Innovative batteries for automotive application

Silvia Bodoardo

Gruppo di Elettrochimica

The Electrochemistry Group

Politecnico di Torino

Electrochemistry group: Main research activities

The **Electrochemistry group** is active in the field of electrochemistry and electrocatalysis from more than 90 years…

Electrochemistry group

Electrocromic Fuel cells

RESSEEPE, SMART-FC

battery/electrocromic devices
materials
polymers
catalysts

Li-ion technology

HORIZON 2020

eCAIMAN, MARS

electrode materials
electrochemical testing
high capacity anodes
high voltage cathodes
electrolyte interaction

Post Li-ion batteries: Li-air, Li-S

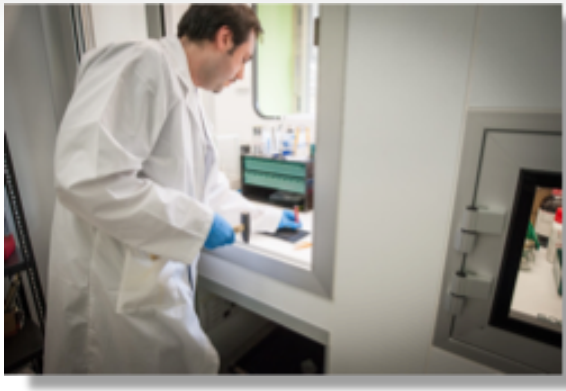
SEVENTH FRAMEWORK PROGRAMME

STABLE, ALISE

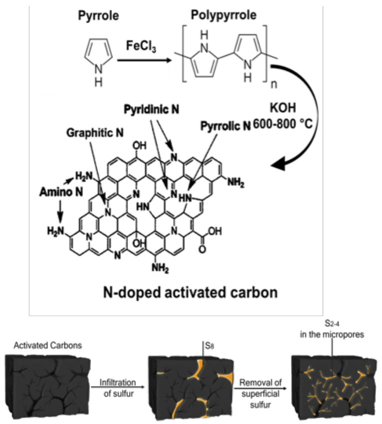
electrode materials
electrocatalysts
reaction mechanisms
protective membranes
interlayers

from Lab-scale to preindustrial-scale assembly

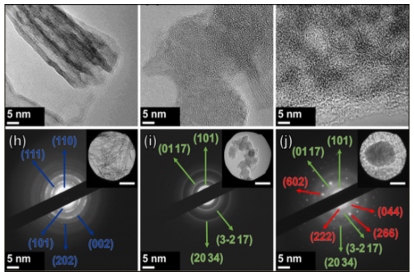
Facilities and main activities

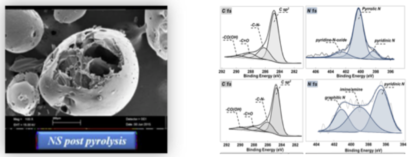


material synthesis

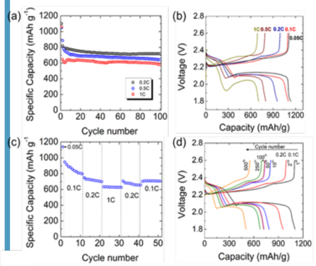


characterization





cell assembly & testing @ labscale

testing battery packs & modules

ENERGY CENTER

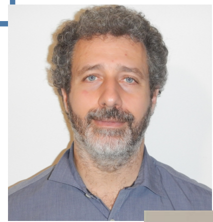
POLITO task force on Batteries

EC-lab, PEIC, CARS interdipartimental labs



Task force on modeling:

Daniele Marchisio DISAT - materials production process
Pietro Asinari DENERG - electrode-electrolyte interface
Massimo Santarelli DENERG - Electrochemical and thermal model





Task force on battery pack, BMS and Power electronics

Paolo Guglielmi DENERG- module and battery pack assembly
Radu Bojoi DENERG - BMS
Michele Pastorelli DENERG- power electronics

Electric vehicle applications and integration

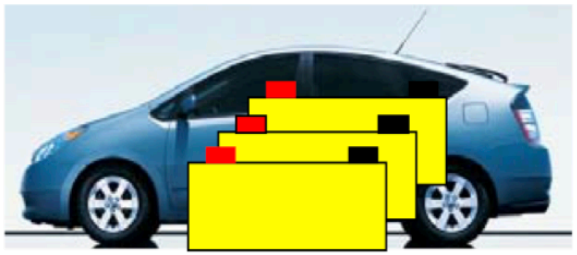
Massimiliana Carello DIMEAS - EVs


renewable energy is not continuous..
and needs to be stored
transition to electric vehicles needs
high energy density batteries
MODEL S

Batteries for electric vehicle

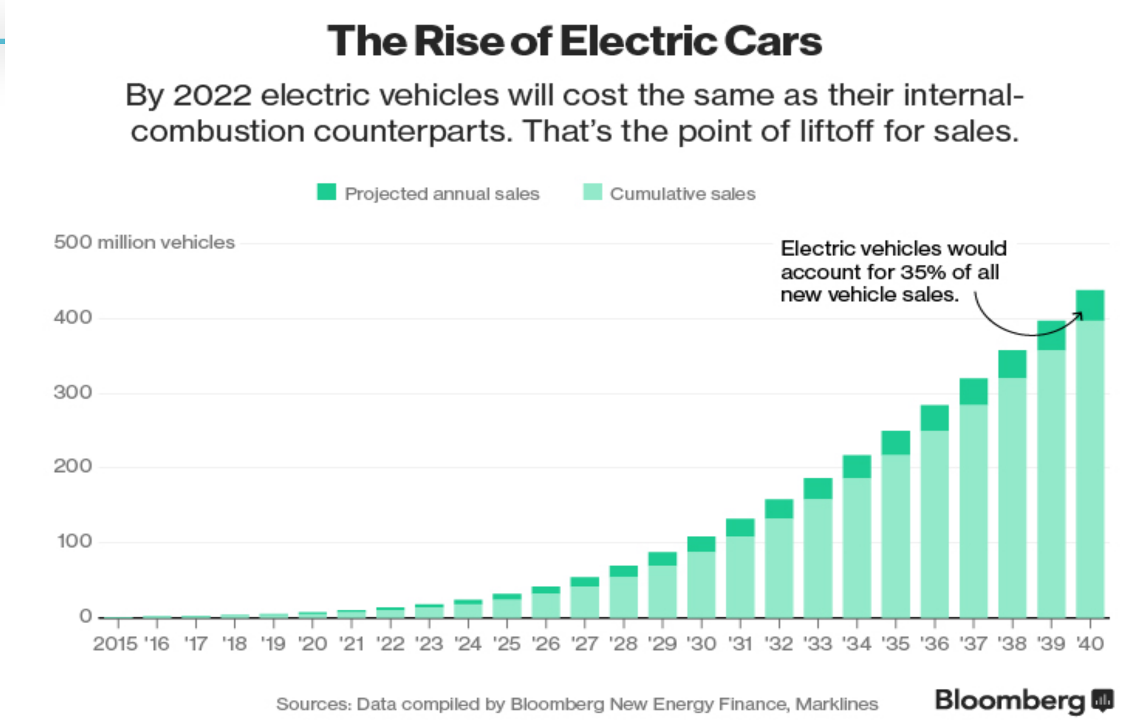
Hybrid electric vehicle (HEV)
Storage capacity approx. 1 kWh, charging only during driving, fuel reduction max. 20%

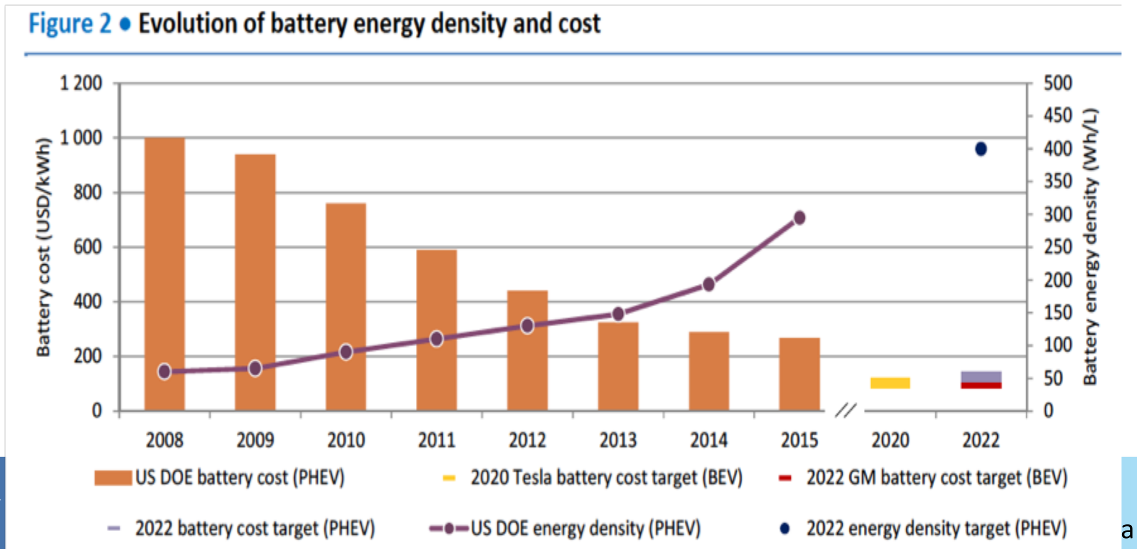
Plug-in Hybrid electric vehicle (PHEV)
Storage capacity 5 – 10 kWh, charging from the grid, 30 to 50 km electrical driving range, full driving range with conventional engine or fuel cell, driving with empty battery possible



Electric vehicle (EV)
Storage capacity 15 – 40 kWh, charging from the grid, 100 to 300 km electrical driving range

Evolution of EV market





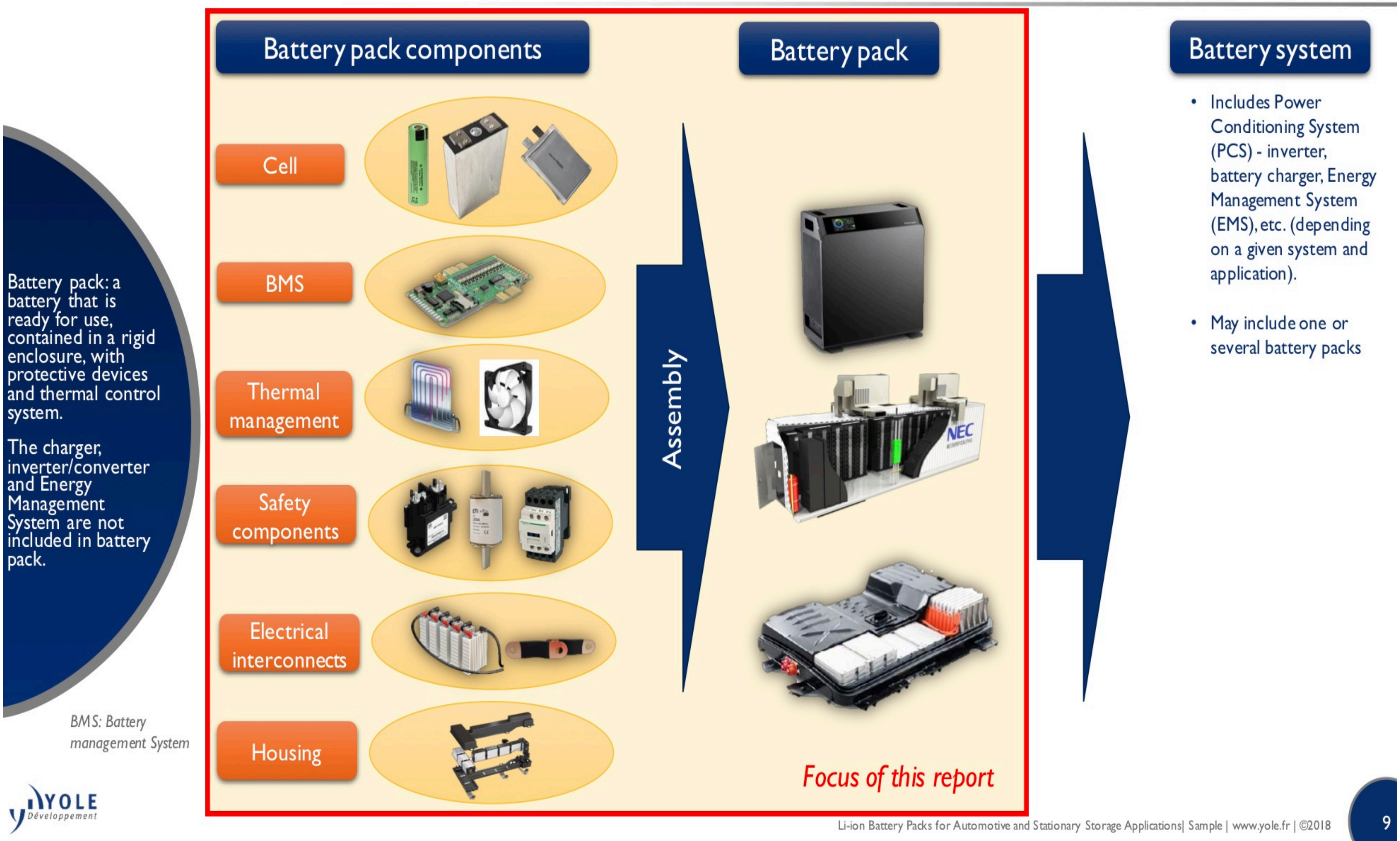
Battery World production facilities

2017

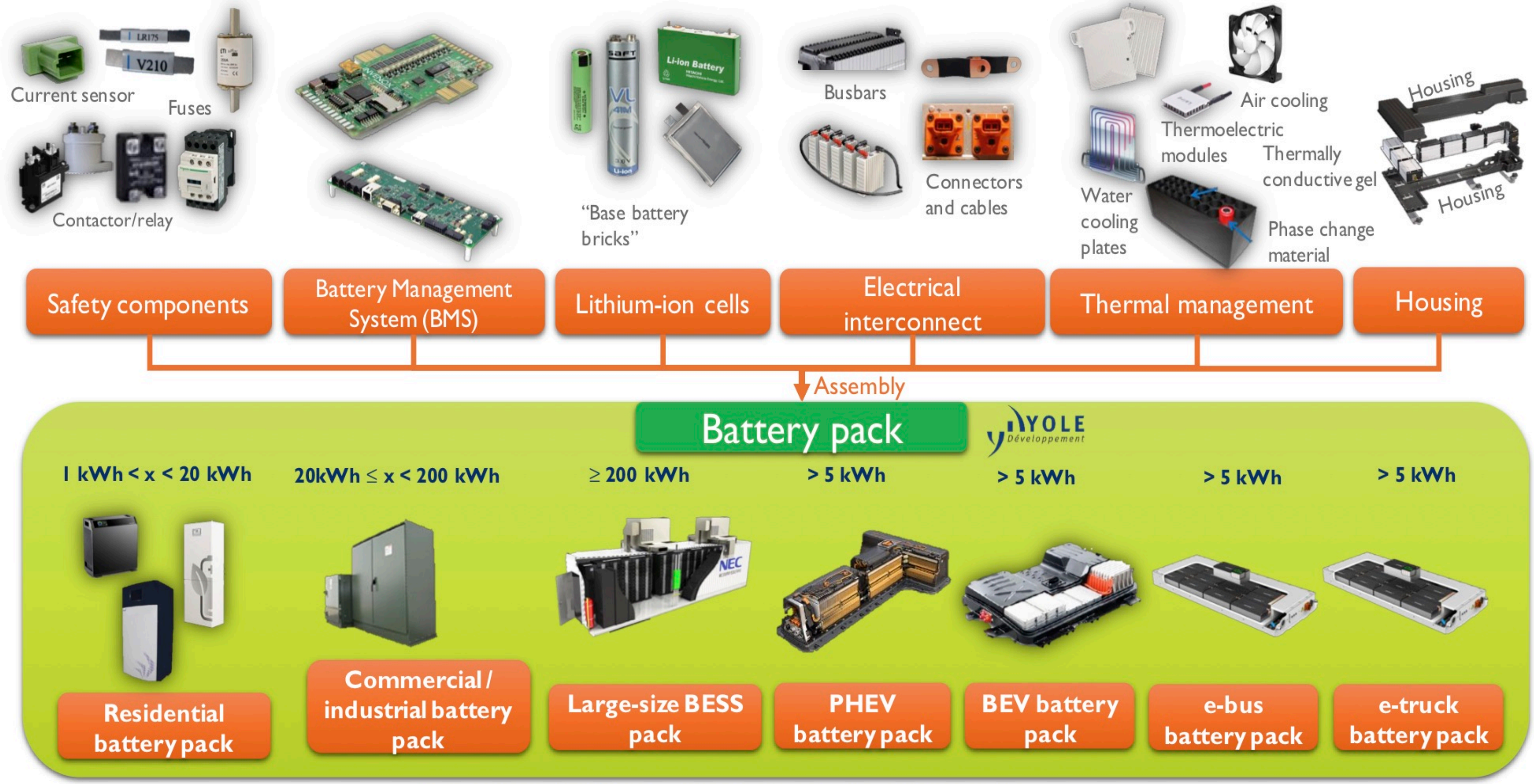
and Europe?
new opportunities?

Batteries are not simply current and voltage

Battery components



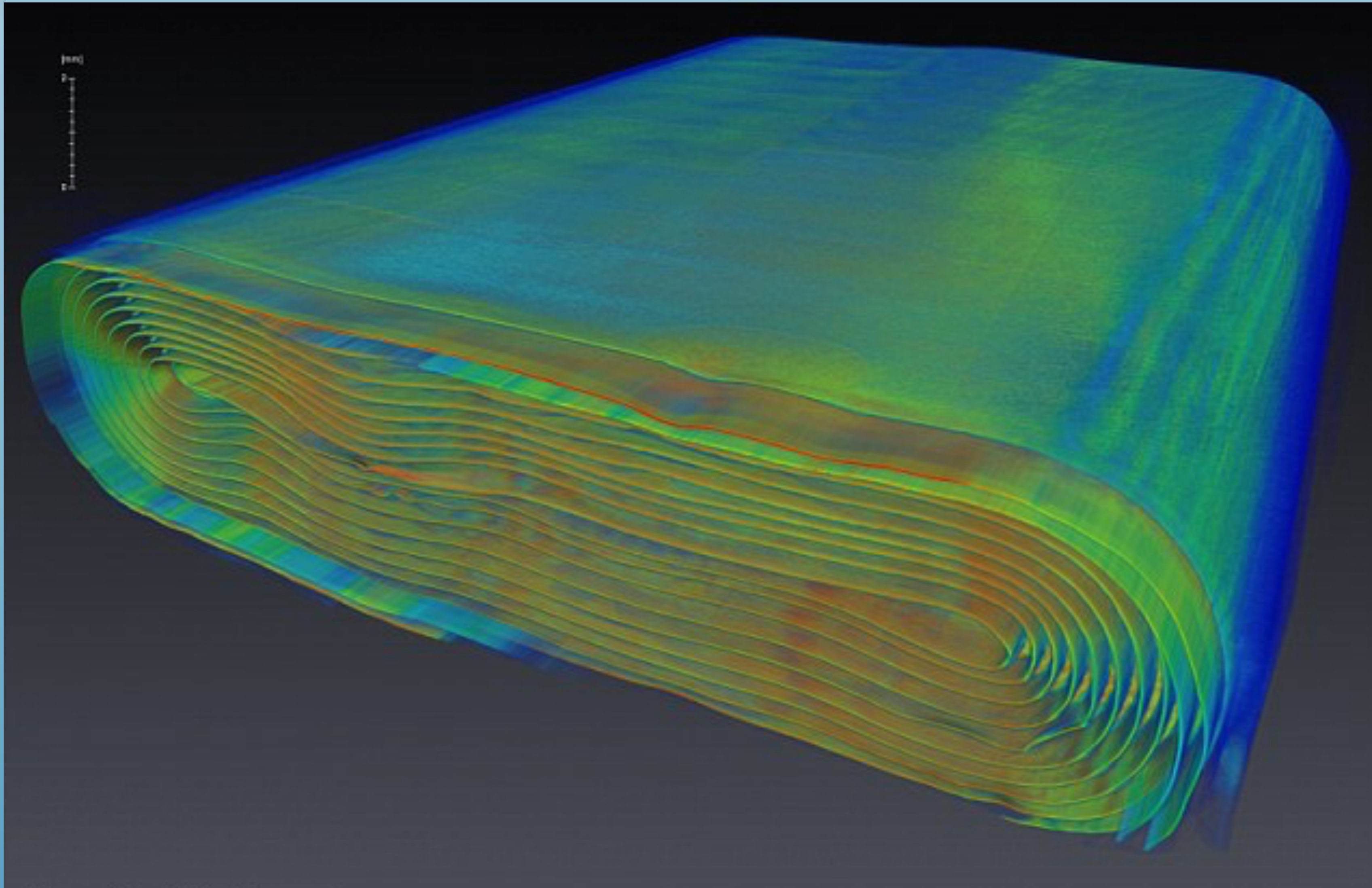
Wide Market segment



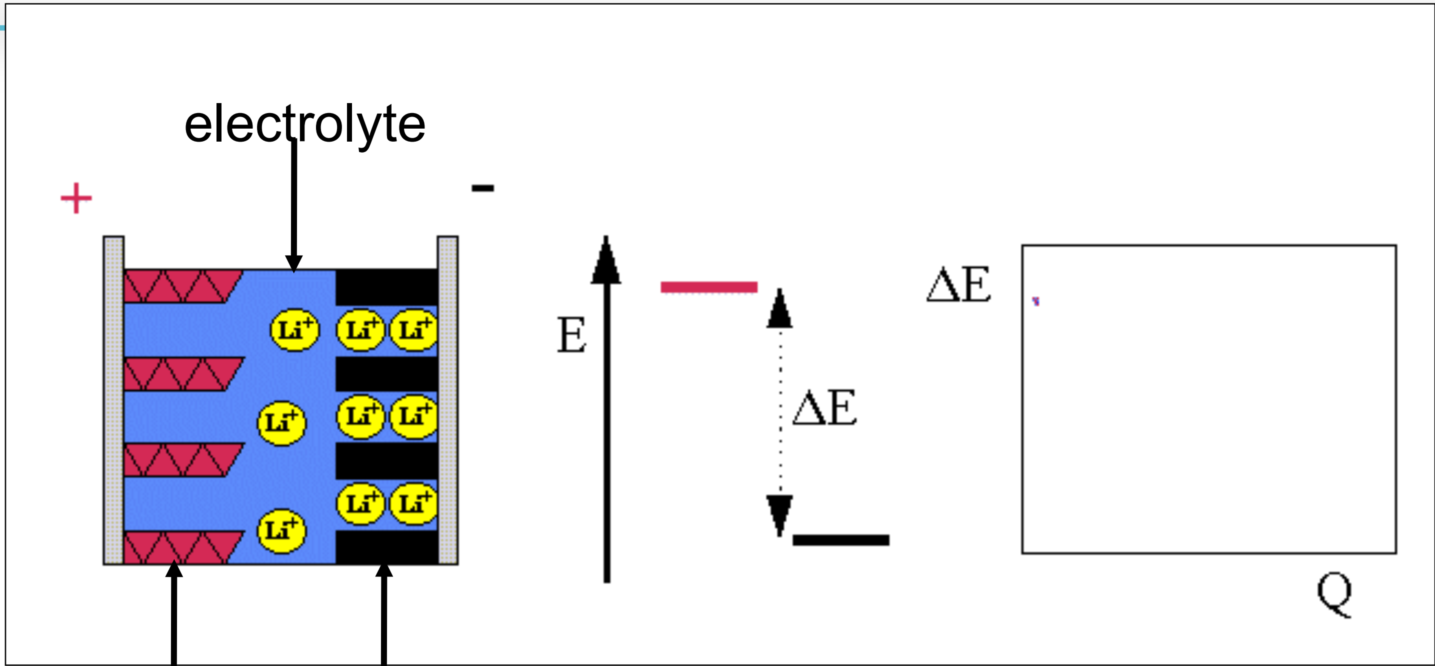
Main components of battery packs and battery pack market segments

good opportunities

Let’s go inside the battery cells



Li-ion cell



Cathode **Anode**

Cathode : $LiMn_2O_4$ spinel
$LiCoO_2$ cobaltite

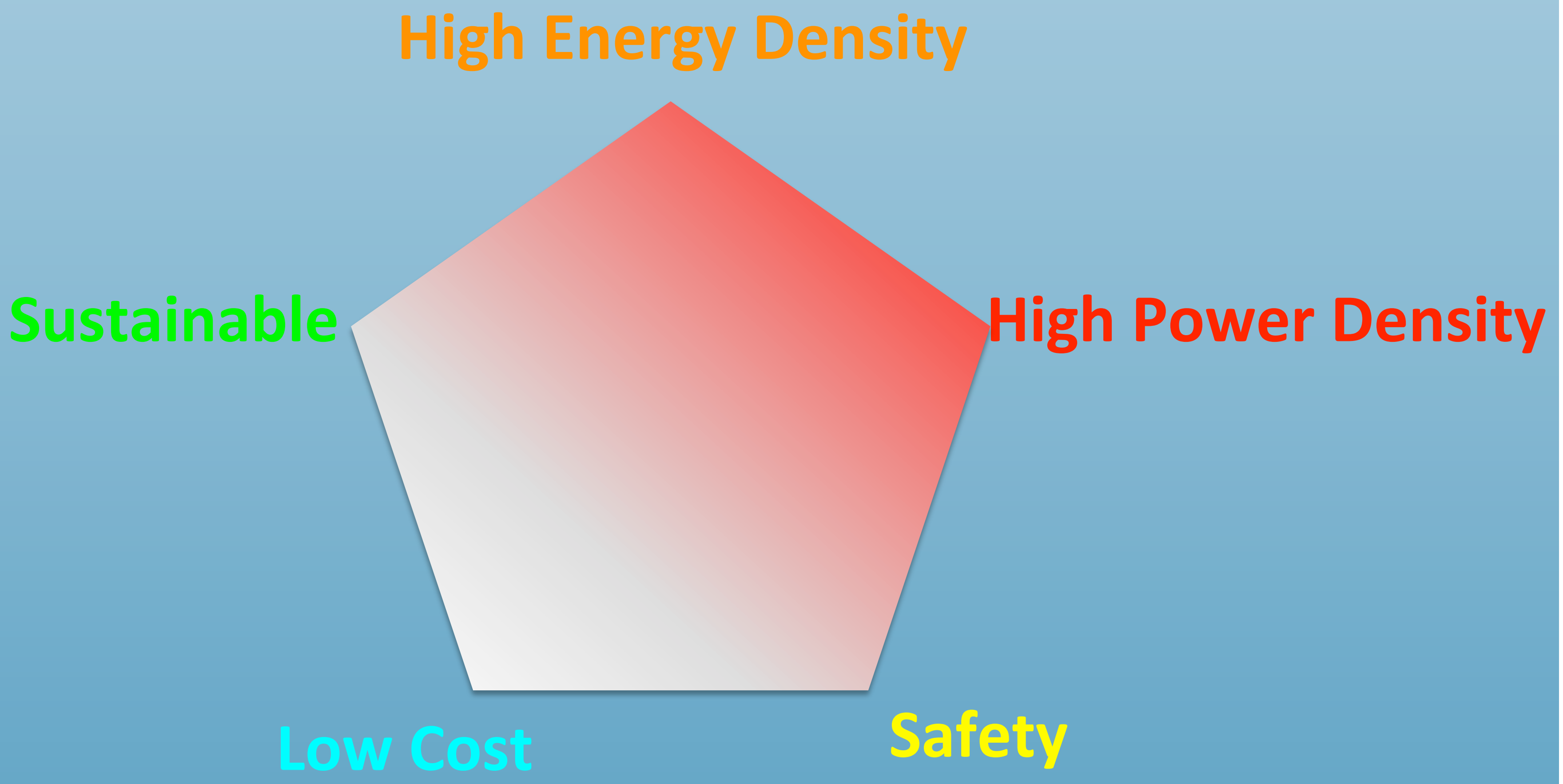
$$LiM^{+n}O_x \xrightarrow{\text{charge}} M^{+(n+1)}O_x + Li^+ + e$$

Anode : graphite
metallic Li foil

$$Li^+ + e \longrightarrow Li$$

$$6C + Li^+ + e \longrightarrow LiC_6$$

The perfect battery



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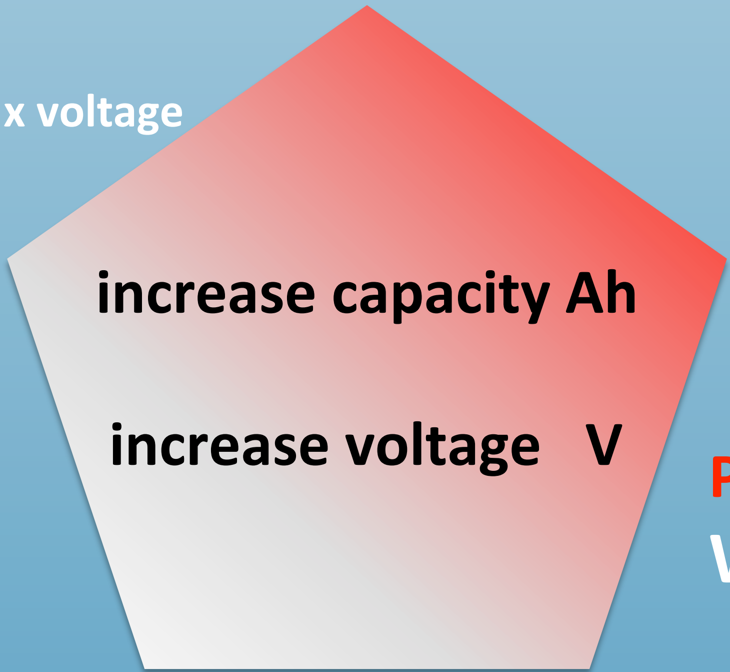
The perfect battery

High Energy Density

Energy: power by time

Wh = Ah x V = capacity x voltage

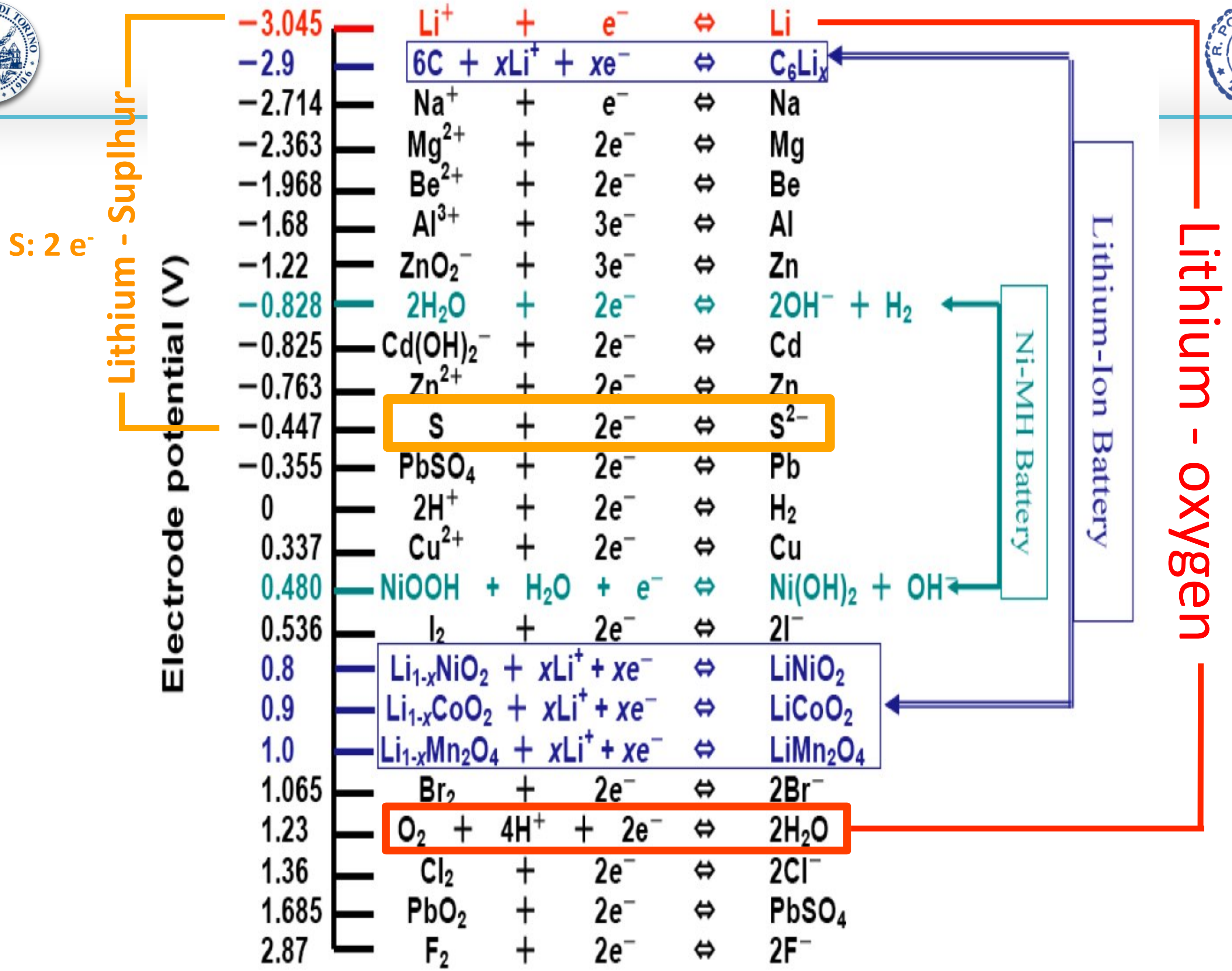


High Power Density

Power: energy per second, watt

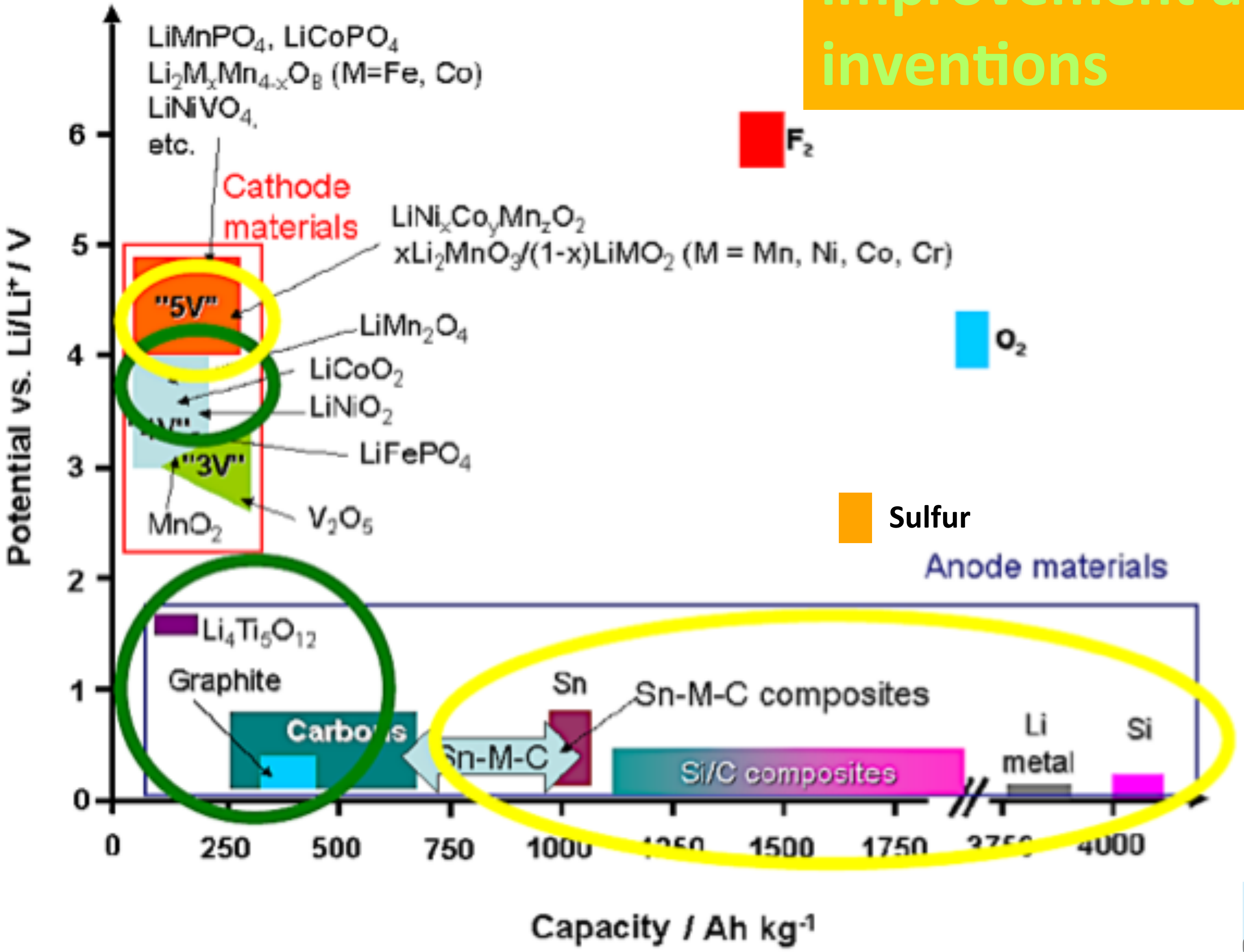
W = A x V = current x voltage

Capacity: current x time **Ah**


S: 2 e-
Lithium - Suplhur
Electrode potential (V)
−3.045 Li+ + e− ⇔ Li
−2.9 6C + xLi+ + xe− ⇔ C6Lix
−2.714 Na+ + e− ⇔ Na
−2.363 Mg2+ + 2e− ⇔ Mg
−1.968 Be2+ + 2e− ⇔ Be
−1.68 Al3+ + 3e− ⇔ Al
−1.22 ZnO2− + 3e− ⇔ Zn
−0.828 2H2O + 2e− ⇔ 2OH− + H2
−0.825 Cd(OH)2− + 2e− ⇔ Cd
−0.763 Zn2+ + 2e− ⇔ Zn
−0.447 S + 2e− ⇔ S2−
−0.355 PbSO4 + 2e− ⇔ Pb
0 2H+ + 2e− ⇔ H2
0.337 Cu2+ + 2e− ⇔ Cu
0.480 NiOOH + H2O + e− ⇔ Ni(OH)2 + OH−
0.536 I2 + 2e− ⇔ 2I−
0.8 Li1-xNiO2 + xLi+ + xe− ⇔ LiNiO2
0.9 Li1-xCoO2 + xLi+ + xe− ⇔ LiCoO2
1.0 Li1-xMn2O4 + xLi+ + xe− ⇔ LiMn2O4
1.065 Br2 + 2e− ⇔ 2Br−
1.23 O2 + 4H+ + 2e− ⇔ 2H2O
1.36 Cl2 + 2e− ⇔ 2Cl−
1.685 PbO2 + 2e− ⇔ PbSO4
2.87 F2 + 2e− ⇔ 2F−
Ni-MH Battery
Lithium-Ion Battery
Lithium - oxygen

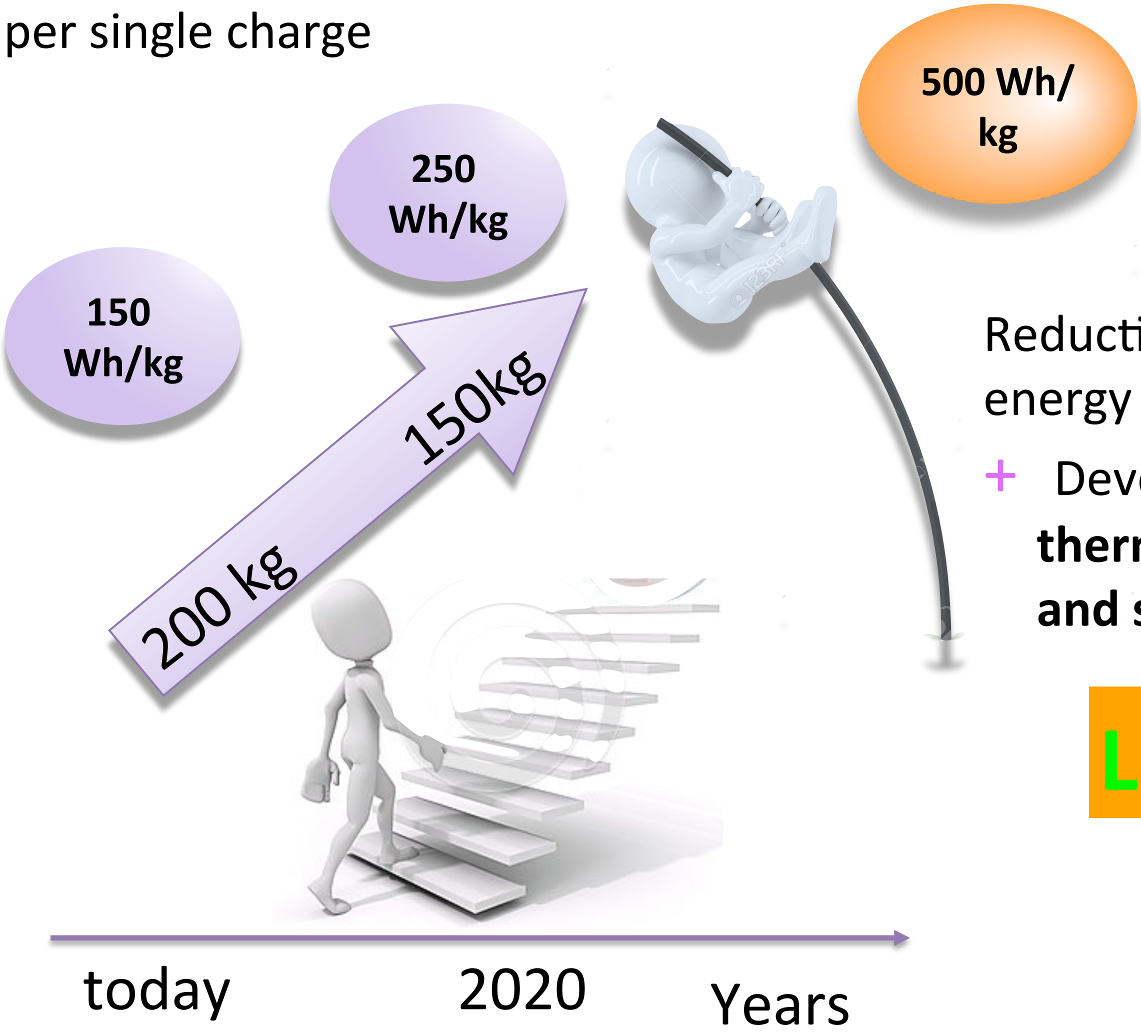
Cathodes and Anodes

many possibilities for improvement and for new inventions



Energy density growth

Around 200 kg of actual Li-ion batteries are needed to reach no more than 200 km per single charge



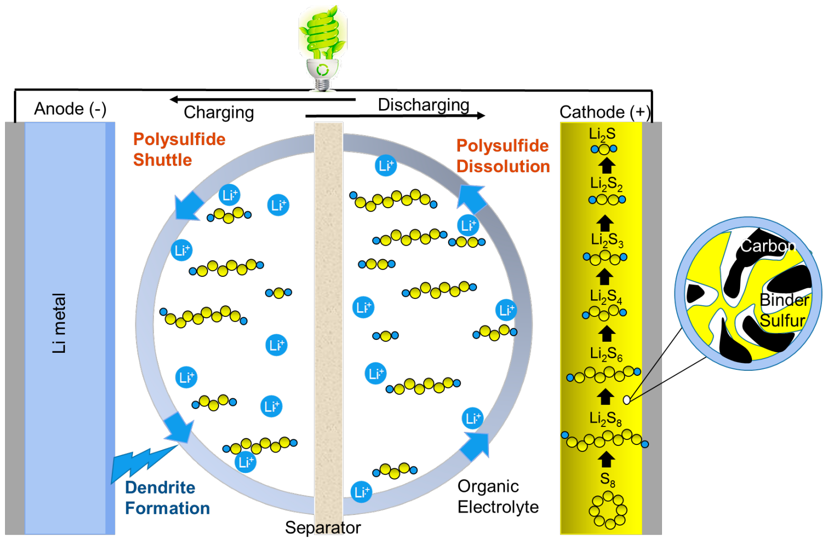
Reduction of weight and Increase of energy density is strongly required

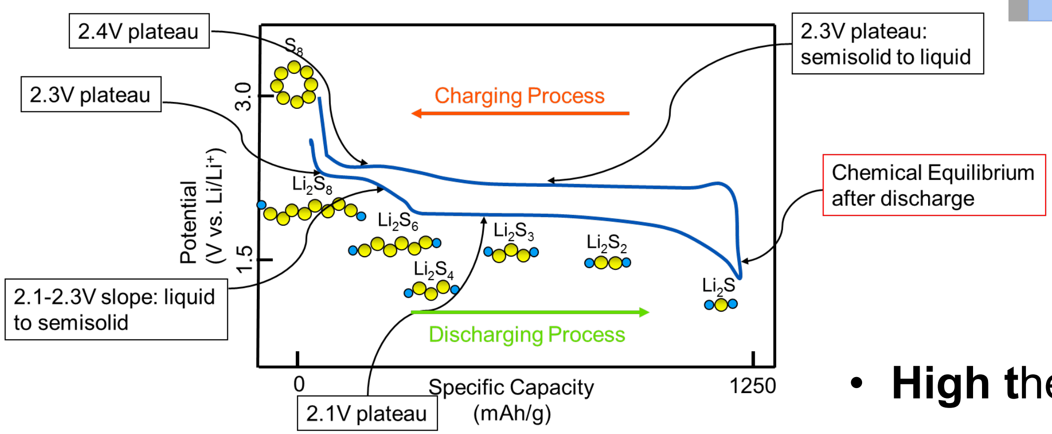
+ Development of **inexpensive, thermally stable, long cycling and safe batteries**

LiS and Li air

Lithium sulfur

- **Insulating nature of sulfur and Li_2S** (electronic conductivity of S is 5 × 10^{-30} S cm^{-1}, 25 °C)
- **Dissolution of polysulfides** in the electrolyte
- Shuttling of polysulfides
- Lack of morphology restoration

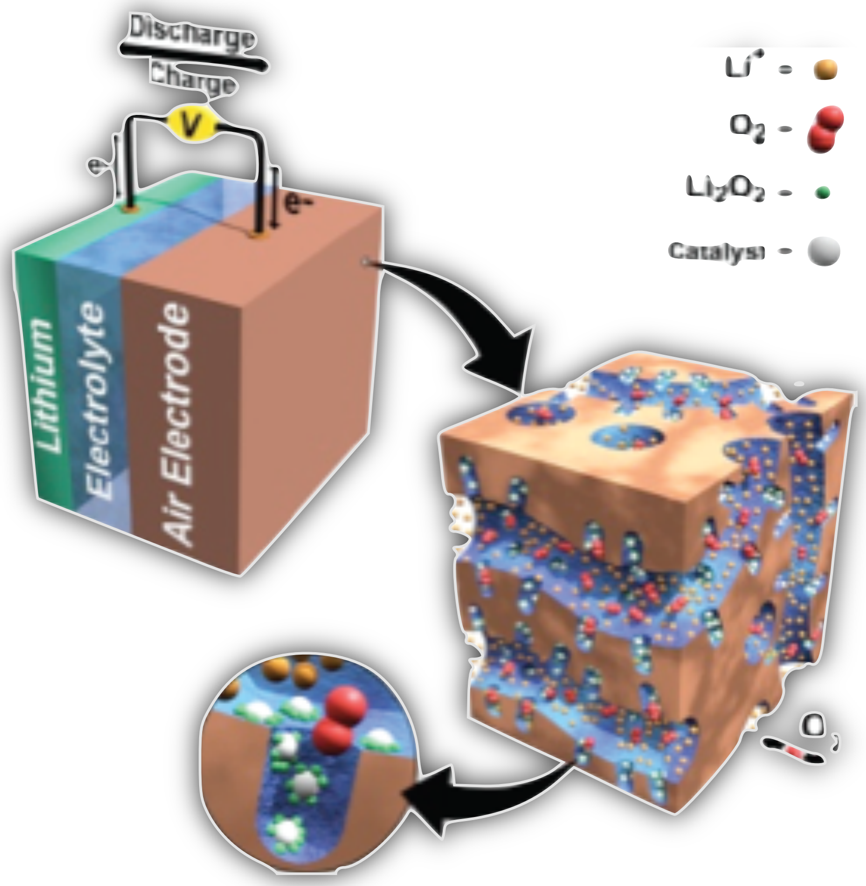




- **High** theoretical specific capacity 1675 Ah/kg
- **High** energy density 2500 Wh/kg

Li air: reactions

-O_2 dissolved in the electrolyte is carried through the pore network of the cathode,
-Precipitation of insoluble products narrow such network lowering oxygen diffusivity



Non aqueous system:

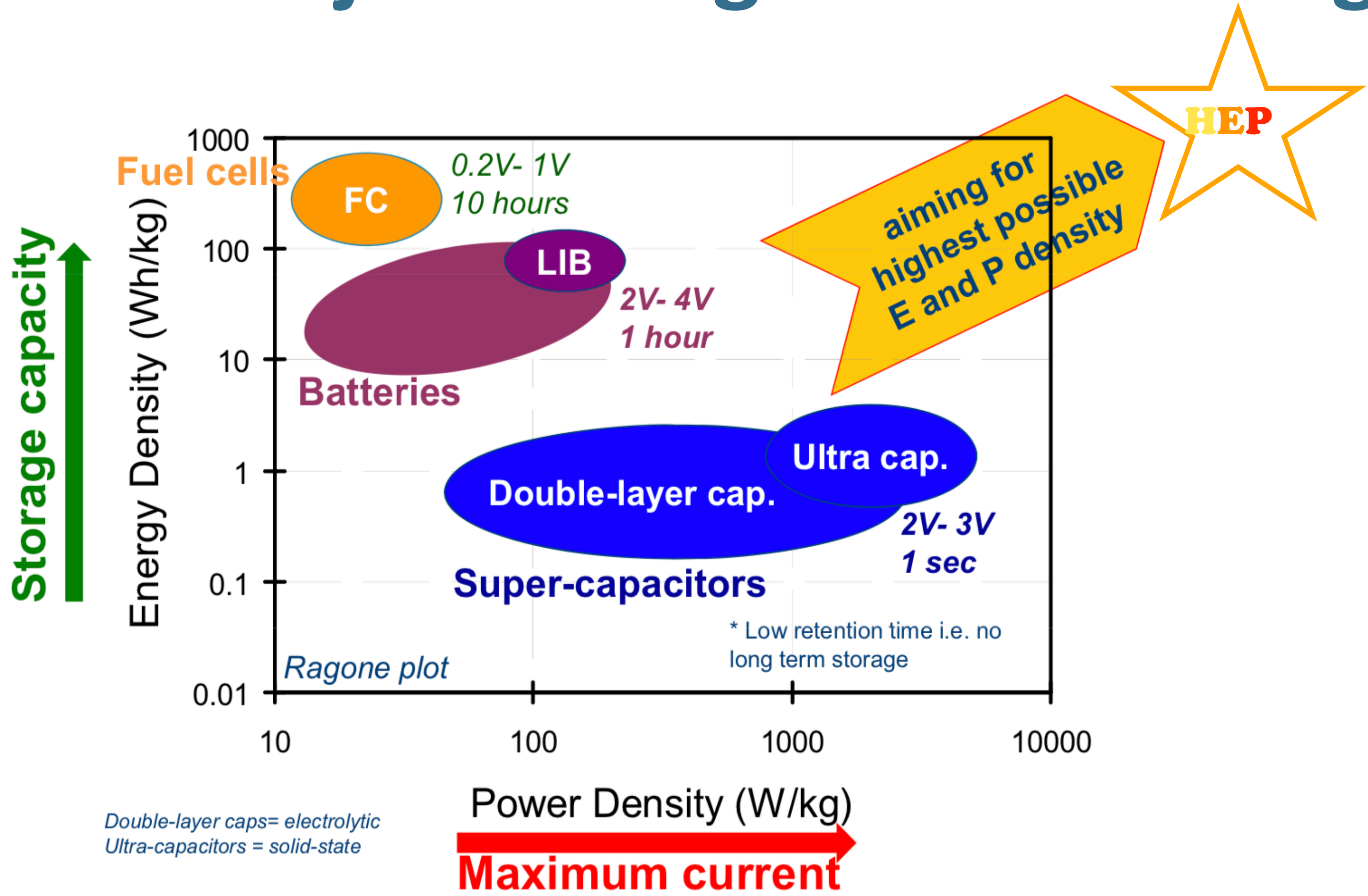
$2Li^+ + 2e^- + O_2 \leftrightarrow Li_2O_2$

$E_0 = 2{,}96V$ vs Li^+ / Li

Theoretical energy density 11500 Wh/kg

Y. Shao, S. Park, J. Xiao, J-G. Zhang, Y. Wang, J. Liu, ACS Catal., ***2012****, 2, 844-857*

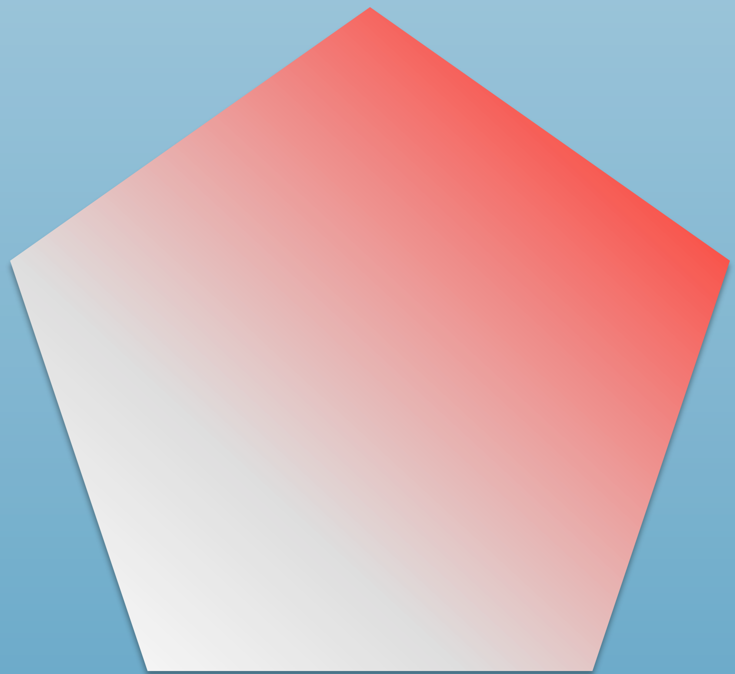
Can we get high energy together with high power?
Yes... just change the cell design



Double-layer caps= electrolytic
Ultra-capacitors = solid-state

POLITO Patent

The perfect battery



Safety

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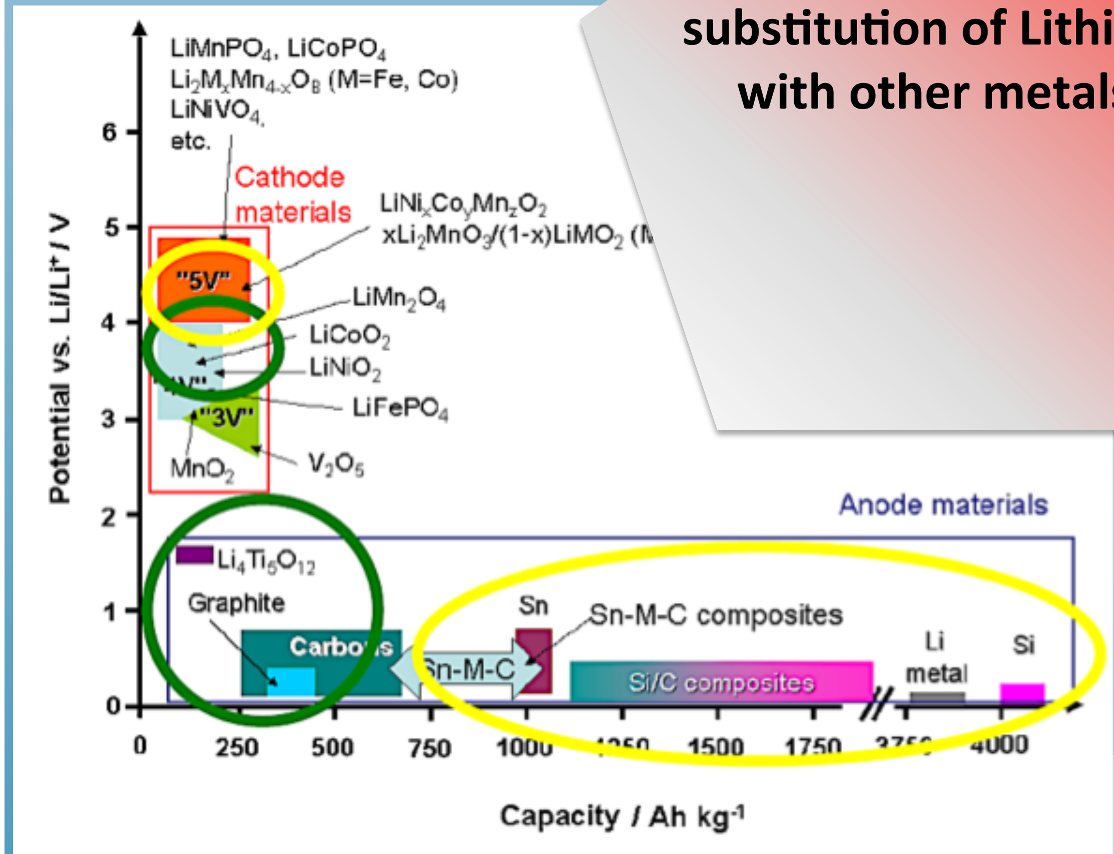
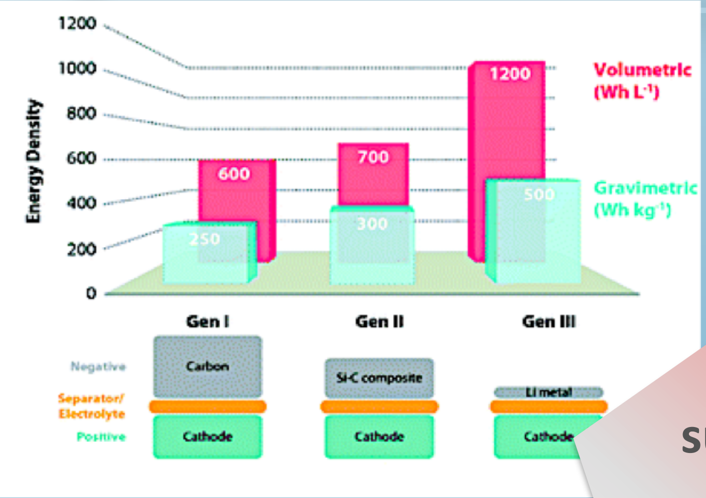
The perfect battery



substitution of Lithium with other metals

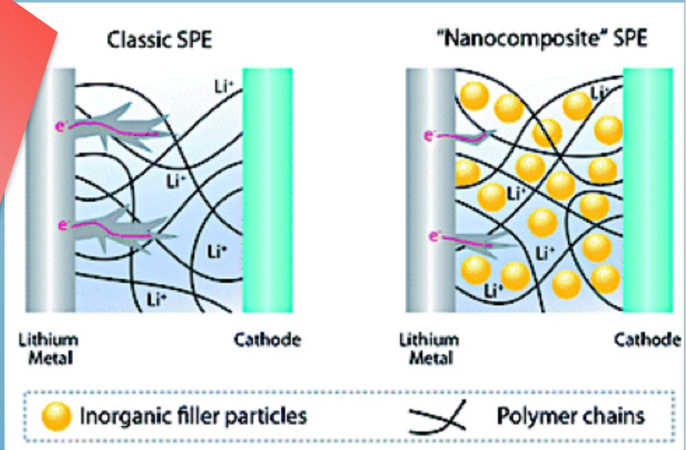
Safety

The perfect battery



substitution of Lithium with other metals

protection of Li metal

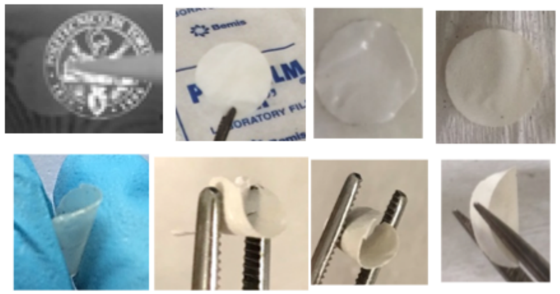


Safety

protection of Li with polymer membranes

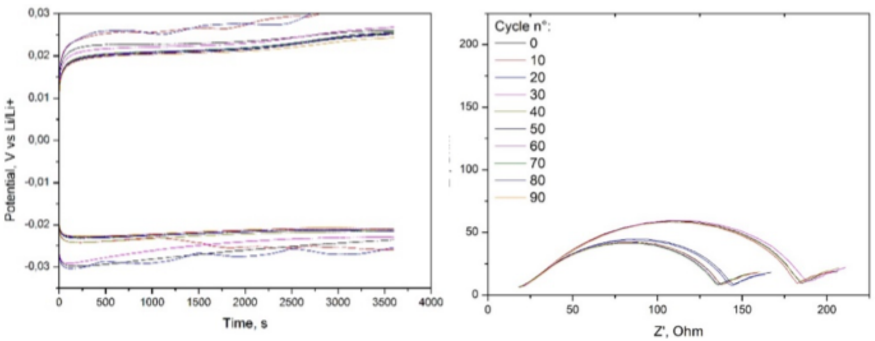
Li-Sulfur batteries

Acrylate based membrane prepared via thermo-initiated polymerization in bulk with commercial monoclinic ZrO_2 filler



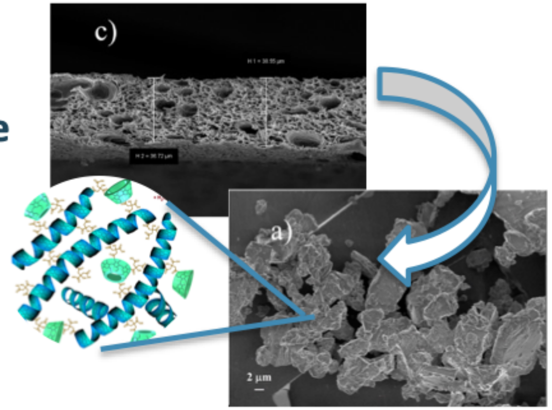
No additive | 38 wt% ZrO_2 | 63 wt% ZrO_2 | 80 wt% ZrO_2

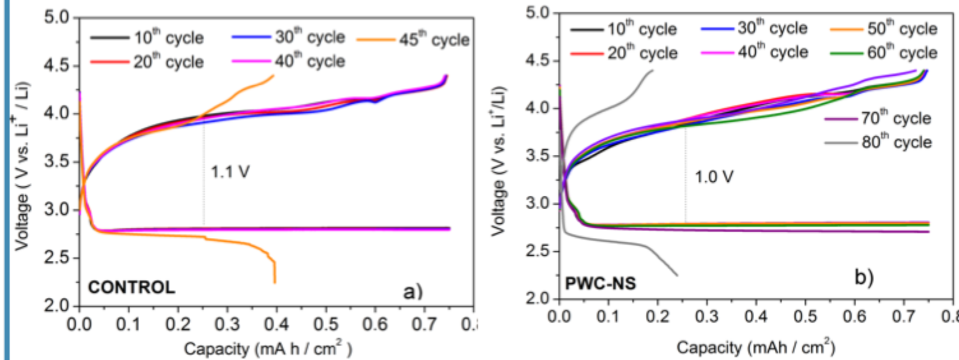
With 38 wt% ZrO_2



Li-air batteries

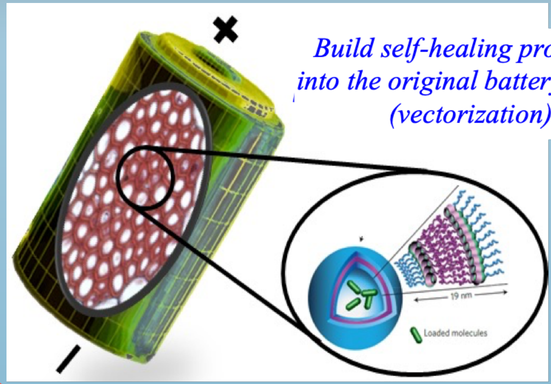
PEEK-WC (modified polyetheretherketone)/nanosponge (cyclodextrines) membrane prepared by solvent evaporation method





Amici, ChemElectroChem 2018, 5, 1599–1605

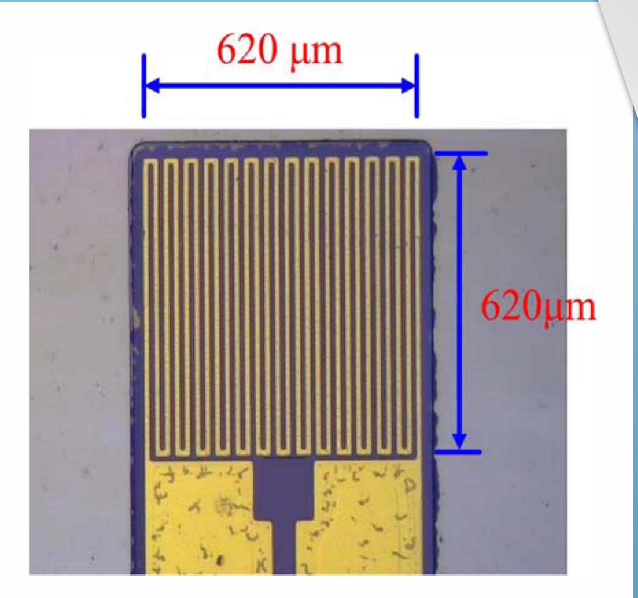
The perfect battery



substitution of Lithium with other metals

protection of Li metal

use of smart batteries



Safety

BMS, number of data, increase of complexity

Main EU initiatives

endorse battery2030.eu

ETIP BatteRIesEurope

BATTERIES EUROPE

Status Working Group Provisional Chairs and Co-Chairs, April 11

Thematic Working Groups	WG1 New & Emerging Battery Technologies	WG2 Raw materials & recycling	WG3 Advanced Materials	WG 4 Manufacturing and Cell Design	WG5 Application and Integration-Transport	WG6 Application and Integration-Storage
Chair (Alternate)	Kristina Edström **Uppsala University**	Ilkka Kojo **Outotec** (Mari Lundström, **Aalto university**)	Fabrice Stassin, **Umicore** (Marcel Meeus, **EMIRI**)	Oscar Miguel Crespo **Cidetec** (Arno Kwade, **TU Münster**)	Simon Perraud **CEA**	Luigi Lanuzza **ENEL** (Rachele Nocera, **ENEA**)
Co Chair	Stefano Passerini **TU Ulm**	Olli Salmi **EIT Raw Materials**	**Silvia Bodoardo POLITO EERA ES**	Name TBC **Northvolt**	Franz Geyer **BMW**	Michael Belsnes TBC **3ES- Research Group,** SINTEF
Co-Chair	TBD	Alain Vassart **EBRA**	TBD	TBD	Josef Affenzeller/ Lucie Beaumel **EGVIA**	TBD

Research	Industry or Association

Thank you Electrochemistry Group

Thank you for your kind attention

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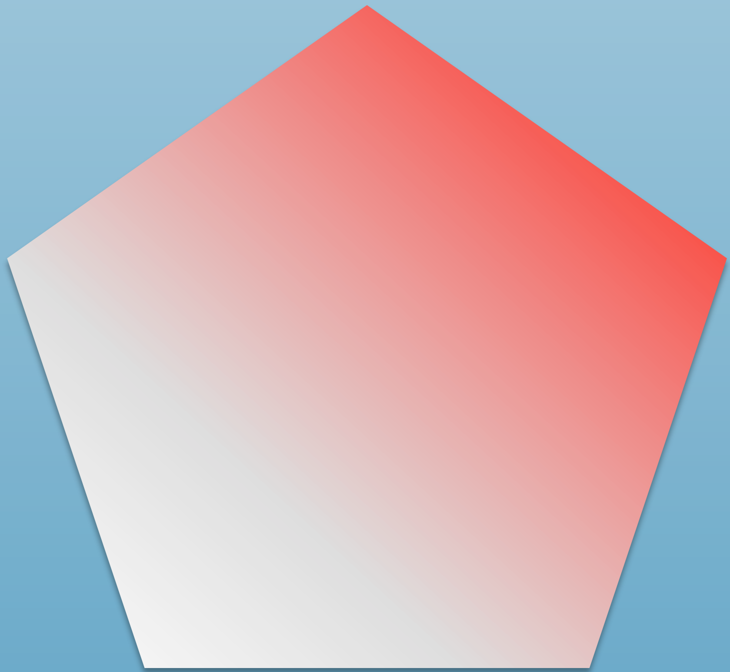
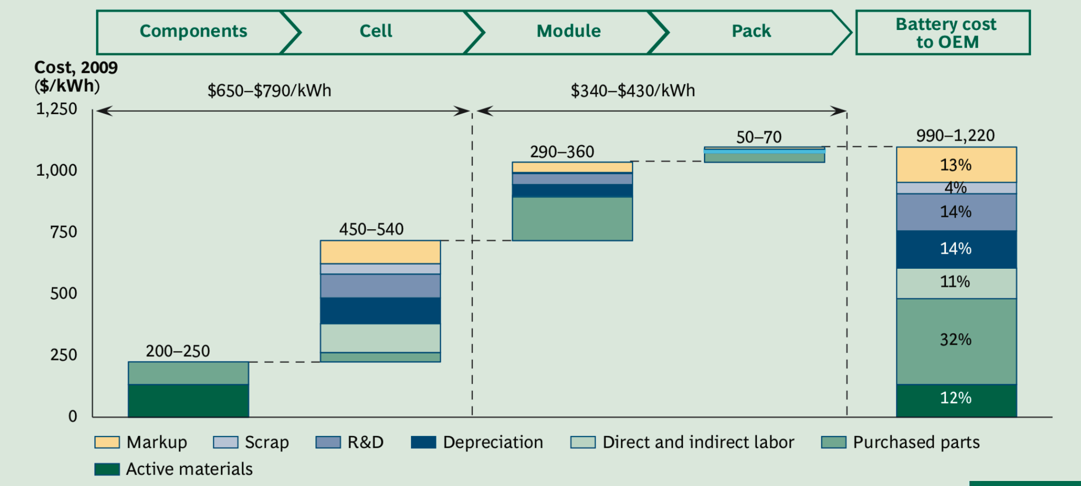
The perfect battery



Low Cost

cost issues

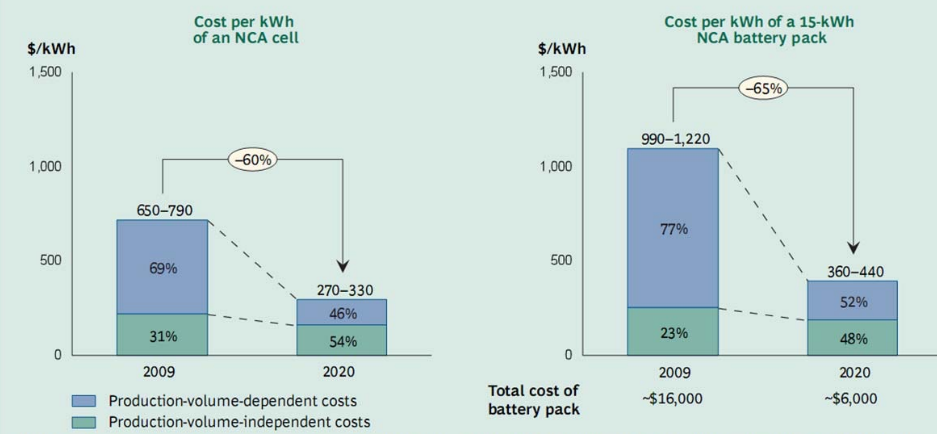
Exhibit 3. Batteries Cost OEMs About $1,100 per kWh at Low Volumes



Sources: Interviews with component manufacturers, cell producers, tier one suppliers, OEMs, and academic experts; Argonne National Labo
analysis.
Note: Exhibit shows the nominal capacity cost of a 15-kWh NCA battery and assumes annual production of 50,000 cells and 500 batteries, as
percent scrap rate at the cell level and a 2 percent scrap rate at the module level. Numbers are rounded.

Expecting big cost reduction for 2020

Exhibit 4. Battery Costs Will Decline 60 to 65 Percent from 2009 to 2020



Sources: Interviews with component manufacturers, cell producers, tier one suppliers, OEMs, and academic experts; Argonne National Laboratory; BCG analysis.
Note: Exhibit assumes annual production of 50,000 cells and 500 batteries in 2009 and 73 million cells and 1.1 million batteries in 2020. Numbers are rounded.

Costs roadmap
US DOE target: 125 $/kWh 2022 (10% every year reduction from 2016 to 2022) GM: <100 $/kWh 2022
Tesla: 100 $/kWh 2020

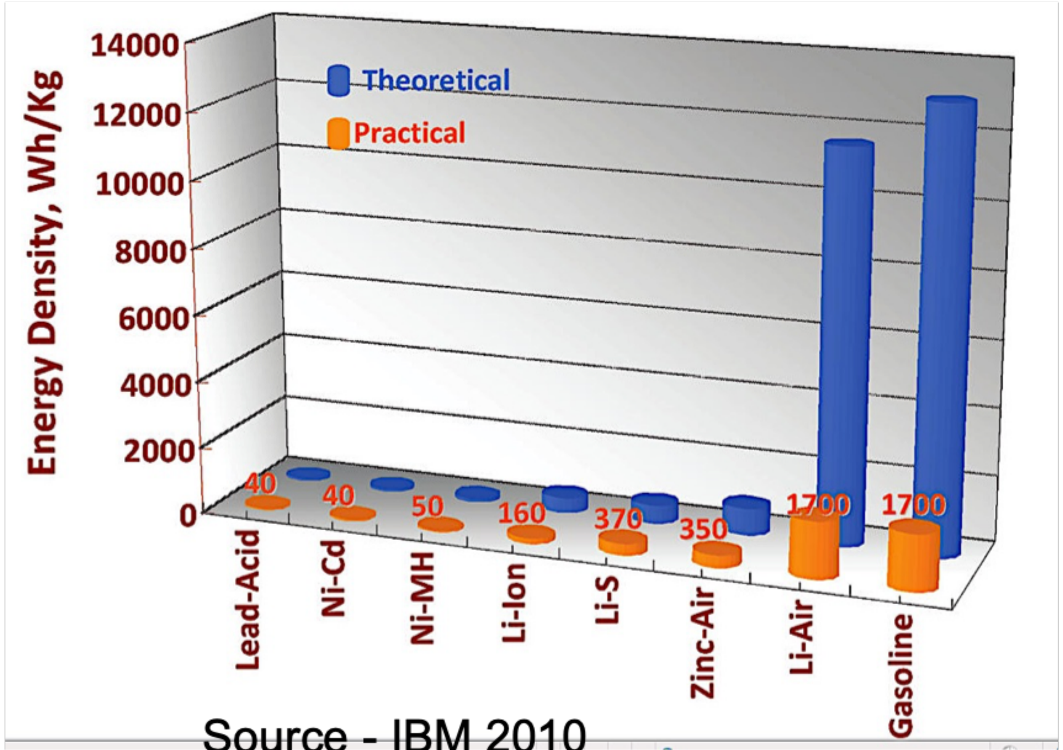
why Li air

Extremely high specific capacity of Li anode material (**2567 Wh kg^{-1}** for lithium)

The Li-air battery has **theoretical specific energy** of **11500 Wh/kg**, when fully developed, Li-air could have practical specific energies of **1000-3000 Wh kg^{-1}**

Use of **air** which is highly available and no cost

They can be produced without CRM



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