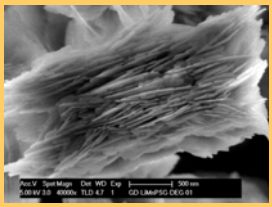


high power lithium

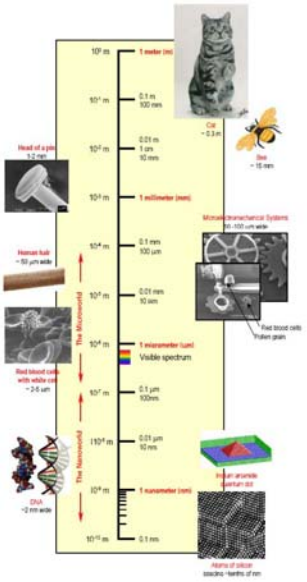
Li-ion Nano-Phosphate
A better ride

Ivan Exnar

NewRide

9th.February, Zofingen, Switzerland

1nm = 10-9m

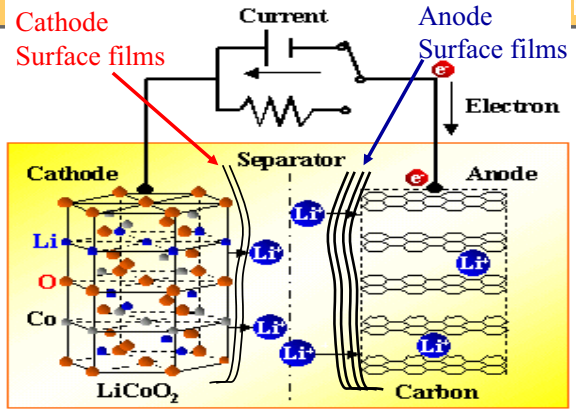


SOME NANOTECHNOLOGY MILESTONES

- 1959-Feynman delivers “Plenty of Room at the Bottom”
- 1974-First molecular electronic device patented
- 1981-Scanning tunneling microscope (STM) invented
- 1985-Buckyballs discovered
- 1986-Atomic force microscope (AFM) invented
- 1989-"IBM" written with 35 xenon atoms
- 1991-Carbon nanotubes discovered
- 1995 Swiss patent for nanomaterials in battery
- 1997-DNA-based nanomechanical device created
- 2000-US launches National Nanotechnology Initiative

Standard (today) Rechargeable Li^+ ion batteries

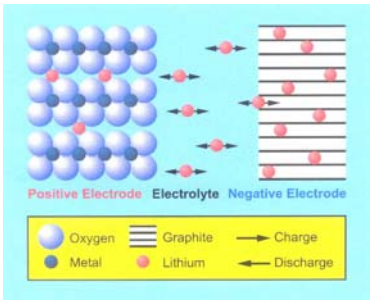
Cathode
Li_xCoO_2

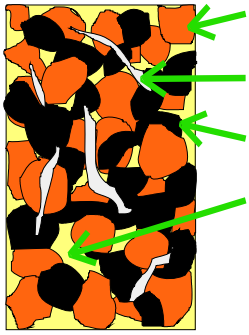


Anode
Li_xC_6

Electrolyte solution: ethylene-carbonate & di-methyl carbonate/ $LiPF_6$

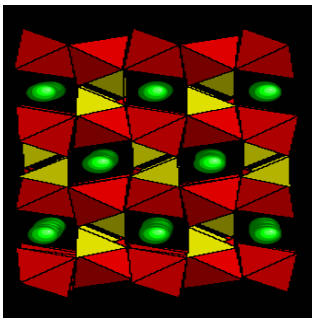
Voltage: 3.6 V Energy density: 150 Wh/Kg





Oxid oder Graphit
Polymer-Binder
Kohlenstoff
Elektrolyt

Why Nano??



Olivine Structure of LiFePO4

Calculating Intercalation Time

General equation:

$\tau = r^2 / D$

where D (diffusion coefficient) = 10^{-14} cm^2/s

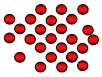
Therefore when:

r = 1µm	→	τ = 270hrs.
r = 10nm	→	τ =1.5secs.
r = 1nm	→	τ =0.3secs.

As smaller the particles as faster the Ion diffusion into the material.

Nano - sized Particles

- higher capacity and better rate capabilities



High surface area

$I \propto A$

Shorter Li^+ diffusion length

$\tau \propto r^2$

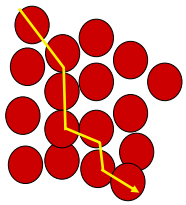
-Accelerate unwanted reaction on the interface - battery aging
-Electrode fabrication issues associated with non-homogeneous mixing

Why Nano??

- Grain boundary resistance (Rgb)=power loss

$$I \propto \frac{1}{nR_{gb}} . A$$

where n is the number of particles in the current path

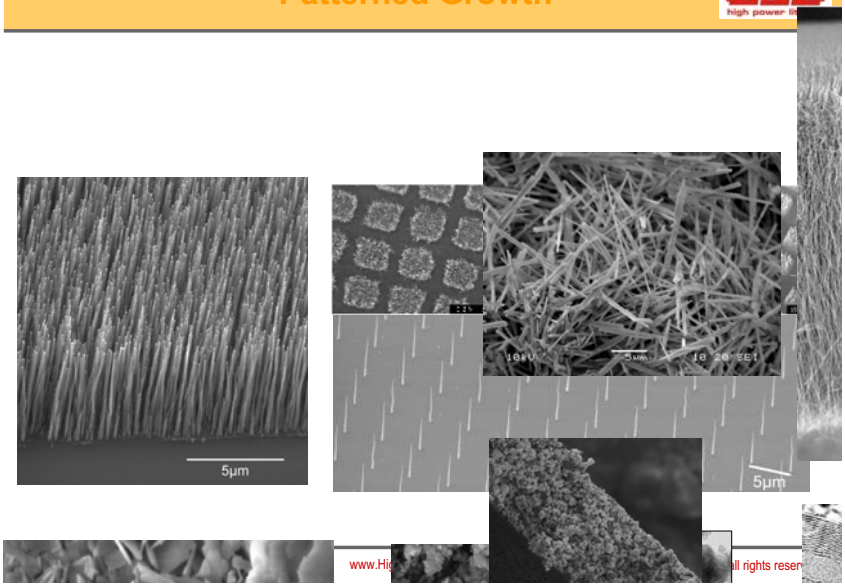


Pros and cons of Nano materials - general statements

- GOOD:
- surface amplification over 1000 times for a 10 micron thick film,
- huge contact area electronic junction.
- ease of electron percolation through the particle network
- very rapid lithium insertion and release

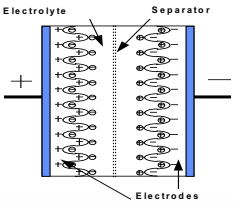
- BAD:
- Nano materials are difficult and potentially dangerous to handle
- They have poor electrical conduction
- Generally a very low tap density
- High reactivity with electrolyte
- Partially lower energy density
- And currently the costs for nano materials are high

Patterned Growth



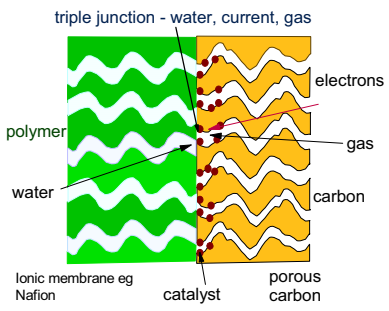
Supercapacitors

- Montena sA (CH)



- Polycarbonate electrolyte
- Ion permeable membrane separator
- Nanotubes would have largest possible surface area, 1500 m^2/g
- 1500 m^2/g = 10 F/g = 20 Wh/kg
- Allows *1000 F* caps at 2.5V in 2" diameter capacitor

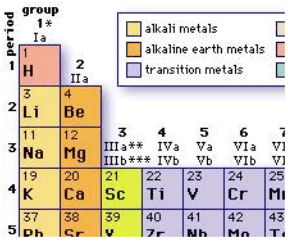
- Fuel cells
  - Increase contact area
  - LT growth of nanotubes or other porous carbon (nanohorns)

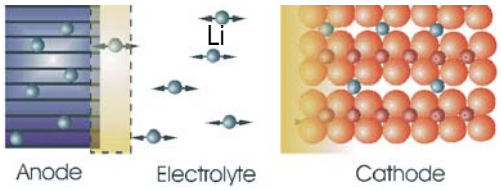


Why Lithium-ion ?

Lithium is:

- Most electronegative metal
  - High Voltage 3.6V
  - High Energy
- Lightest metal
  - Low size
  - Low weight

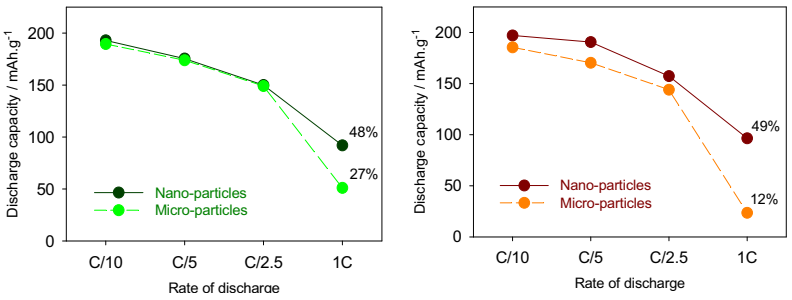




Lithium's Chemistry gives it extraordinary performance

Rate Capability: role of Nano

T=30⁰C **T=60⁰C**

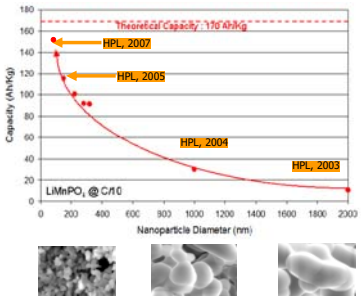


$LiNi_{0.5}Mn_{0.5}O_2$, High capacity
but an intrinsically slow material

HPL's novel cathode technology

nano-structured $LiMnPO_4$ + Carbon coating

Performance, safe material

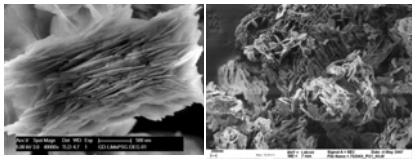


Different Synthesis → Different morphology
Different performance

4 years to "make $LiMnPO_4$ work"
validated by Toyota, Bosch, ITRI, Sanyo

9 patents filed

- Polyol, Solid State, Sol gel, Hydrothermal
- Carbon Coating, Molecular wiring



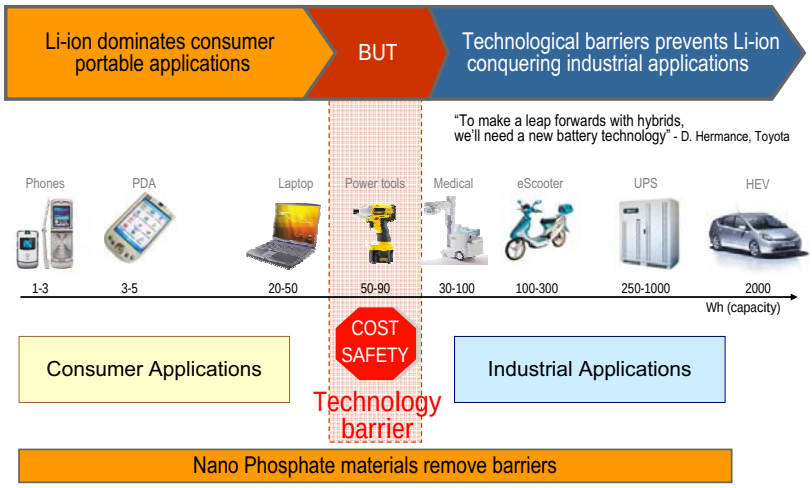
HPL have a proven, protected new cathode technology

Nano Challenge

Nano materials

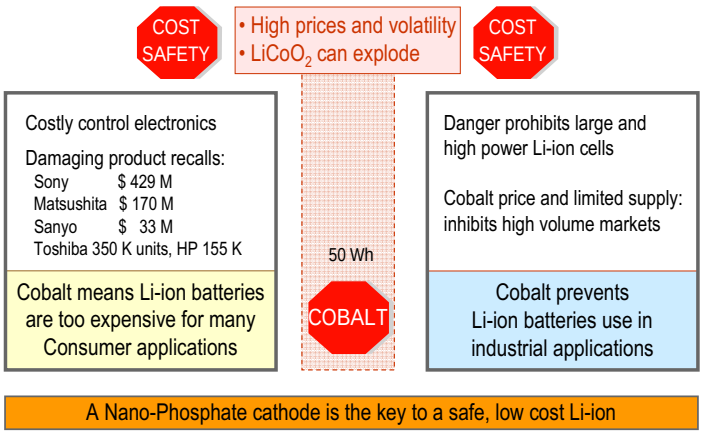
- A potential source of improved materials through improved thermodynamic and kinetic properties.
- However, unlike the microelectronics components, we must get **Energy** (= volume, weight): problem of **density, taped density**
- From **nano** materials, we must build **macro** electrodes and batteries.....
- The challenge
  - Interface with electrolyte, to insure battery life.
    - Negative side: amount of lost lithium in SEI, self discharge through SEI, volume changes, ...
    - Positive side: current collection if no electronic conductivity, density....

Large applications demand the performance benefits of Li-ion



Cathode inhibits the development of Li-ion

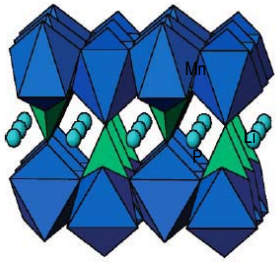
Consumer Li-ion batteries use Cobalt



Why Phosphate cathodes?

Advantage of phosphates

- Low cost
- Excellent structural stability (strong bond P-O)
  - Good cycle life
  - Thermally and chemically stable - Safe
- Over-charge & under-charge resilient (1 Li)
  - Safe
  - Rapid charge possible
- High Performance, once nano-sized



Phosphate choice

• Iron	low V	3.2 V vs. C	Available today
• Manganese	ideal V	3.8 V vs. Li	Swiss development

Phosphates are theoretically attractive: but need to be nano to work!

Next generations of nano-phosphate

Industry requirements:

- Intrinsically safe
- Low cost
- Durable

Do not meet requirements:

• Cobalt	Not Safe, Cost
• Mixed cobalt	Not Safe, Cost
• Mn Spinel	Poor durability at high T

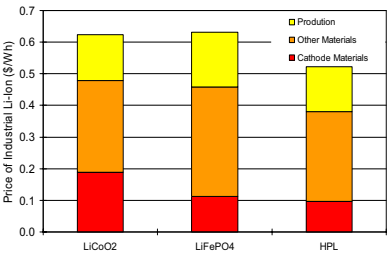
Achieve requirements	Nano Iron Phosphate	HPL $LiMnPO_4$
Voltage (vs. C)	3.2	3.85
Implication		20% less cells
Price ($/Wh)		20% less cost

In battery pack

20% more Voltage = 20% less cells in series

= 20% less electronics cost

Price breakdown of a 3.6 Ah HEV Li-ion cell



HPL combine the benefits of Nano-Phosphate with High Voltage… coming soon!

 $LiCoO_2$: $50 Kg, $LiFePO_4$: 25 $/kg, $LiMnPO_4$ 25$/kg

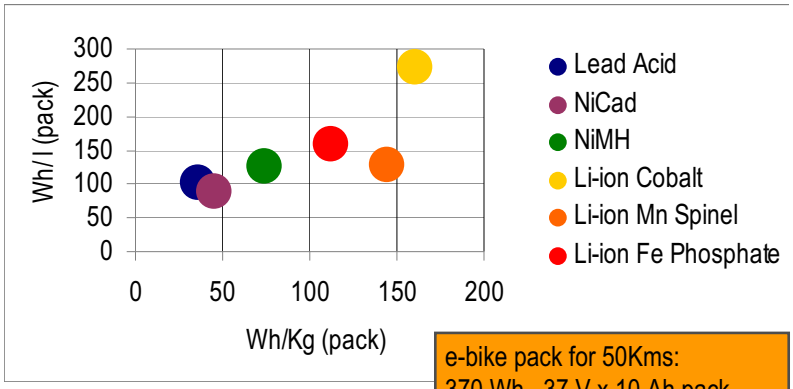
Li-ion technologies choice -pack data 36V 10Ah

Cathode Material	Cobalt (small Li-ion)	Manganese Spinel (Mn)	Fe Iron Nano Phosphate	Manganese Phosphate
Voltage (V)	3.7	3.85	3.2	3.85
Energy pack (Wh/kg)	160	145	115	140
Size pack (Wh/l)	275	130	160	200
Life cycles	1000	400	2000	2000
Safety	Poor	OK	Excellent	Excellent
Price pack 2009 ($/Wh)	1.2	1.6	1.5	1.2
Trade name	Not used in E-bike	Li-ion Mn Ebike standrd Bionx, Panason	Fe Nano Phosphate	HPL SA

Iron Nano phosphates have benefits, but a lower Voltage… new standard for HEV

HPL combine the benefits of a Phosphate with the voltage of an Oxide

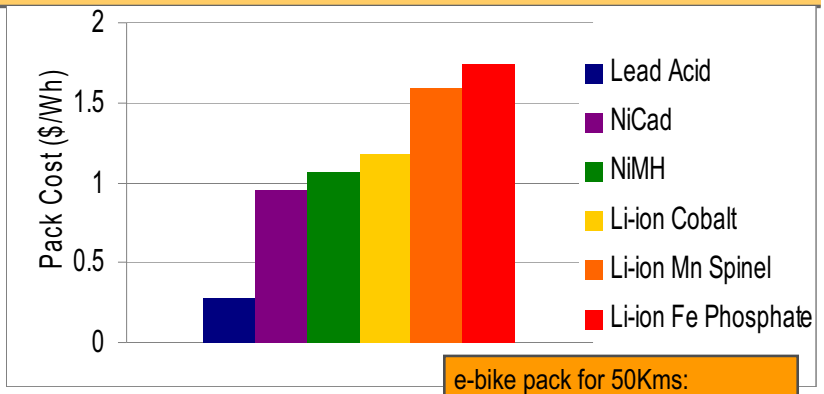
E-bikes Pack Performance with different batteries



e-bike pack for 50Kms:
370 Wh 37 V x 10 Ah pack
37V 250W DC motor (0.66C)

Li-ion battery packs are 4x lighter and 3x smaller than Lead acid

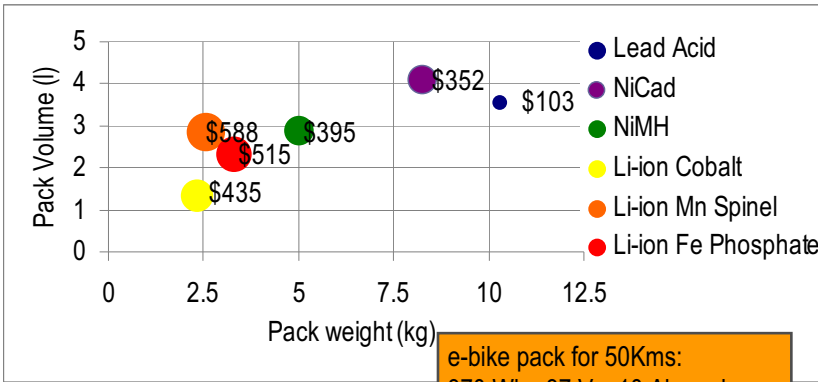
E-bikes Pack Price



e-bike pack for 50Kms:
370 Wh 37 V x 10 Ah pack
37V 250W DC motor (0.66C)

Performance has a cost

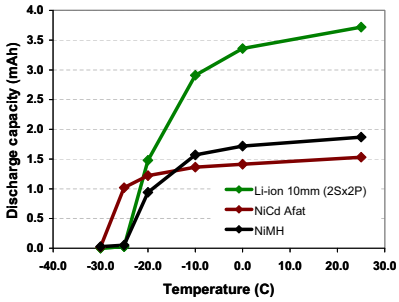
E-bikes Pack Performance



e-bike pack for 50Kms:
370 Wh 37 V x 10 Ah pack
37V 250W DC motor (0.66C)

Two extremes: performance solution, and the low cost option

Batteries: low temperature performance



Comparison of battery technologies (pack data)

Battery	Cost	Weight	Size	Comment
Lead-Acid	low	very heavy 4.5x Li-ion	bulky 2.7x Li-ion	poor perform low cost solution
NiCad	medium	very heavy 3.6x Li-ion	very bulky 3x Li-ion	environmental
NiMH	medium	medium 2.2x Li-ion	small 2.2x Li-ion	compromised
Li-Ion Co small	medium	light	small	performance less safe
Li-Ion Mn	medium	light	small	performance durability at T
Iron Nano Phosphates	high decreasing	light 1.4x Li-ion	small 1.7x Li-ion	Next generation ideal solution

Nano Phosphates are becoming the performance solution for motive applications

Li-ion powers new E-applications

www.RothMotors.com
8.5 kg, 20 Kmh
800 CHF, powertool cells

Piaggio PhEV!

www.quantya.com

Low cost Li-ion can revitalise high value e-applications

Comments

Nano tech is a Swiss invention

E-bike use Spinel as standard “Li-ion Mn” 10Ah

E-bike is low power (C/2) 360Wh for 250 W engine

E-bike does not need cell with faster charge (charger cost limits rate)

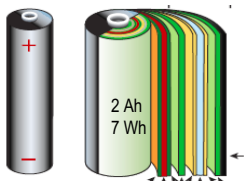
E-scooters are still with NiCd (waiting for a proven tech)

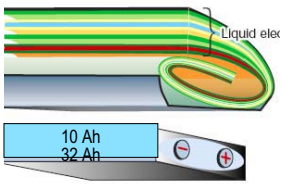
3x 3.6V*100Ah (need higher power ~2C)

Li-ion = Li-polymer (only format changes)

Next steps in Li-ion and nano phosphate

- Volume Production of industrial Li-ion
  - reduce cost
  - improve perform
- Standard Li-ion Formats
  - Larger
  - Polymer
- HEV effect
- Regenerative braking (also E-scooters)
- Manganese Phosphate





Cost will drop rapidly as large Li-ion becomes standard

Getting the best Li-ion

- Store at low temperature
  - 10 °C less = 2x durability
  - Sunny day in black pack ages cells!
- Store at mid charge (<80% of capacity)
- Don’t leave charging for days (in contrast to Lead-acid)
- Don’t need to fully discharge - in contrast to NiMH
  - Many small discharges are better than 1 full
- Li-ion is best environmental battery technology
- Good quality cells = good durability
  - Buy from Japan or Korea

HPL is happy to help you get the best from your cells!

HPL at a glance

History	spun-out from EPFL (Switzerland) in 2003 technology in development since 1996
Technology	nanostructured materials for industrial lithium-ion batteries
Markets	Power tools, telecoms, military, mobility and automotive
Partners	include Bosch & Toyota since 2003
Team	highly experienced entrepreneurs and technologists 10 full time equivalents
Advisors	world battery and electrochemistry experts Profs: Winter, Whittingham, Graetzel, Kavan, Hofmann
Intellectual Property	9 patents filed
Financing	CHF 8.3 M from DFJ ePlanet, Bank Invest and Swiss investors CHF 1.7 M R&D contracts