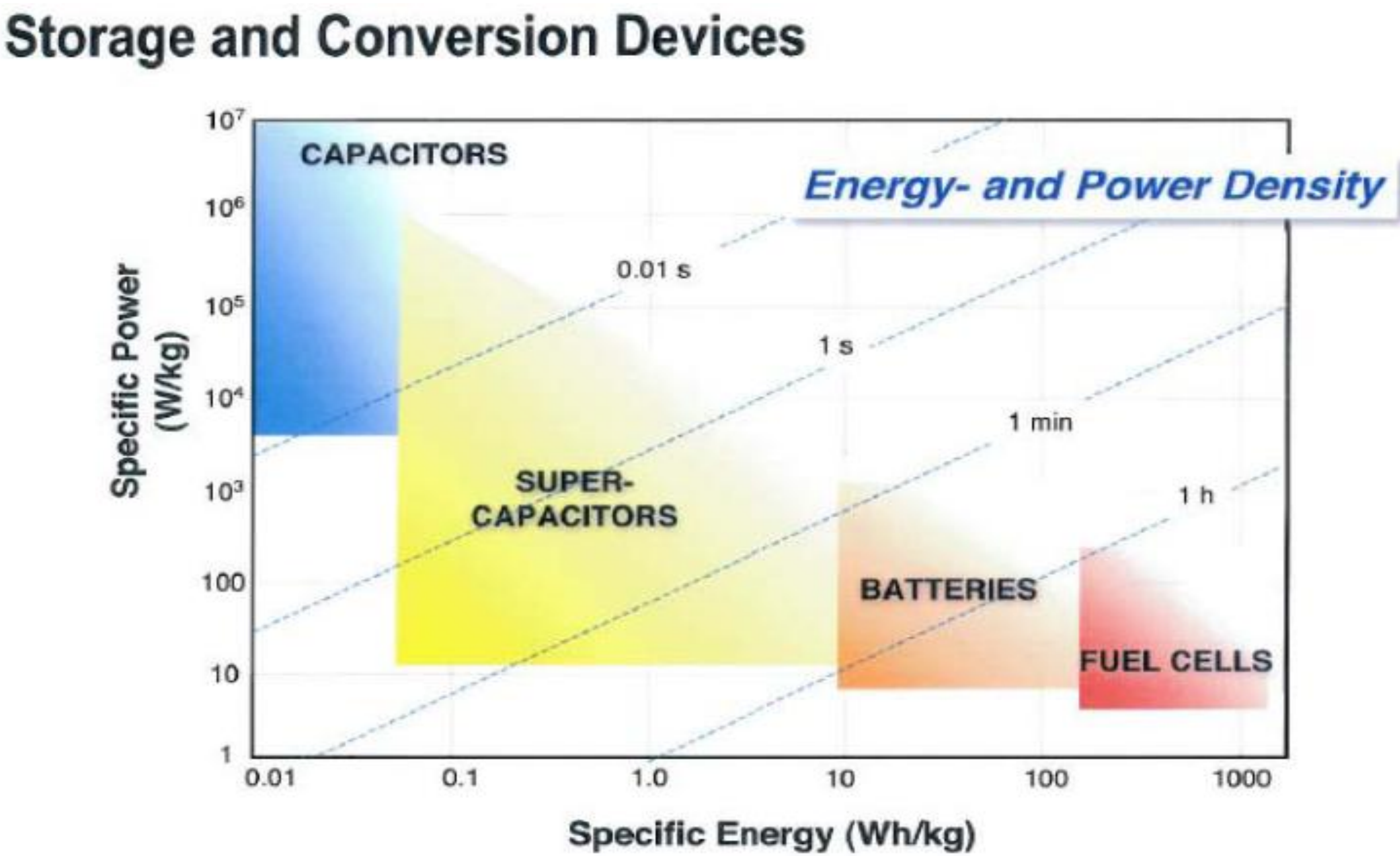


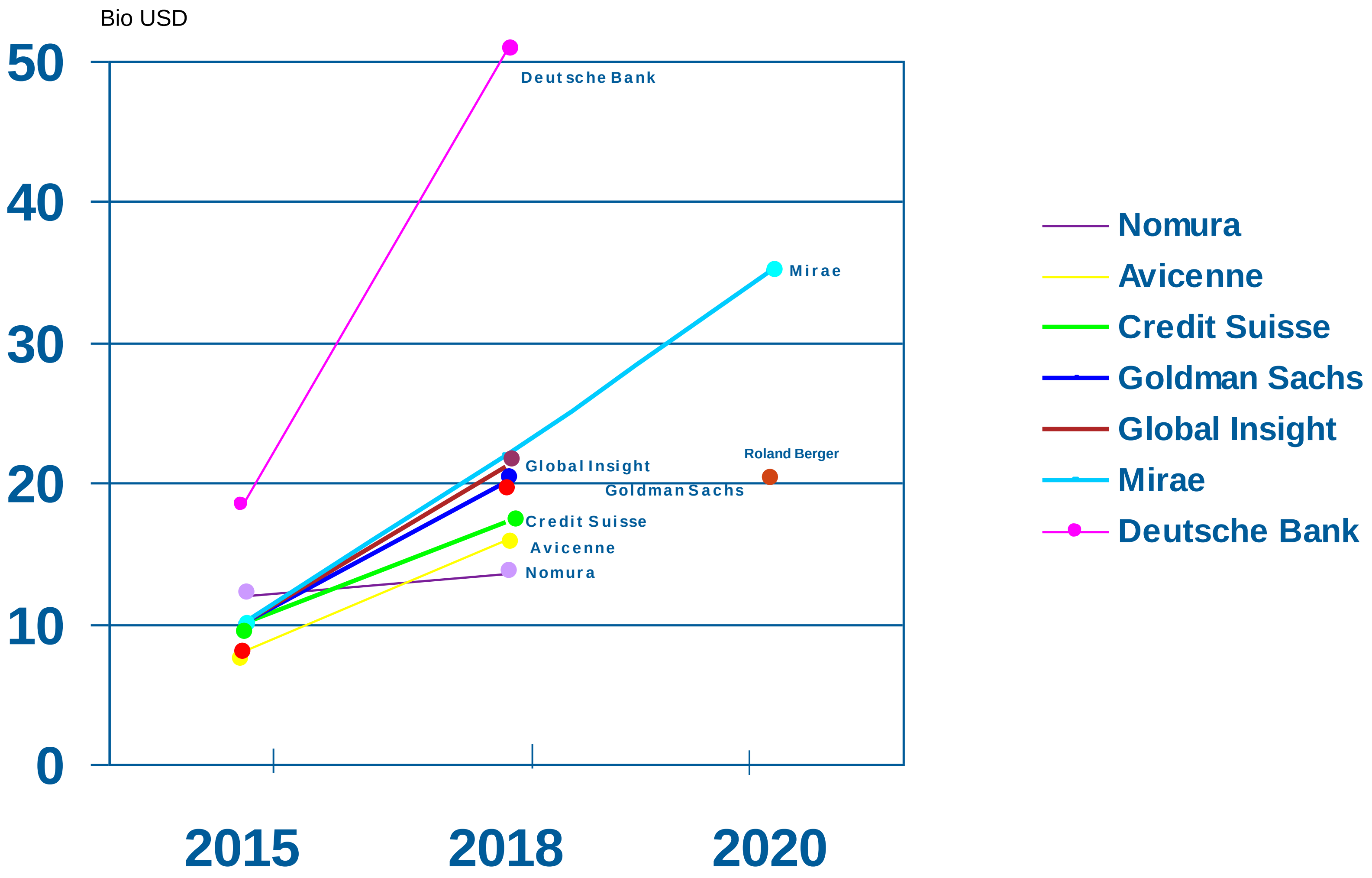

Vehicle Energy Management Functions
Engine ECU
Energy Demand
Battery Management System
Communications
CAN Bus
Battery Monitoring Unit
CAN Bus
Battery SOC Model
Demand / Personality Module
Safety Devices
Vehicle Management & Displays
HV Battery Power
Temperatures Voltages & Currents
Power Out
Sensors
In / Out
Power Train Controller
DC
AC / DC Power
Battery
Get You Home
Status
Ref
Test/Program Access RS485
Bypass
DC/DC Converter
Comparator / Decision Logic
Log Book Chip
Thermal Management Pumps/Fans
Radio Comms
Motor
Switching Signals
Control Signals
12 Volt Power Rail
Power
Charging and Equalisation
Battery Control Unit
Power In
External Charger or Alternator
Regenerative Braking
axeon

Ragonne Plot



Supercaps, in combination with batteries, can provide more power





Bio USD
50
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Deutsche Bank
Mirae
Roland Berger
Global Insight
Goldman Sachs
Credit Suisse
Avicenne
Nomura
2015
2018
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Nomura
Avicenne
Credit Suisse
Goldman Sachs
Global Insight
Mirae
Deutsche Bank

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Conclusion

- New battery and battery materials developments are key to success of HEV/PHEV/EV cars
- Hybrid applications (1-2 kWh) will become a major market opportunity for traditional Li-Ion batteries
- Plug-In (8-10 kWh) and pure EV (35 kWh – 100 km = 15 kWh) require advanced Li-Ion batteries and ultimately maybe new battery systems
- Development of light weight batteries, based on new cathode and anode materials, is continuously ongoing.
- Their optimization strategy is aligned with new applications in portable, stationary, automotive and light/ heavy duty.

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Glossary

Precursor	Feed material to produce the lithium metal oxide compound
Spinel	a crystallographic structure (AB204)
Ionic Liquids	a term generally used to refer to salts that form stable liquids
LMO	Product designation for Li-ion battery cathode oxides containing Manganese (Lithium Manganese Oxide)
NCA	Umicore product designation for Li-ion battery cathode oxides containing Nickel, Cobalt and Aluminium
HEV	Hybrid Electrical Vehicles
EV	Electrical Vehicle
NiMH	Nickel Metal Hydride battery