Fuel Choices and Smart Mobility Initiative

FUEL CHOICES AND SMART MOBILITY 2017 THE SUMMIT

Fuel Choices and Smart Mobility Summit 2017

31 October - 1 November, Habima Theater, Tel-Aviv

Battery research for smart mobility: Achievements and new directions

J.M. Tarascon

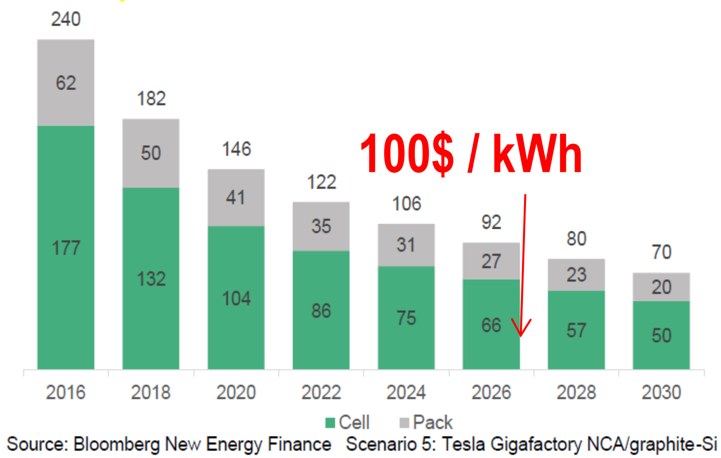
cnrs dépasser les frontières

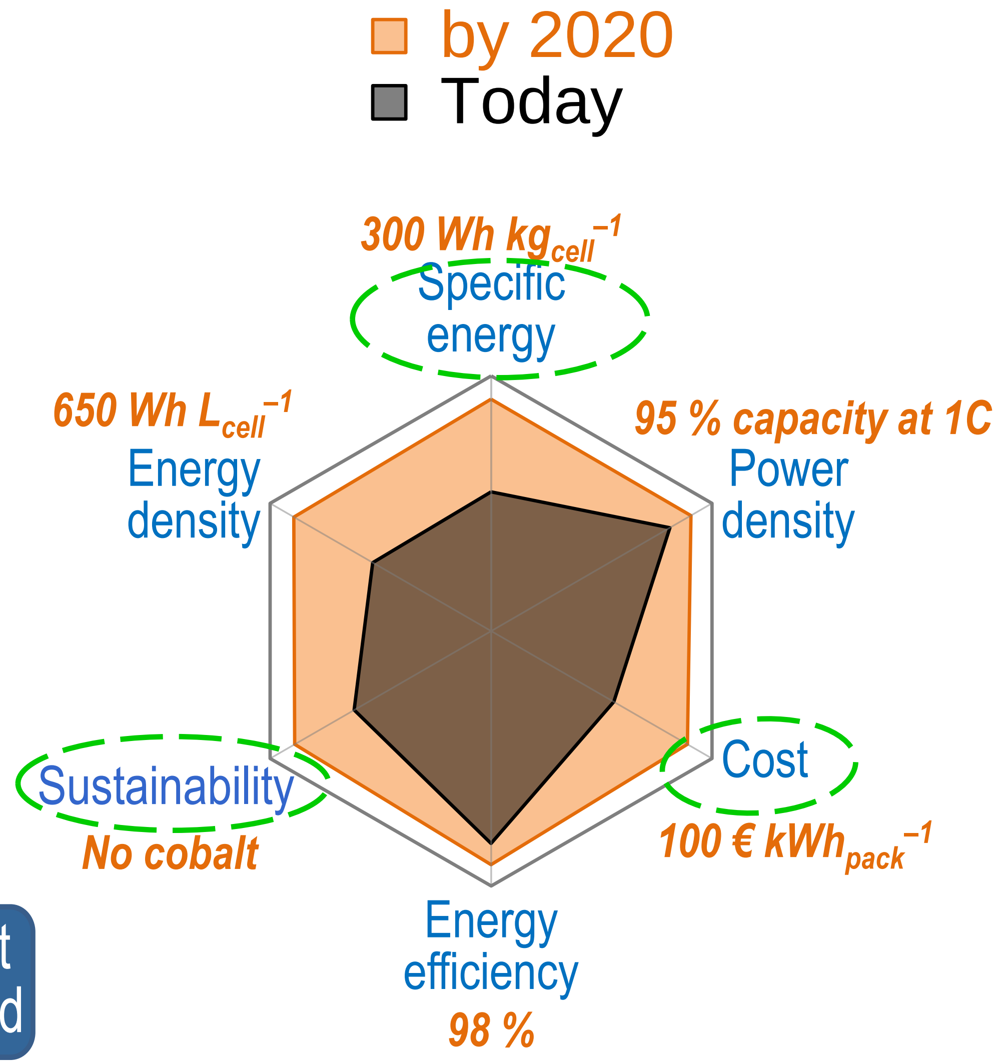
COLLÈGE DE FRANCE 1530

ENERGIE RS2E

Electric mobility: an introduction

Battery research is business-driven
so are the basic research needs

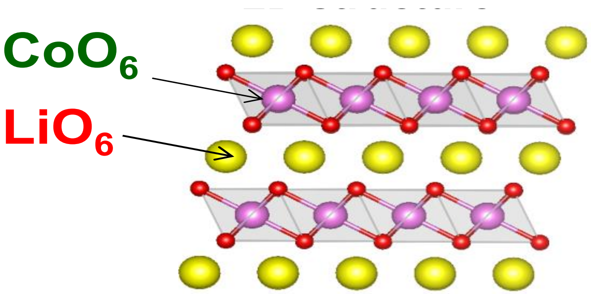


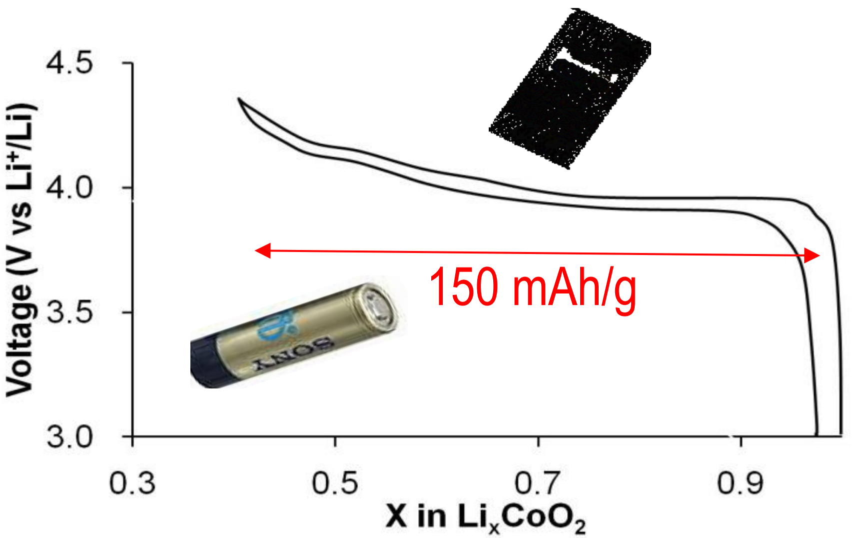


Revolution in the word of energy management but also in the way that research must proceed

The layered oxides and their evolution through the years

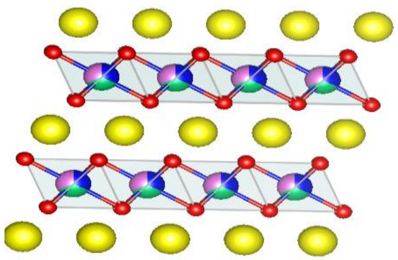
❑ $LiCoO_2$ (1991)





❑ Chemically substituted samples

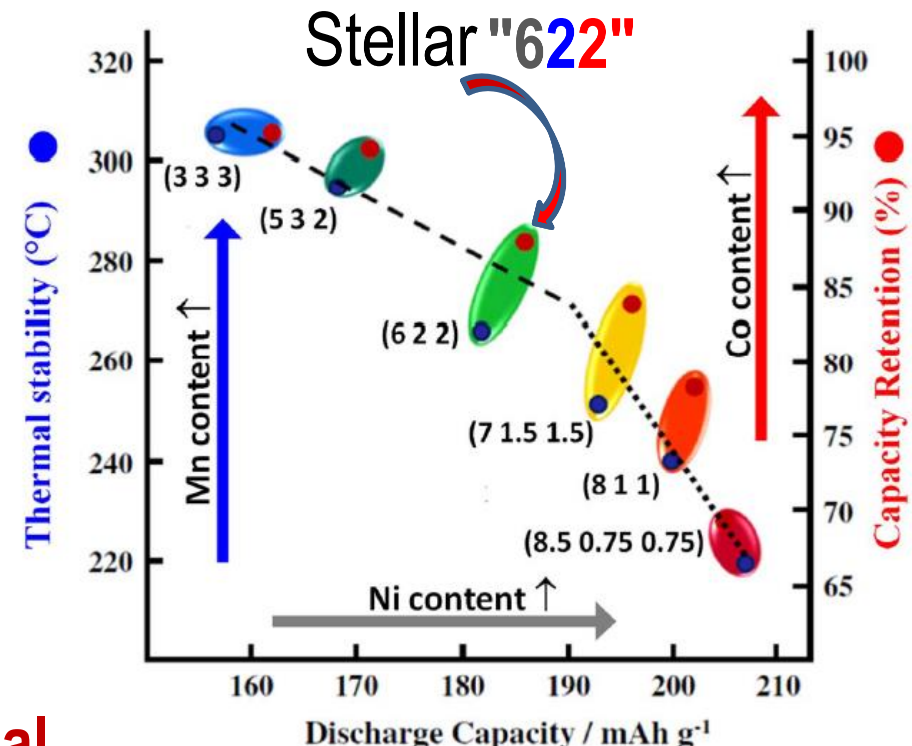
Replace partially Co by Mn and Ni



Li[NiMnCo]O_2

NMC phases

(170-1900 mAh/g)



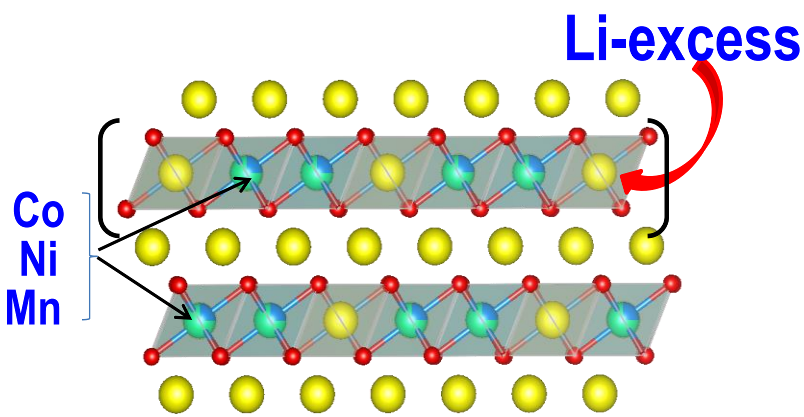
➔ Less than 1 Li^+ exchanged per metal

Noh et al., *J. Power Sources*, 2013

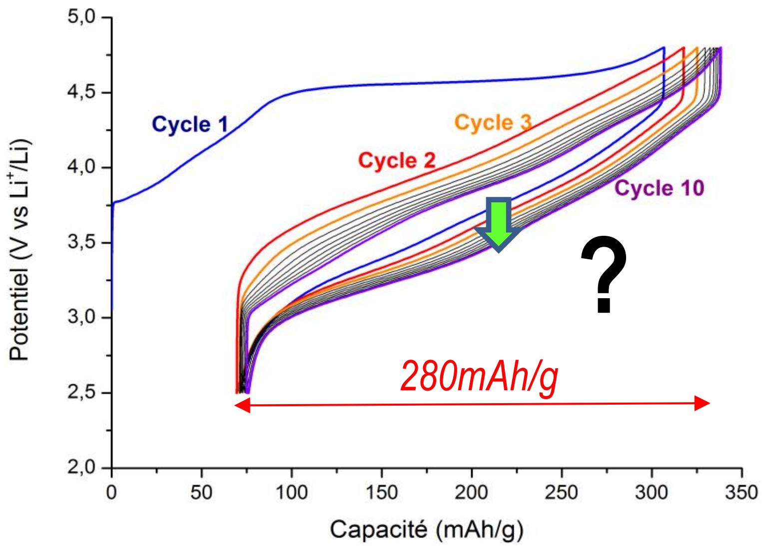
T.Ozuku, Y. Makimura: Chem Lett. 642 (2001)

Increasing the capacity further via chemical substitution

The Li-rich NMC phases



$Li\,[Li_{0.22}Ni^{II}_{0.11}Mn^{IV}_{0.54}Co^{III}_{0.13}]O_2$



Design model materials

Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd

3d → 4d

$Li_2Ru^{IV}_{0.75}Sn^{IV}_{0.25}O_3$:

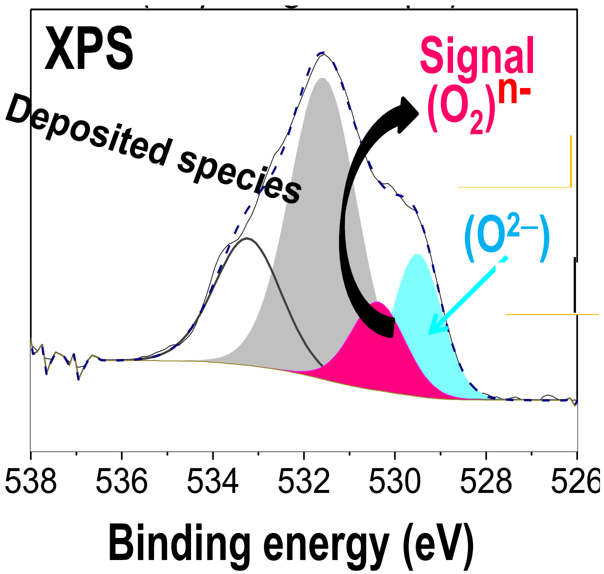
A single cationic redox center

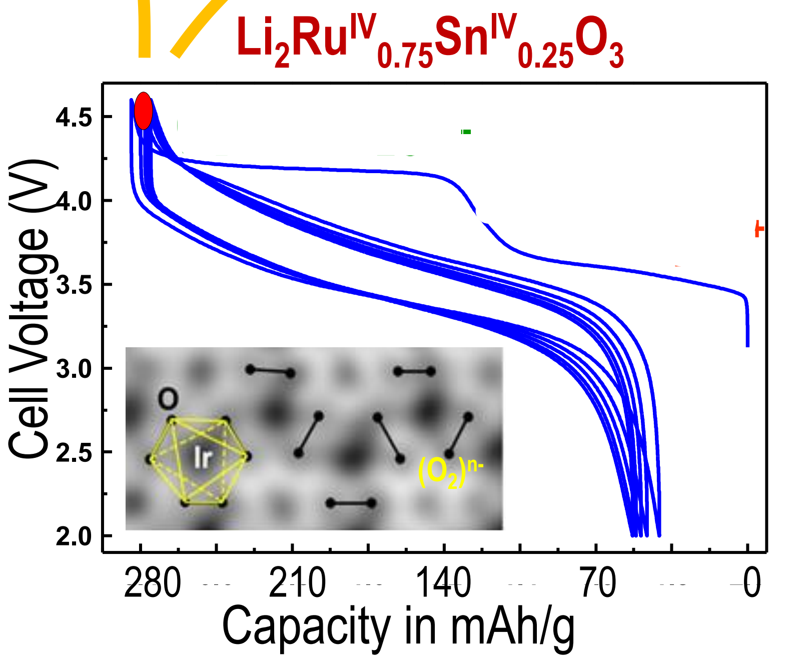
Dahn et al. , Chemistry of materials 15, (2003),3214-3220

Sathiya , Tarascon et al., *Nature Mater.*, 2013 + worldwide patent *

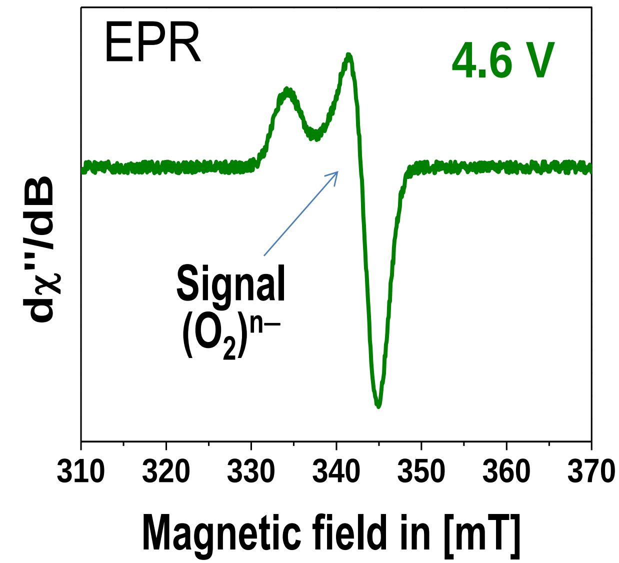
Origin of the extra capacity in Li-rich materials

❑ XPS measurements





❑ EPR measurements



Direct evidence for an anionic redox process ($2O^{--} \leftrightarrow (O_2)^{n-}$) in Li-rich lamellar compounds

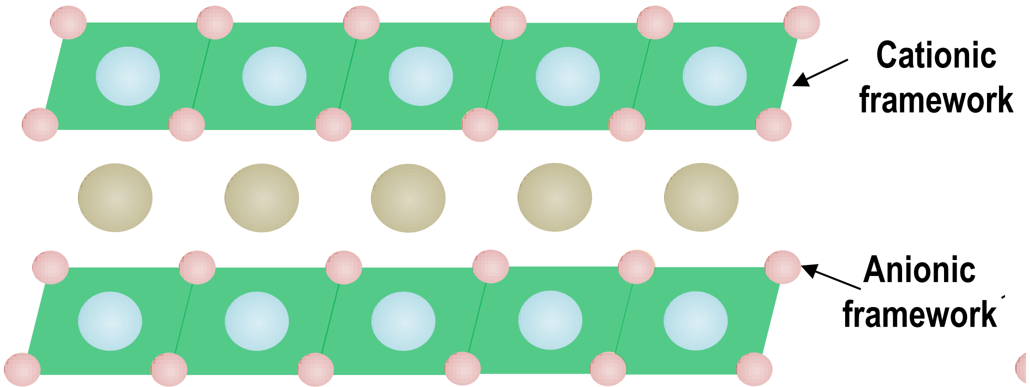
E. McCalla , J.M. Tarascon et al., *Science* , 2015

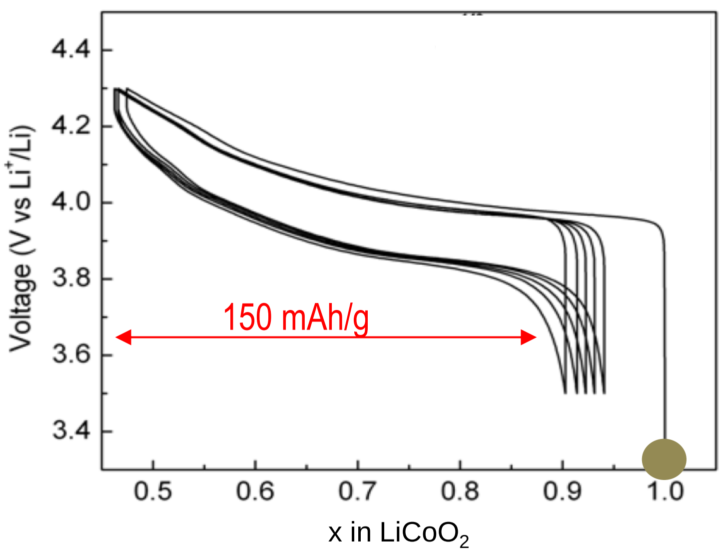
M. Sathya, J.M. Tarascon et al. (Nature communications, Fevrier 2015)

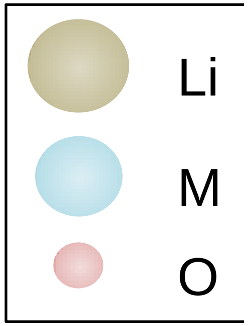
The anionic redox activity: a transformational change

❑ LIB has relied on cationic redox reactions

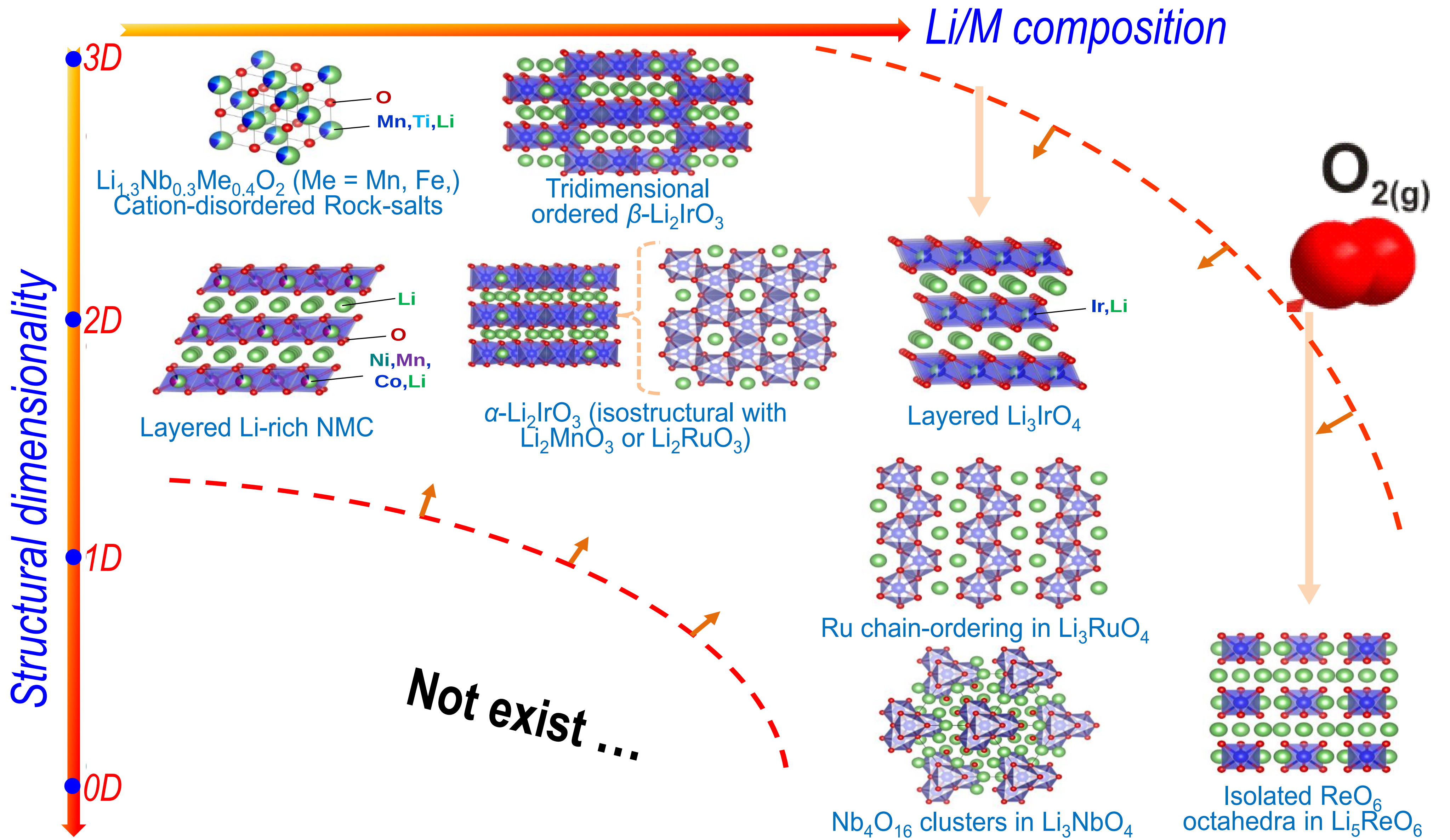
(2D Layered oxide)







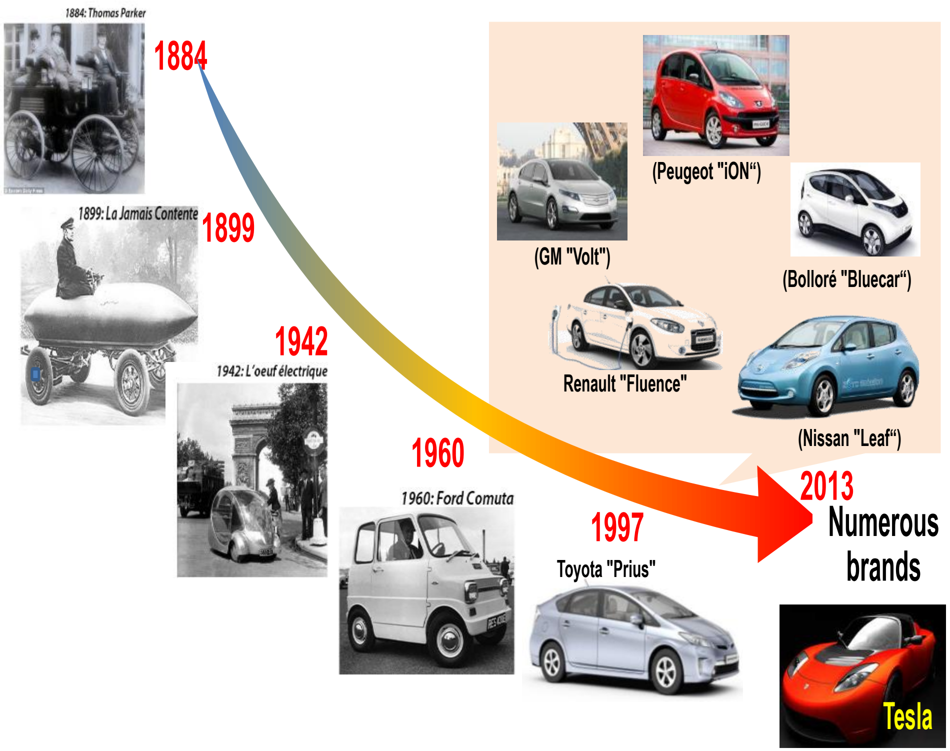
A new playground for designing high capacity electrodes



A. Perez, et al. Nature energy (2017)

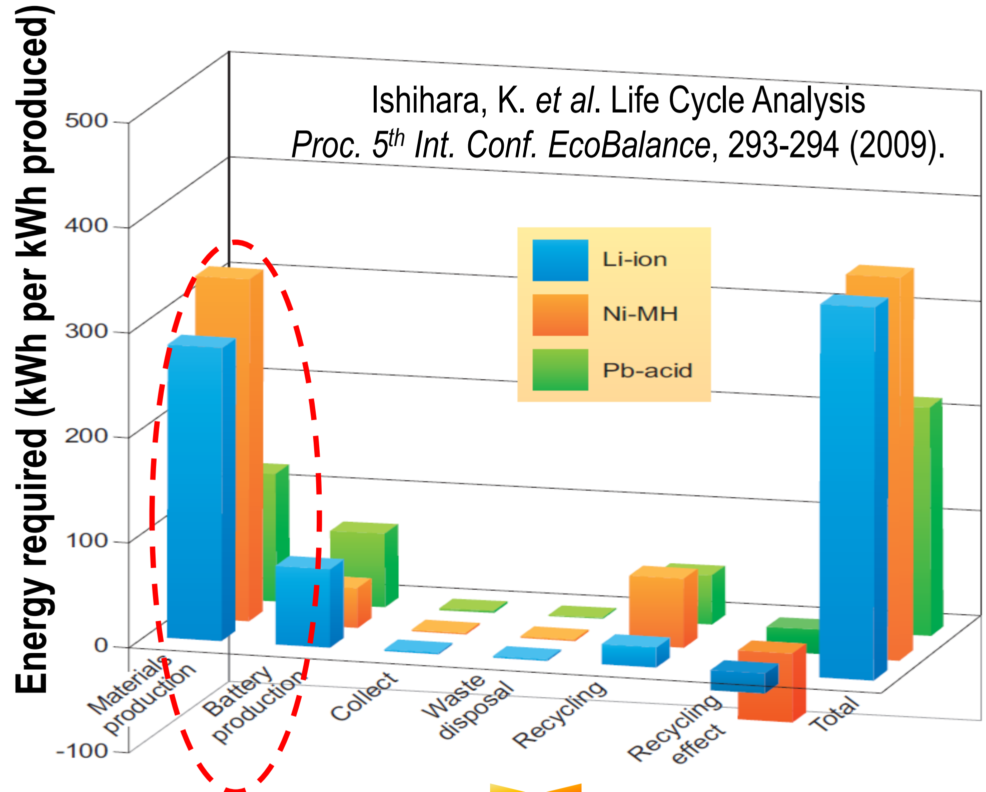
Layered $LiMO_2$ oxides have enabled today's boom in EV's

❑ Today's EV boom



Is it the perfect solution with respect to sustainability ?

❑ Life cycle analysis



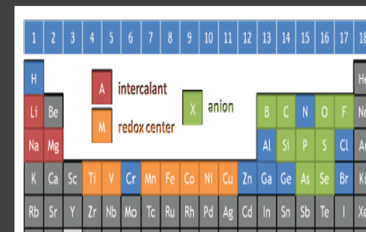
➢ **A**ssembly of a battery of **1kWh**

✓ Energy needed **≈ 327 kWh**

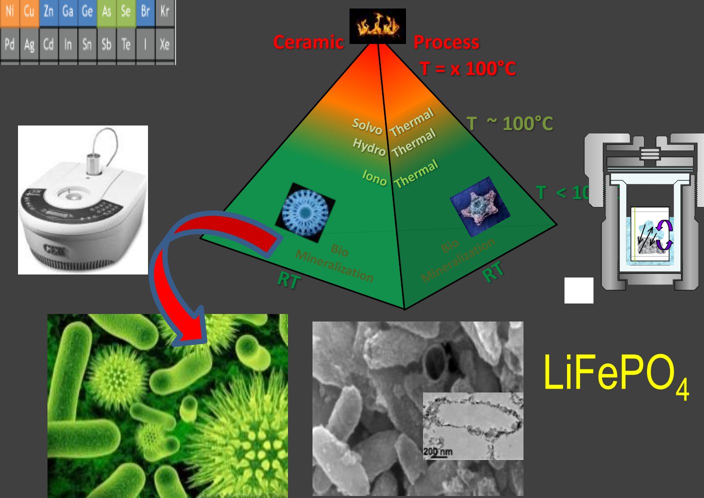
✓ **CO_2** rejected **≈ 110 kg**

How to make more sustainable Li-ion batteries ? A few trends

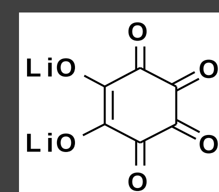
- ✓ **Design electrode materials based on abundant chemical elements**



- ✓ **Develop energy-saving synthesis routes**



- ✓ **Use of renewable organic electrodes**



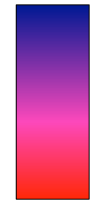
$Li_2C_6O_6$

- ✓ **Explore chemistries beyond Li**

D. Larcher and J.M. Tarascon, Nature Chemistry (2015)

Sustainability thrust: diversification of the battery systems for enhanced performances

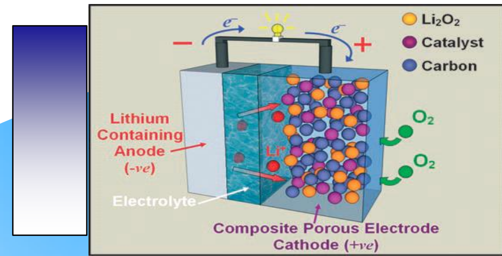
Time to market



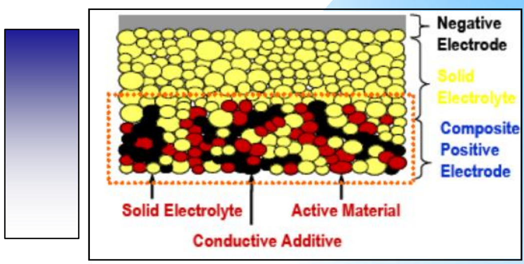
long

moderate

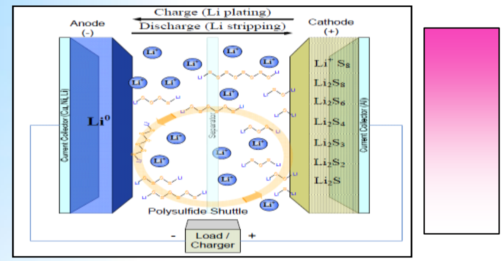
soon



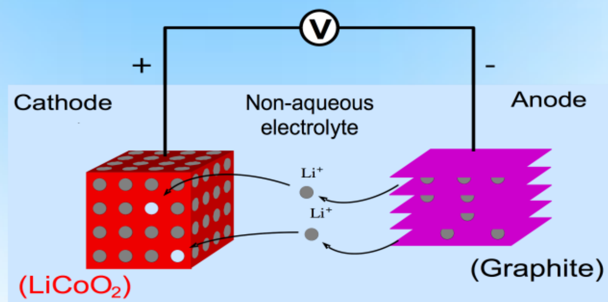
Li/air batteries



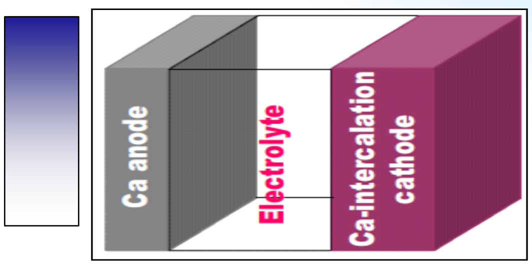
All solid-state (Li/Na) batteries



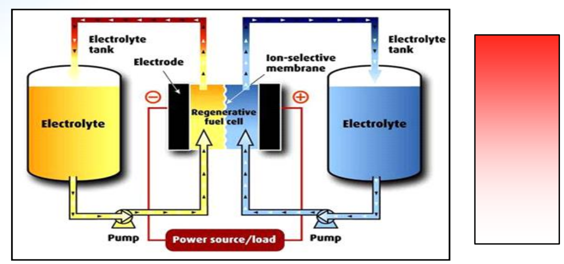
Li/S batteries



Li-ion batteries



Multivalent cation (Mg^{2+}, Ca^{2+}) batteries



Redox flow batteries

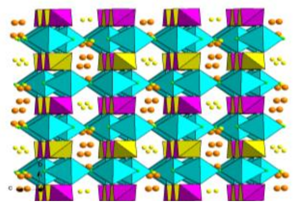
None have reached the maturation stage …

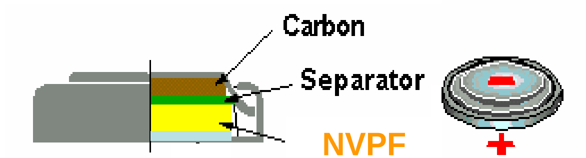
The Na-ion battery: an alternative to Li-ion for sustainability

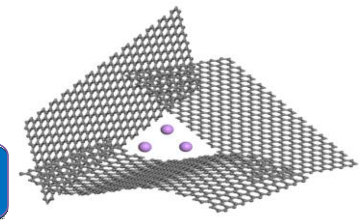
3 6.941
0.98
180.5
0.534
Li
$1s^2 2s^1$
Lithium

Name		Earth abundance	
Hydrogène		0.88 %	
Lithium	Lithium	0.006 %	0.006%
Béryllium		0.00053 %	
Sodium	Sodium	2.6 %	2.6%

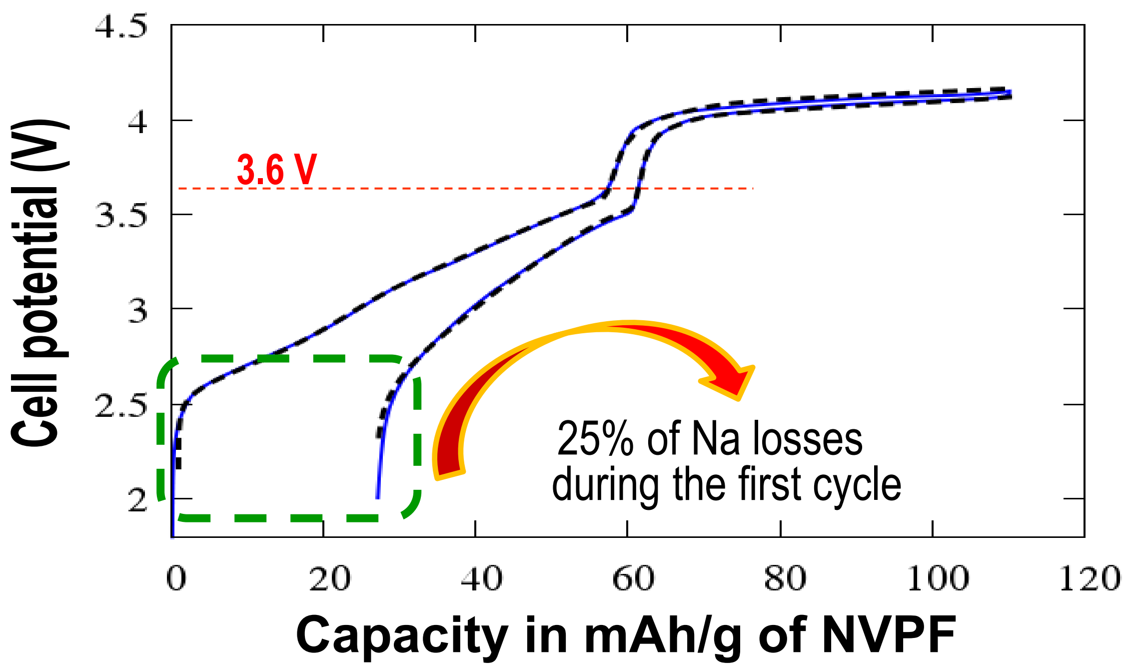
11 22.941
0.9
98
0.97
Na
$2s^2 2p^6 3s^1$
Sodium







$Na_3V_2((PO_4)2F_3$ || $NaPF_6$ in PC/EC/DMC|| C



Need of an extra Na source ..

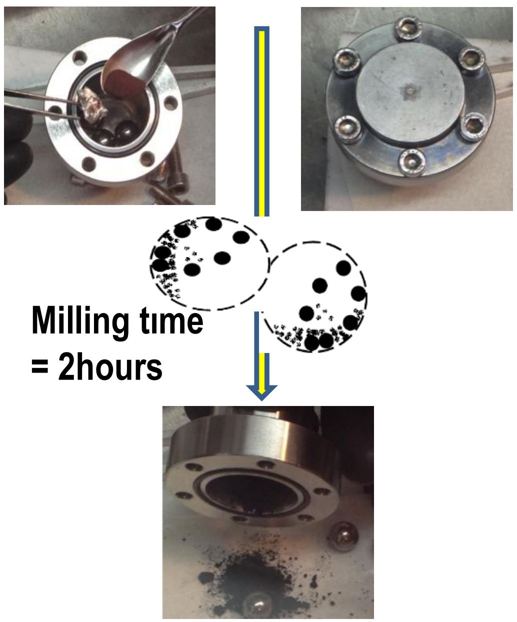
Oversodiated materials
($Na_{3+x}V_2(PO_4)_2F_3$)
???

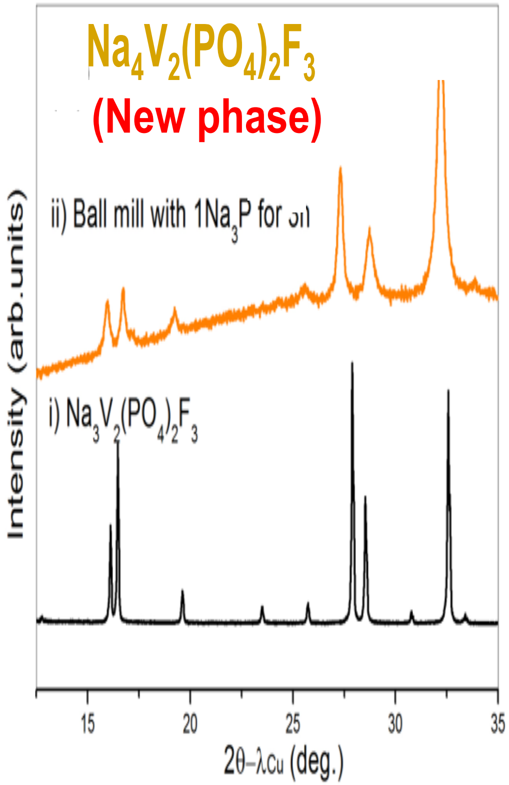
How to prepare a Na-rich phase via a sustainable approach?

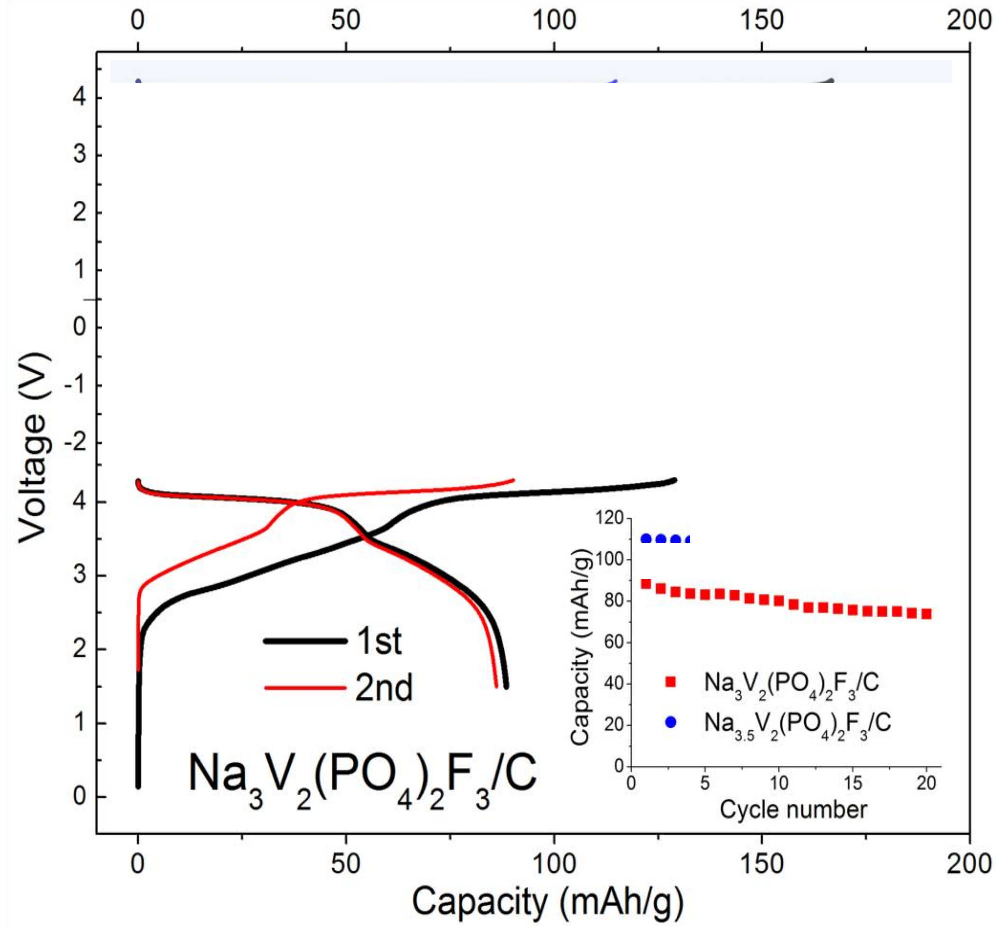
❑ Synthesis via ball milling

Electrochemical performance

$Na_3V_2(PO_4)_2F_3$ + Na



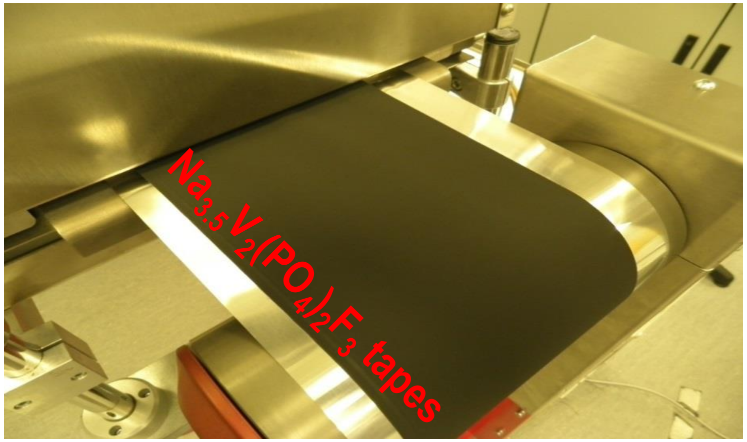




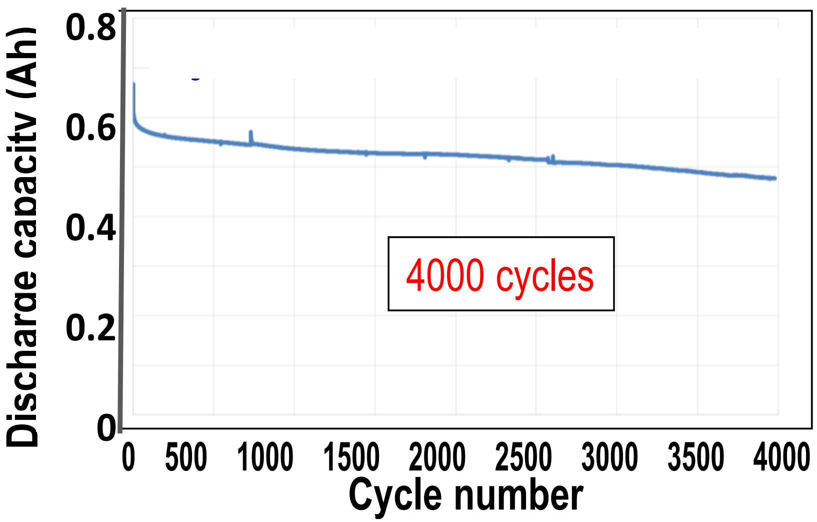
"$Na_{3+x}V_2(PO_4)_2F_3$ composites
(3<x<4)

Assembly of 18650 Na-ion cells for benchmarking against Li-ion

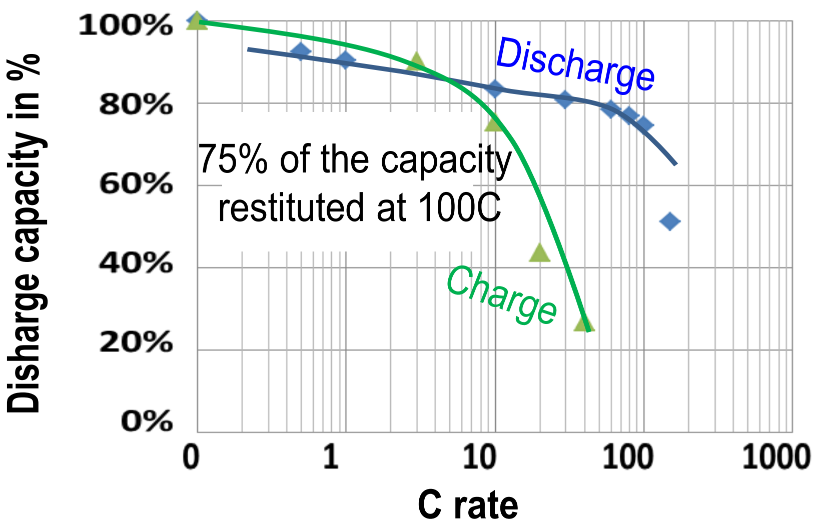
The $Na_3V_2(PO_4)_2F_3$/C technology: First 18650 prototypes



Cycle life of C/NVPF Na-ion cells at 1 C



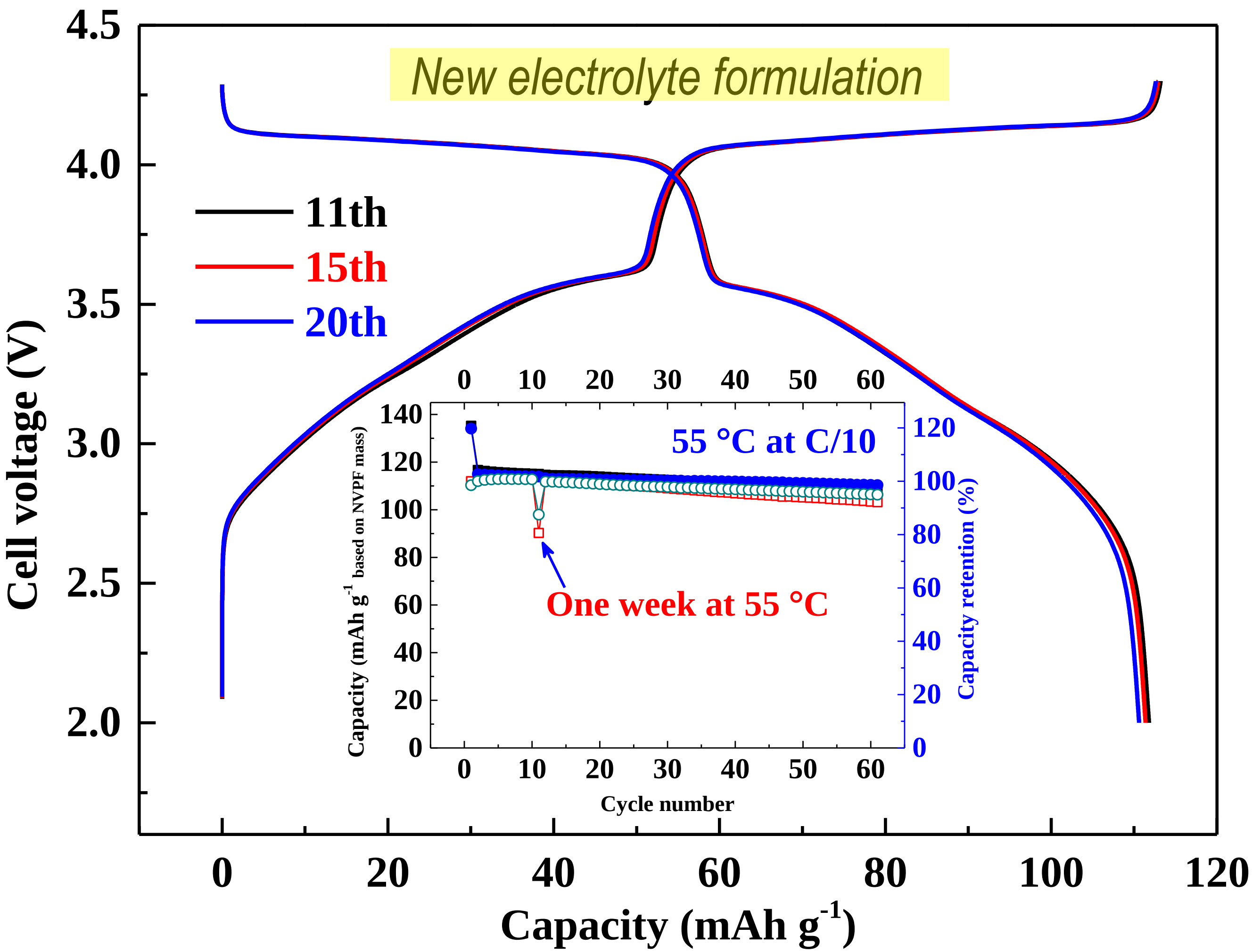
Power rate of C/NVPF Na-ion cells



Poor 55°C cycling and self-discharge performances

The $Na_3V_2(PO_4)_2F_3/C$ technology: 55°C cycling & self discharge

❑ *Cycle life & One week self-discharge of NVPF/C at 55°C*



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- *105Wh/kg*
- *80 % at 10C*
- *~ 3000 cycles*
- *55°C storage*

What could be tomorrow's battery research

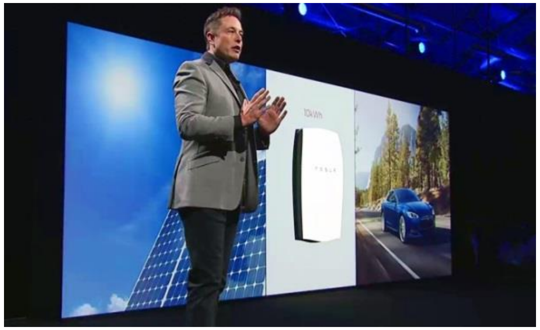
Basic problems emerging from concrete technological challenges

Looking ahead: New research challenges

Business players change today's traditions

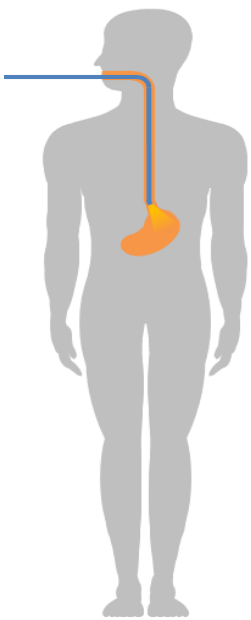
Cost per kWh of stored energy = ∑ [Chemistry/Material performance + Volume production + Battery second life]

Better traceability

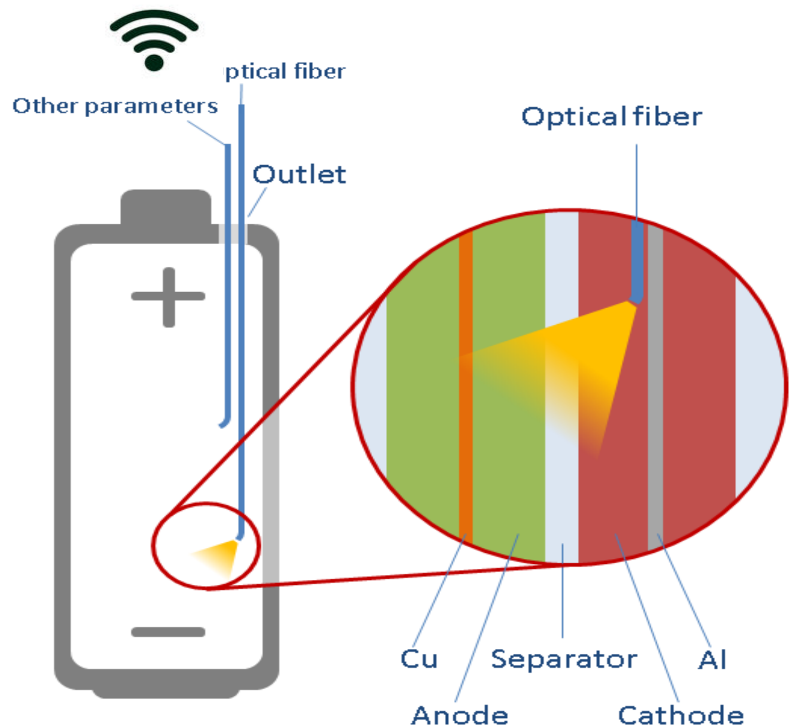


► E. Musk: (100 $ kWh in 2025)

Establish the state of health record of the battery just like for humans



Efforts towards instrumental miniaturization for real time monitoring of the batteries in the field



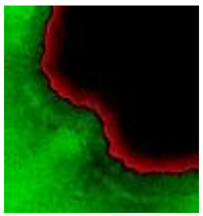
C. Grey and J.M. Tarascon, Nat. Mater. 2016, *16*, 45–56.

Looking ahead: New research challenges

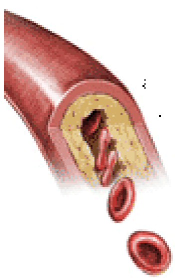
Establish the state of health record of the battery just like for humans

Develop self-healing processes

Electrode recovered by an SEI

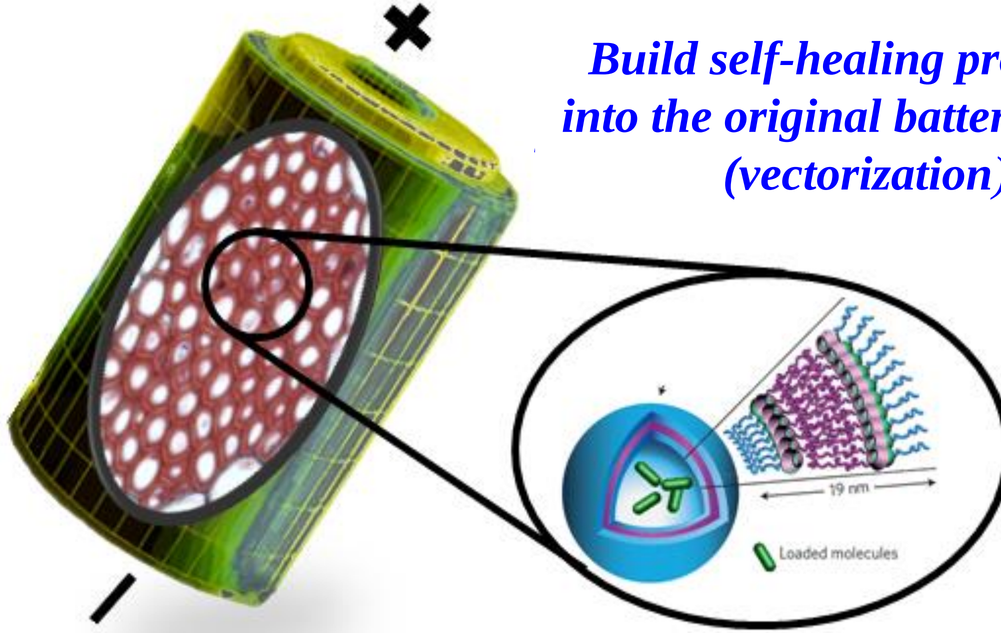


(Prevents the crossing of Li^+)



Clogged artera by cholesterol

(Prevents blood circulation)



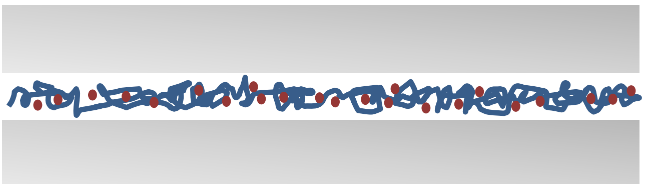
Build self-healing processes into the original battery design (vectorization)

Interdisciplinary research which is still in its embryonic state

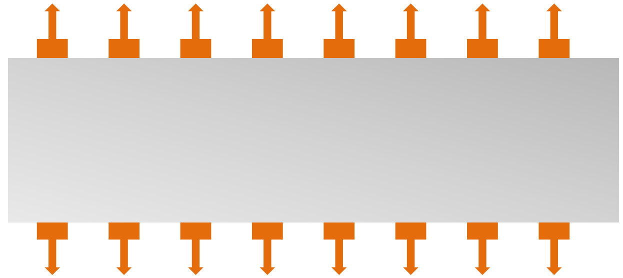
C. Grey and J.M. Tarascon, Nat. Mater. 2016, *16*, 45–56.

How to tackle this issue ?
Innovative chemistry on the battery separator

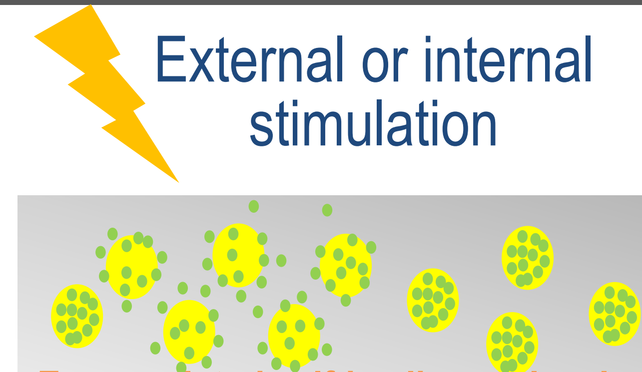
Multilayers



Surface-functionalization

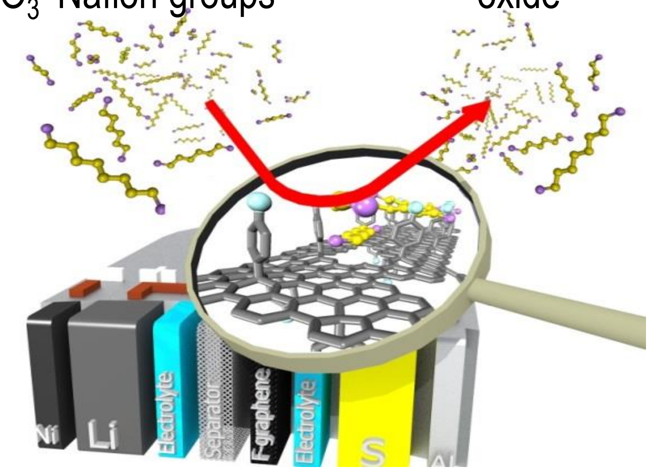


External or internal stimulation



Functionalization with SO_3^- Nafion groups

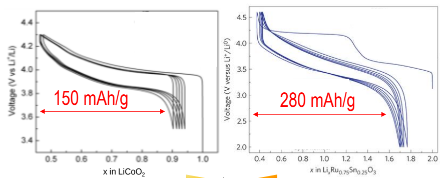
Fluorinated graphene oxide



Functionalization to trap species released from side reactions

Electric mobility: Conclusions

Anionic redox as a new paradigm to design electrodes with double capacities



Li-ion batteries with ~ 20% energy density improvements

Development of a $C/Na_3V_2(PO_4)_2F_3$ Na-ion technology via materials and electrolytes innovations

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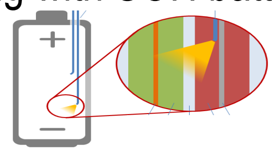
Na-ion batteries with attractive power rate performances

Future research challenges dealing with SOH batteries



Development of sensing and self-healing processes via innovative chemistry

Foreseen EV future

Hardware

Software + services

Foreseen battery future

Materials

Sensing + monitoring)

Acknowledgments

Thank you for your attention

erc European Research Council

http://www.college-de-france.fr/site/en-college/index.htm