Perspectives of battery development based on non-critical raw materials

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Sources: Lunghammer – TU Graz, Stadt: metamorworks – AdobeStock, Büro: Emilian Hinteregger

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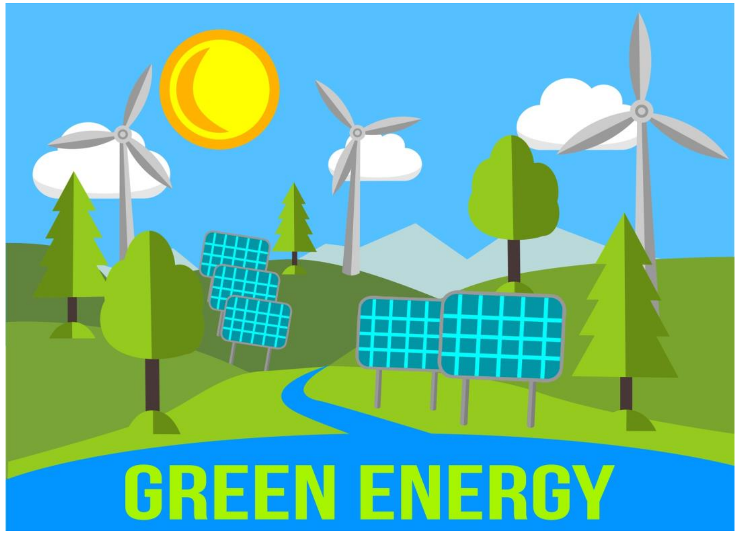
ADVANCED MATERIALS SCIENCE
Fields of Expertise TU Graz

Battery technology context

Portable electronics

Electric automotive transportation

Renewable energy storage



Batteries for portable electronics

- Li-ion: the most advanced battery system.
- The „master“ battery technology inherited to a significant extent by all other applications (*e.g.* automotive batteries).
- Key property to improve: (volume) energy density (Wh/L) rather than (mass) specific energy (Wh/kg).

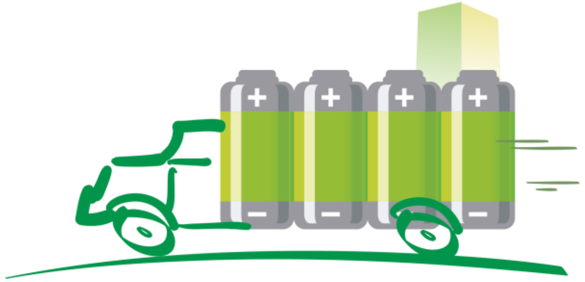
Batteries for electric cars

- Key property to improve: (mass) specific energy (Wh/kg).

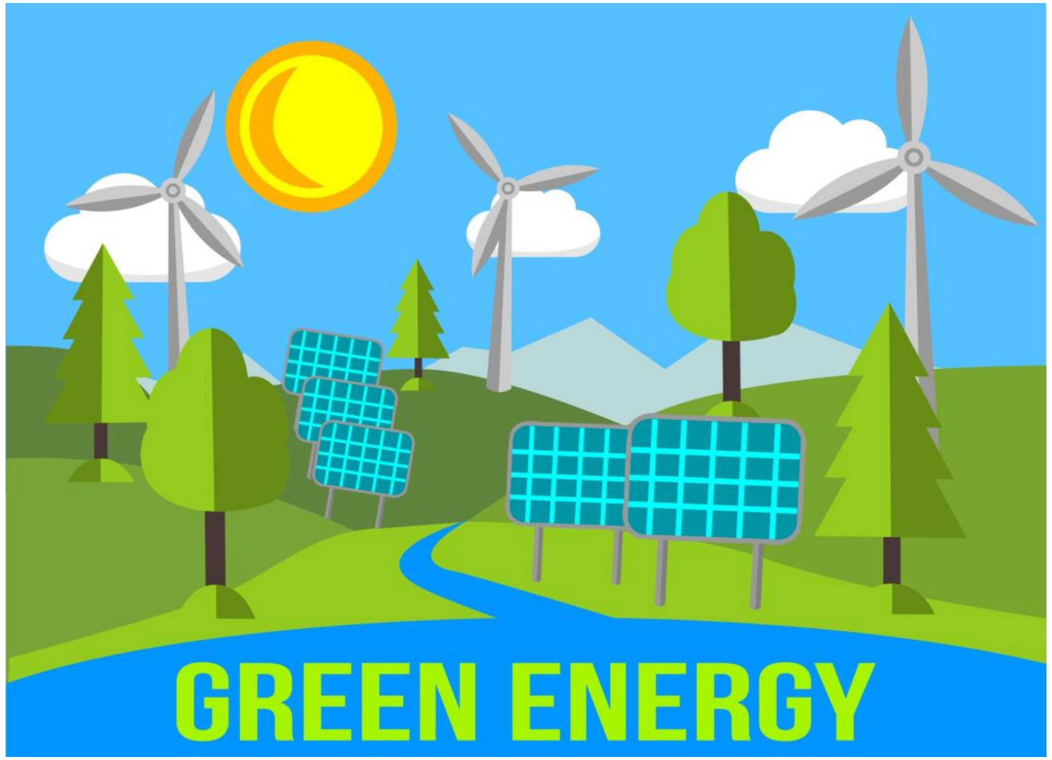
- Fast charging: an enabling technology for a significantly higher competitive edge!

- Significant advances in the past 5 years.

- Serious development is on going.

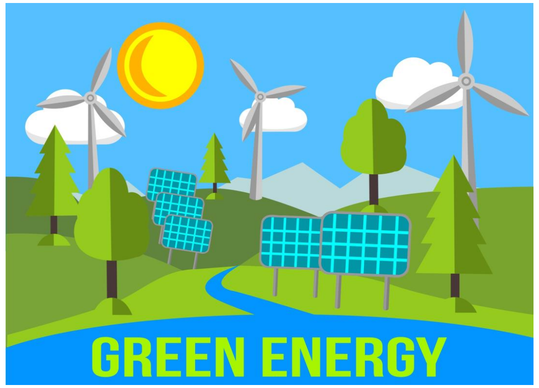


Batteries for renewable energy storage



- Key properties to improve: cost and life-time.
- Is Li-ion the most suited system? Na-ion is a plausible battery system for stationary applications.
- Efficient recycling technologies are required.

The technological context of battery research



The final application dictates the key property to be improved !

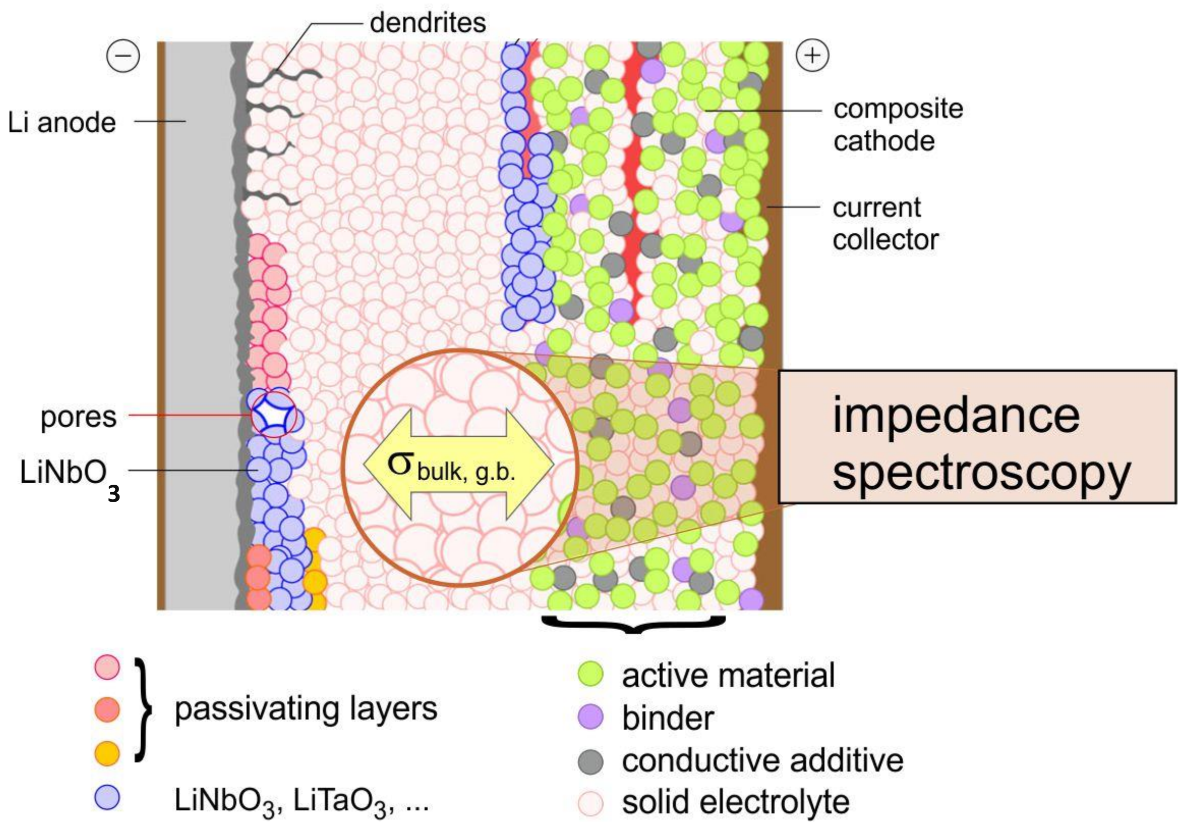
New negative electrodes

Graphite has reached its theoretical capacity limit!

- Silicon
  - Very high capacity.
  - Volume expansion – limits Si content in the electrode (8 -10 %).
  - Commercial technology.

- Li metal
  - Very high capacity.
  - Not usable with liquid electrolytes : Li dendrites and electrode pulverization.
  - Solid electrolytes: a Li metal enabling technology?

Solid electrolytes & all solid-state batteries



M. Uitz, M. Wilkening *J. Electroceram.* **2017**, 38, 142-156

Why?

+ safety, thermal stability
+ no corrosion
+ no leakage
+ high voltage application

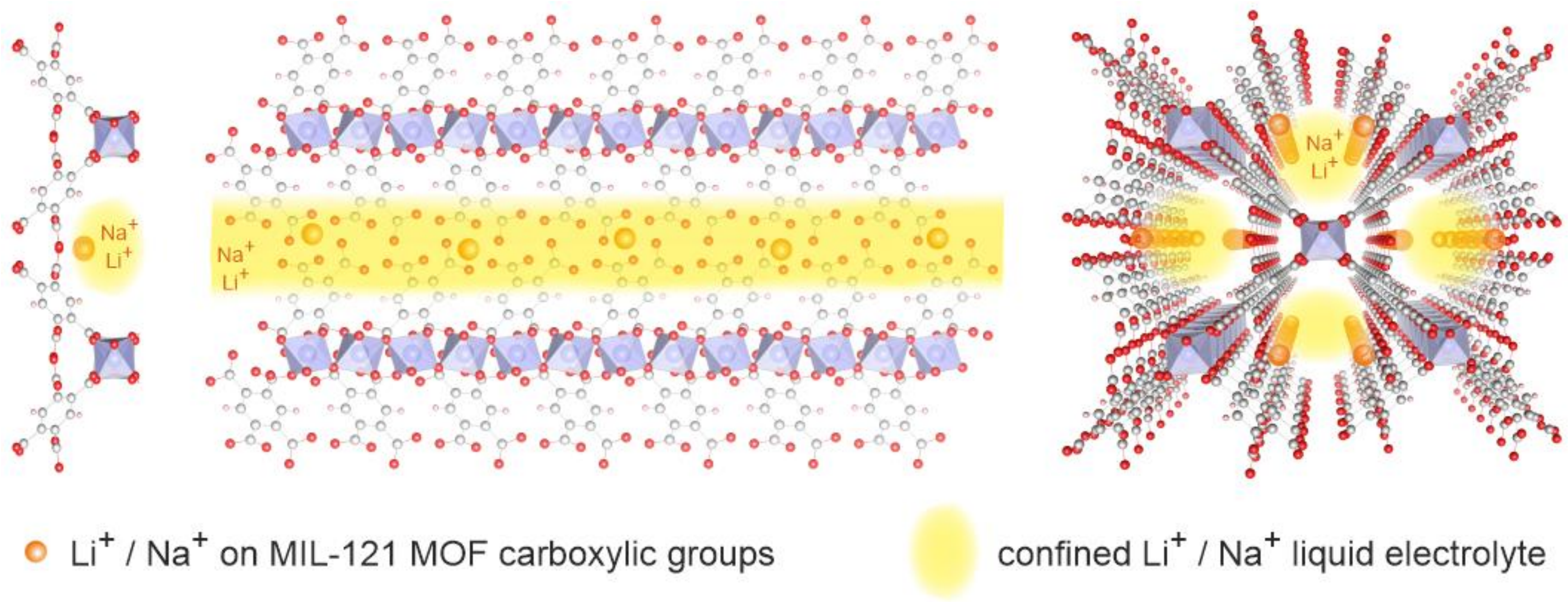
Drawbacks

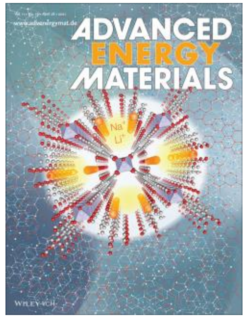
- low power density, resulting from lower ionic conductivity
- limited diffusion kinetics
- significant interfacial resistance

CRM perspective

- relatively rare chemical elements (La, Zr, Ge, Hf etc.) required.
- The process / thickness of materials is critical!

New solid electrolytes – MOF-based hybrid electrolytes





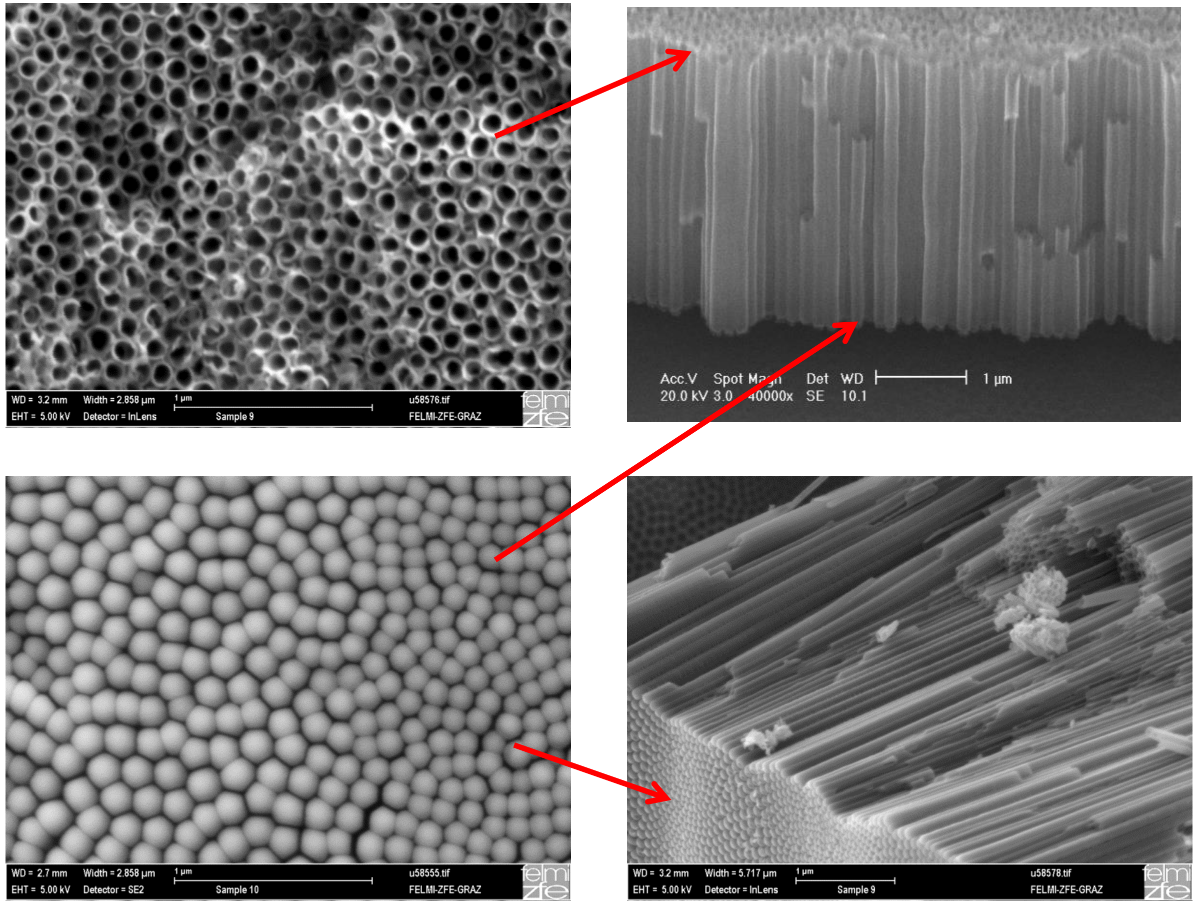
R. Zettl, S. Lunghammer, B. Gadermaier, A. Boulaoued, P. Johansson, H.M.R. Wilkening, I. Hanzu, High Li^+ and Na^+ Conductivity in New Hybrid Solid Electrolytes based on the Porous MIL-121 Metal Organic Framework, Advanced Energy Materials, 2021 (11) 2003542.

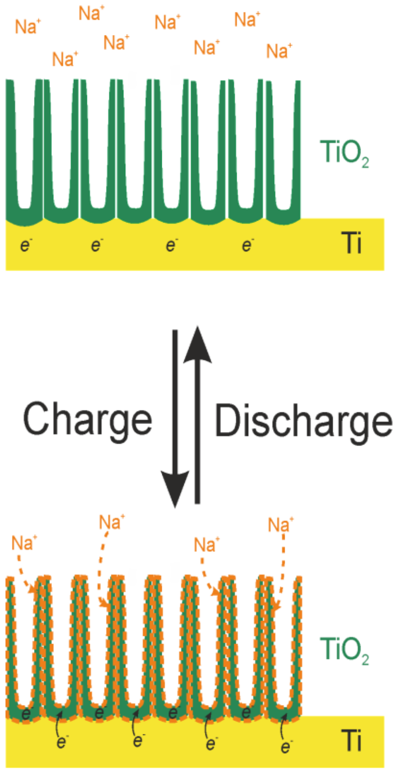
From small to large ceramic batteries ?

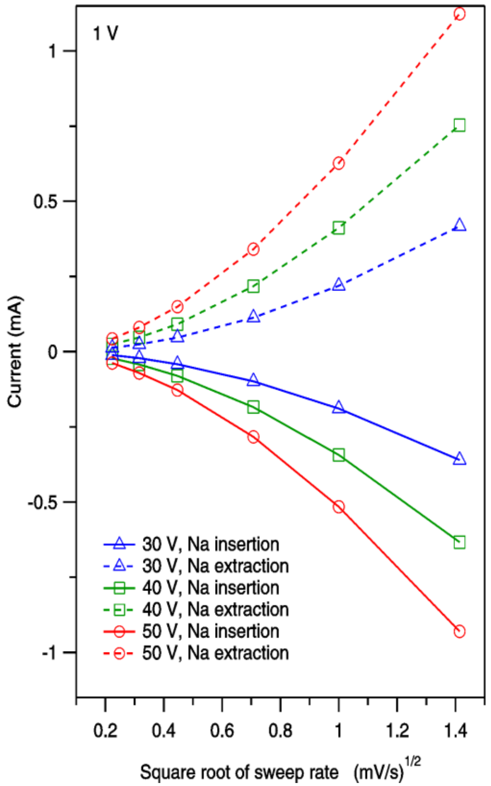
- Ceramic batteries today: typically small batteries, designed for Internet of Things (IoT)
- Low voltage is sufficient for IoT but not for EVs.
  - Enable the use of many known materials that are impractical for high energy density applications.
  - Not yet practical for electric vehicles, high voltage materials are needed – a change of paradigm!
- Cycle life is a critical parameter.
- Critical raw materials in the solid electrolytes: La, Zr, Ge, Ga, (P) – new solid & hybrid electrolytes systems are required. Some solid electrolytes are CRM-free (e.g. LATP)

CeraCharge by TDK:
The first full-ceramic solid state microbattery

Na-ion technology: TiO_2 anodes



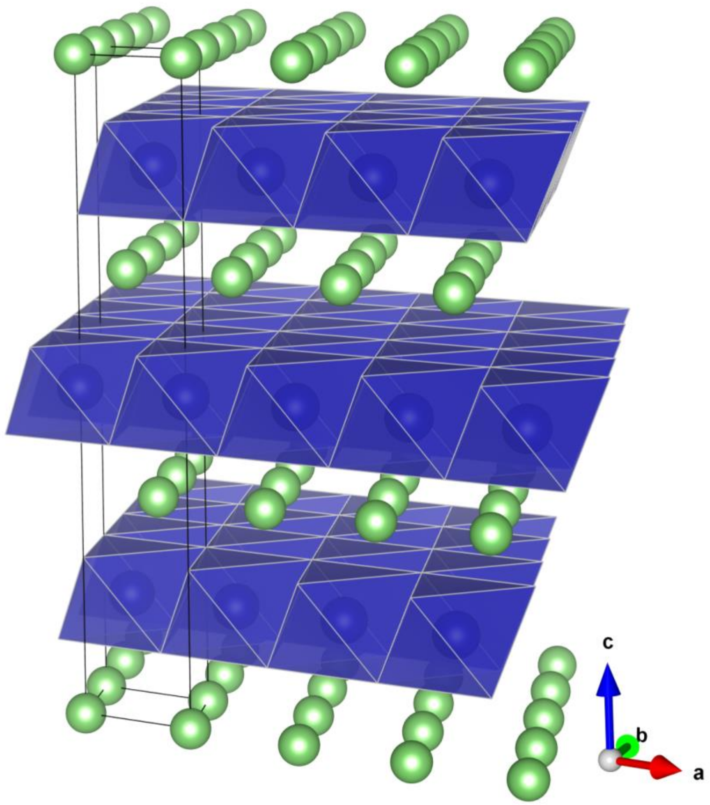




D. Prutsch, M. Wilkening, I. Hanzu, Long-Cycle-Life Na-Ion Anodes Based on Amorphous Titania Nanotubes-Interfaces and Diffusion
ACS Applied Materials & Interfaces, 7 (2015) 25757-25769.

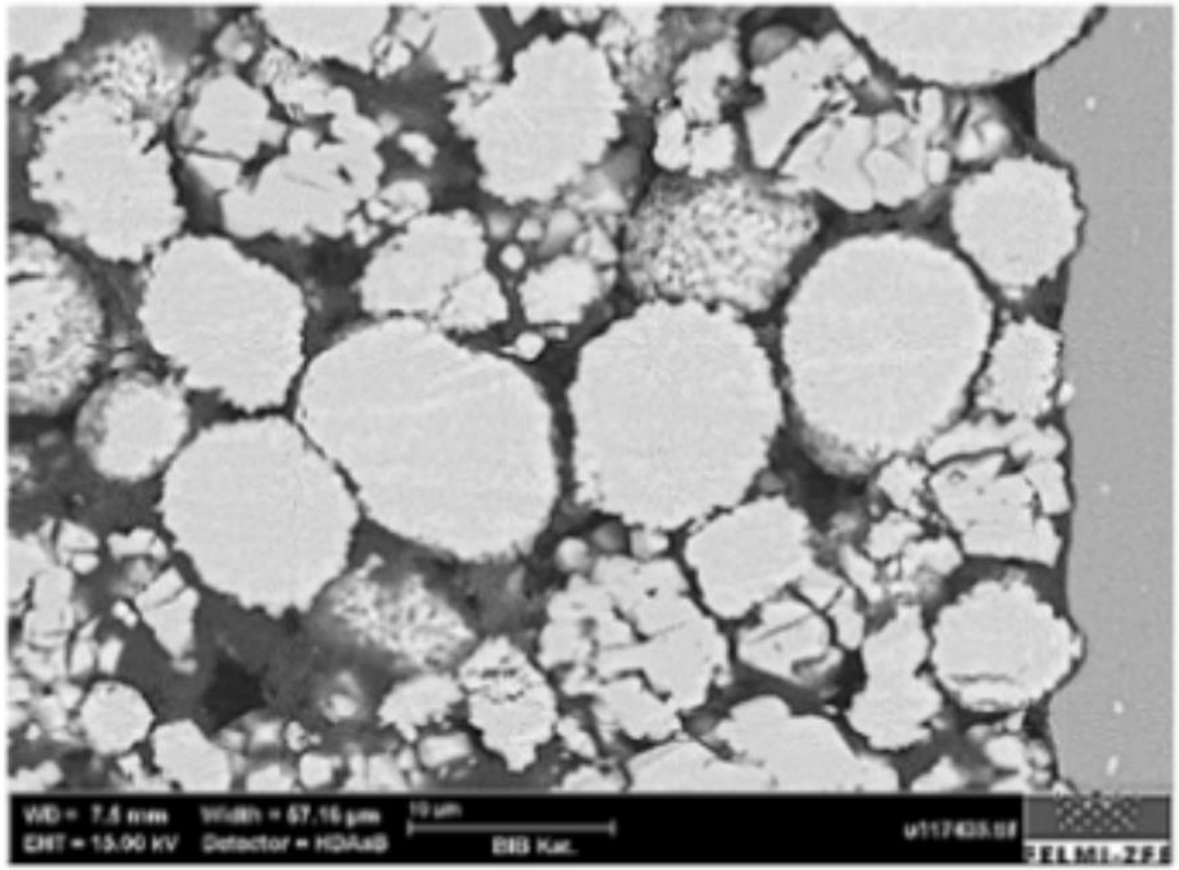
Cathode materials

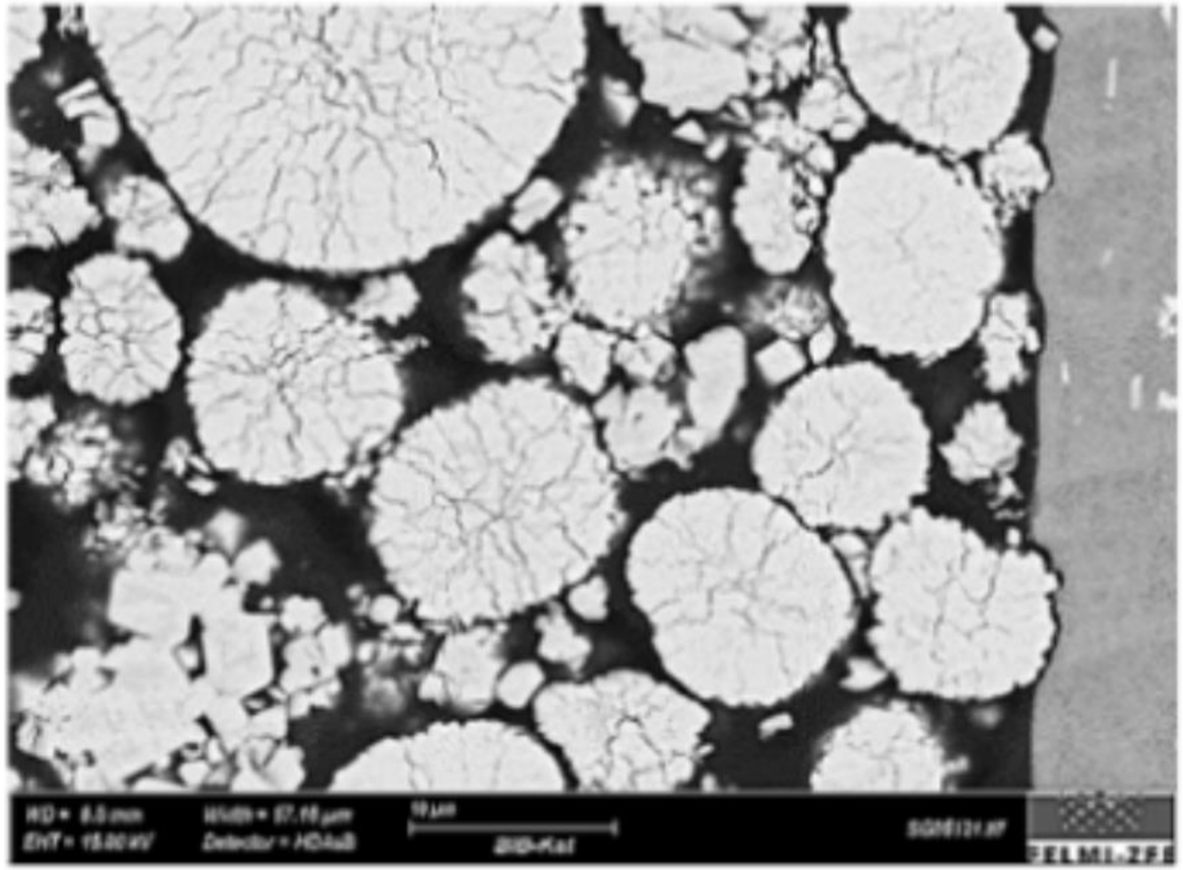
- Layered materials (NMC) are state-of-the-art today. Yet, Co (CRM!) is an obbligated element in layered transition metal compounds.
- The trend is to reduce Co content:
- NMC 111 > NMC 622 > NMC 811 > NMC 955 (?)
- Careful surface coating and materials preparation is required – cost increase is innevitable! Sometimes coating requires CRM: Ta, Nb



LCO:	$LiCoO_2$
NMC111:	$LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$
NMC622:	$LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$
NMC811:	$LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$
NMC955:	$LiNi_{0.9}Mn_{0.05}Co_{0.05}O_2$

Ageing and surface engineering



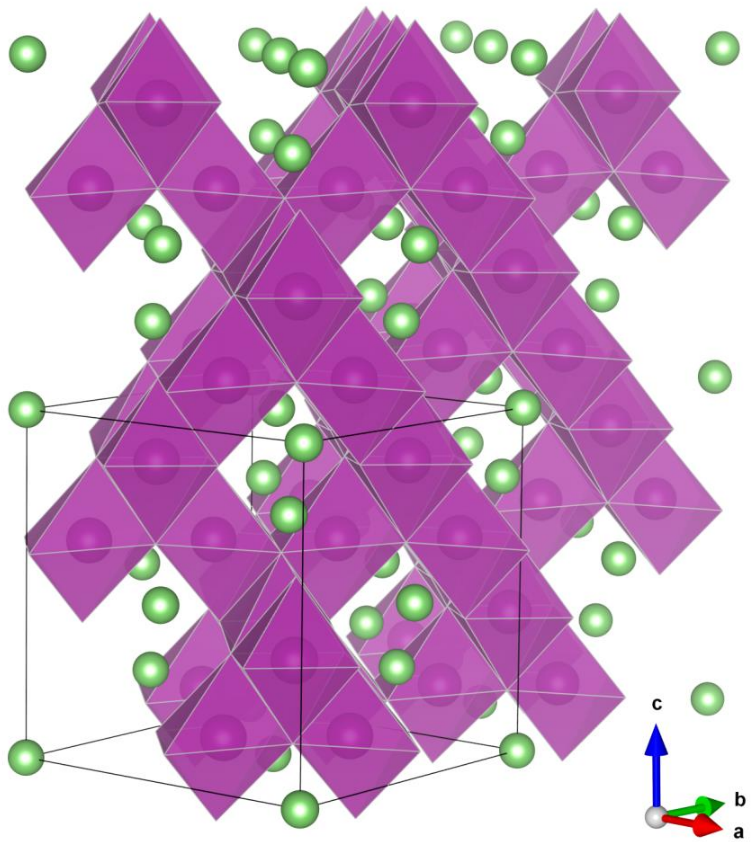


Can we replace cobalt?

Manganese spinels – a CRM-free solution?

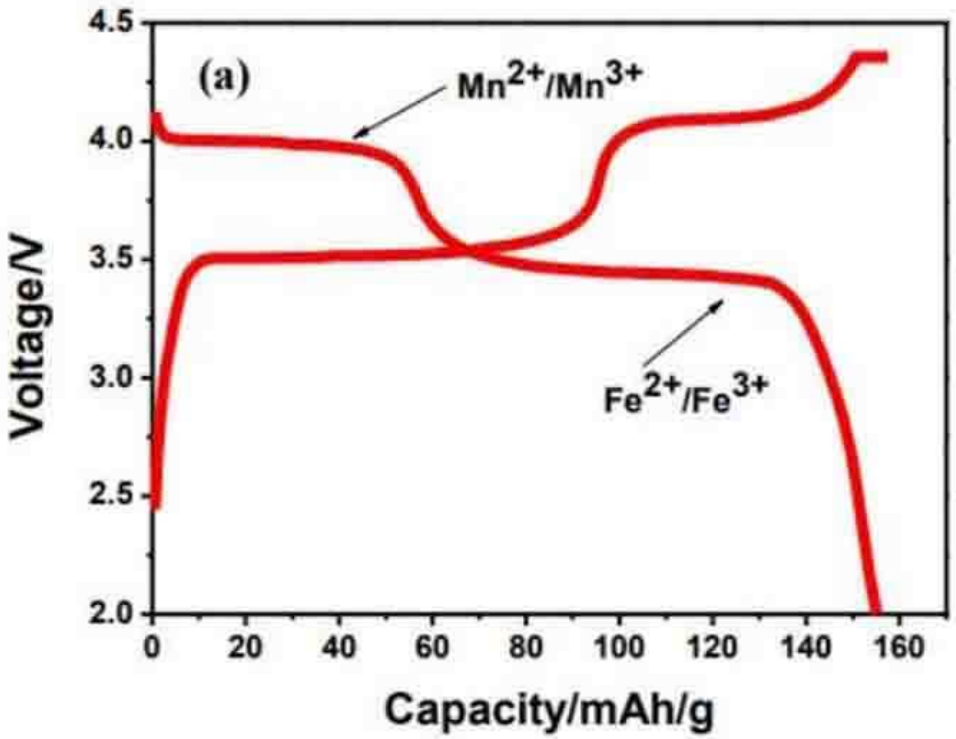
$LiMn_2O_4$ - the prototype material

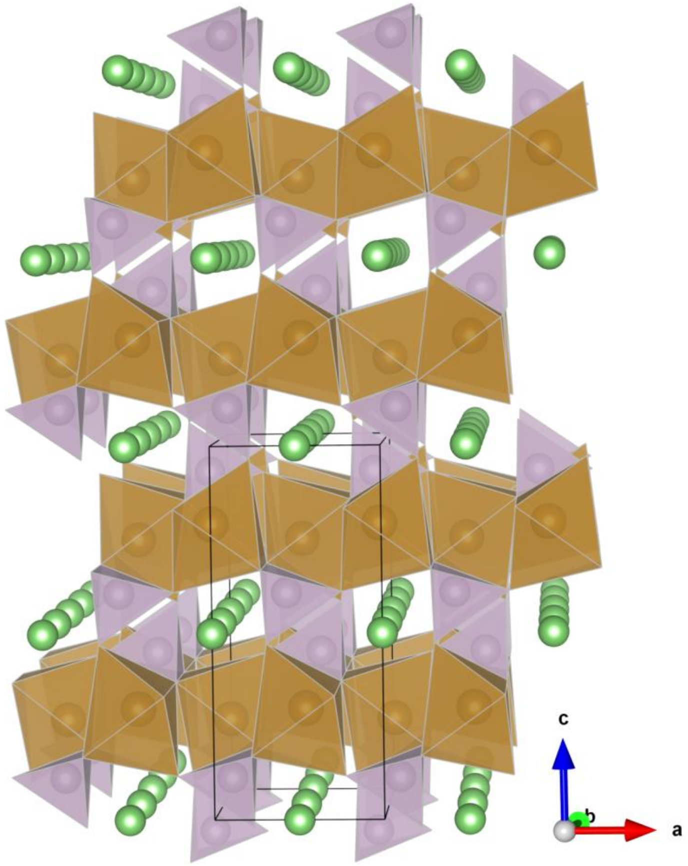
- High power material
- Ni required to reduce Mn leaching
- Less capacity than layered materials
- High voltage spinels (more Ni)



Can we replace cobalt?

LMFP materials – a CRM-free solution?





New battery chemistries : main issues

- Li-sulphur :
  - High specific energy (Wh/kg), low energy density (Wh/L).
  - Cathodes (S electrode) are technologically challenging.
- Li-air
  - The air (O_2) electrode implementation is challenging.
- Na-ion
  - Stable, cheap and high capacity anodes not available.
- Ca-ion
  - Ca^{2+} electrolytes and cathode materials are under-developped.

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FFG
SFG
DFG

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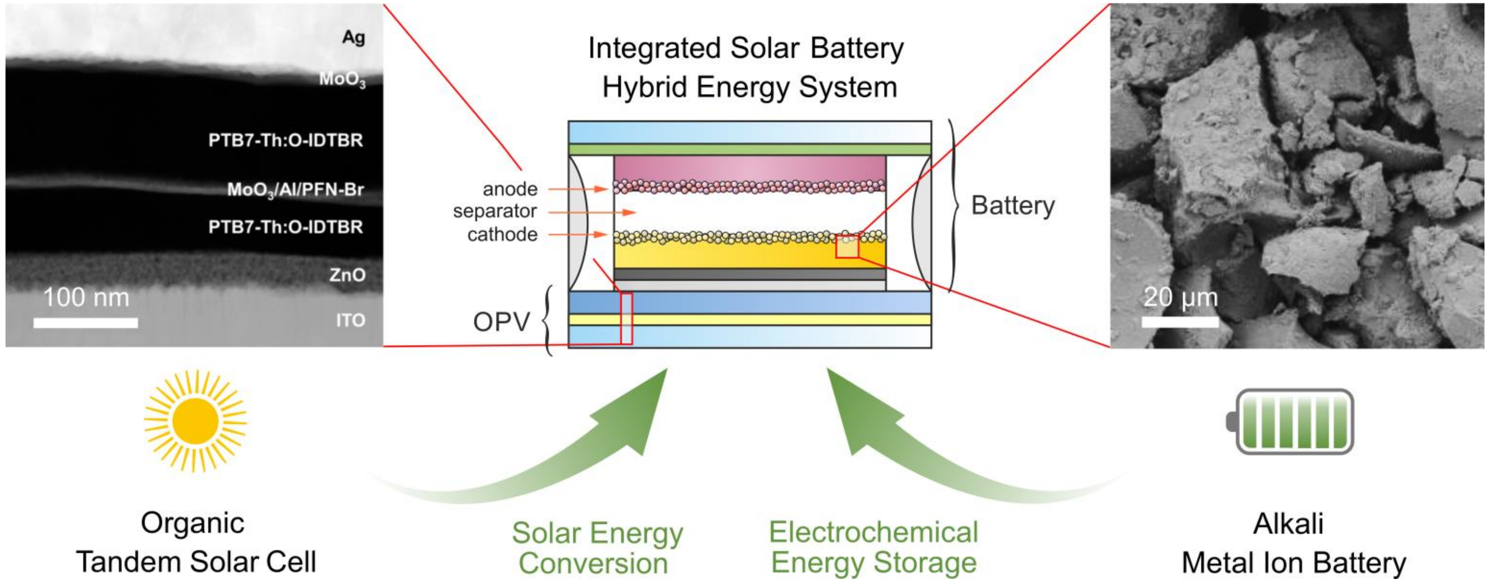
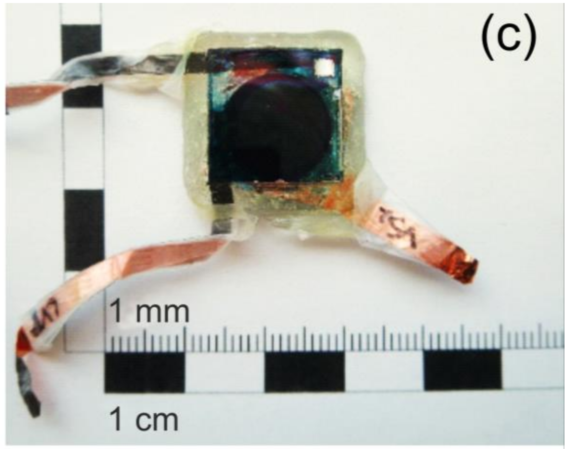
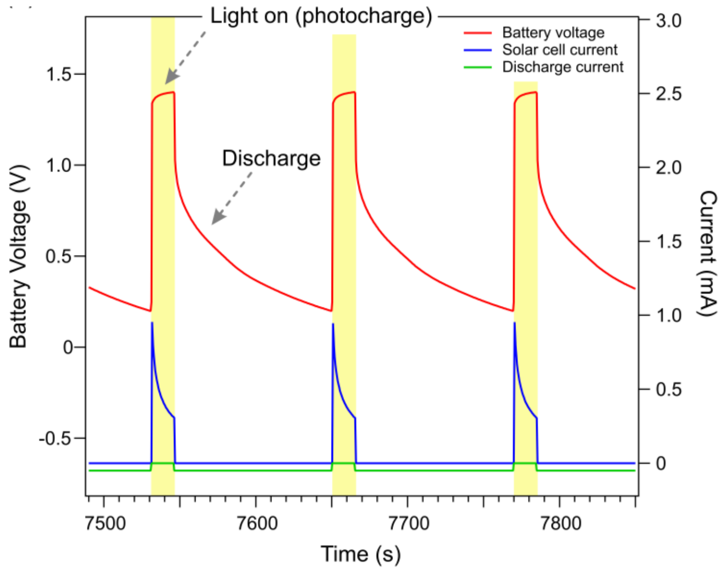
A solar cell – battery hybrid







S.F. Höfler, R. Zettl, D. Knez, G. Haberfehlner, F. Hofer, T. Rath, G. Trimmel, H.M.R. Wilkening, I. Hanzu, ACS Sustainable Chemistry & Engineering, 2020, 8, 51, 19155–19168 DOI: 10.1021/acssuschemeng.0c07984