Emerging Energy Technologies : reduction and substitution of critical materials

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CEA Key Figures

80 **years** (founded 1945)

27	General Motors	United States
28	Foxconn	Taiwan
29	Samsung Electro-Mechanics	South Korea
30	CEA	France
31	Hitachi	Japan

+ 21 000
employees

+ 236
start-ups

633
Patents registered
(INPI 2023)

€ 6,1 B
annuel budget
(civil and defence)

+ 700
Industrial partners

+ 7 200
active patent portfolio

Clarivate™

For the 13th year, in the

World top 100 innovators

(Ranking 30th – Clarivate 2025)

1st Non-profit Organization

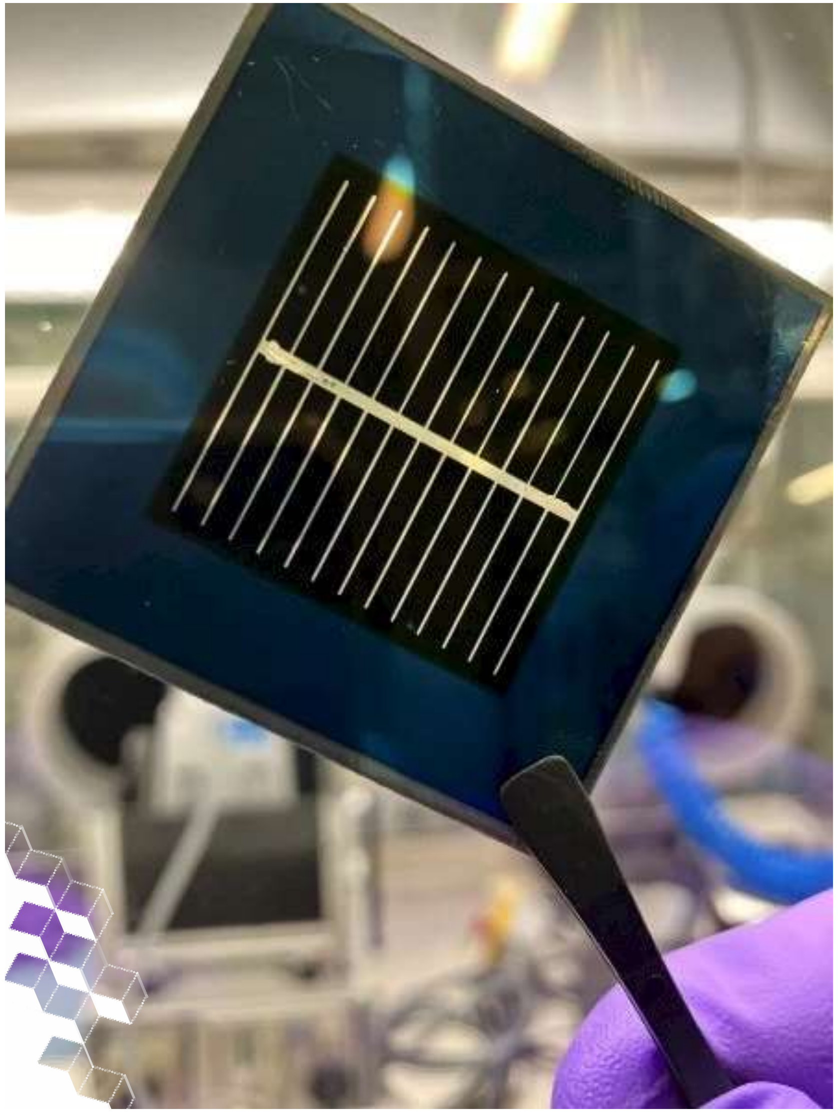
2nd European Innovator

The CEA made them possible, last year

- **CEA and 3SUN break a new record for photovoltaic cell efficiency !**

  As part of the joint development program between CEA and 3SUN on tandem perovskite-on-silicon **solar cell** technology, a new milestone has been achieved, setting a new **efficiency record of 30.8%** *(certified)*

January 28th, 2025



cea liten

Critical materials for low carbon energy systems at CEA

Solid state & Metal-ion
Li, C, (Si), Cu

Lithium-ion LFP
Li, Fe, P, C, (Si), Cu

Lithium-ion NMC
Li, Ni, Mn, Co, C, (Si), Cu

Batteries

Magnets Gen3
RE-free

Magnets Gen2
RE_1Fe_{12}

Magnets Gen1
Nd, Ce, Dy, Tb

Electric machines

Tandem cells
Cu, Si, (Pb), (Sb)

HTJ cells
Ag, In,, Si, (Sb), Cu

PERC cells
Ag, Cu, In, Si, (Sb), Cu

Solar Panels

Catalyst
(Pt, Co, Ir), Nafion

EHT
Y, Ni, Zr, Co, La, Pr, Mn, Ce, Cu

Electrolyzers and fuel cells

Fuel cladding
Zr, Nb, (Ni, Sn, Cr)

Fuel controls
B4C, Hf, Ag/In/Cd

Nuclear plant
Alloy(*Ni, Cr,...*), *Al, Cu*

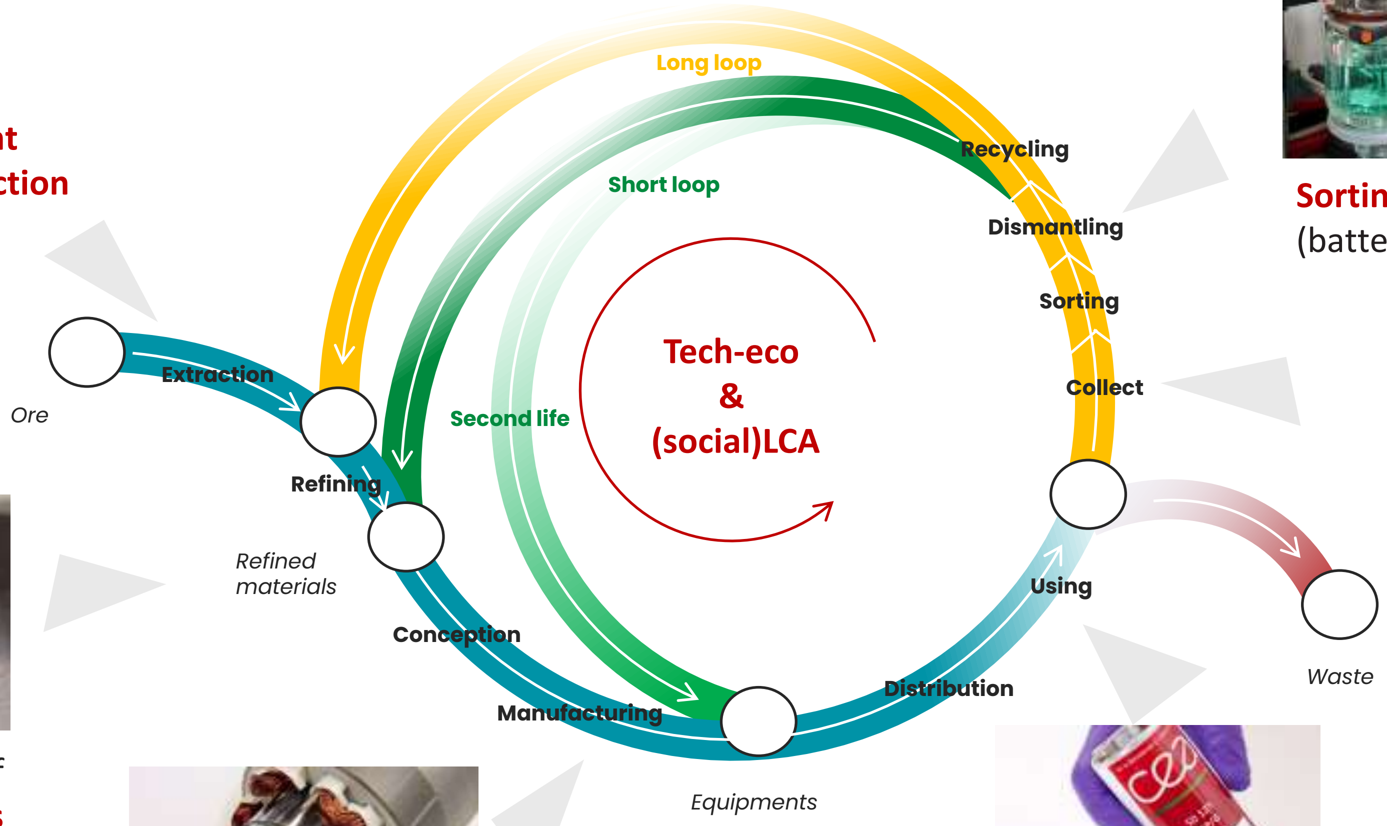
Nuclear plants

Electronics
Cu, Au, Ag, Pd et Pt, Ga, Ge

Circular economy of materials for low carbon energy systems

Clean (effluent) and **efficient** (yield, water, energy) **extraction** of raw materials (mine)

Reduction or **substitution** of **critical materials** (RE for magnets, …)



Material-saving
Manufacturing processes

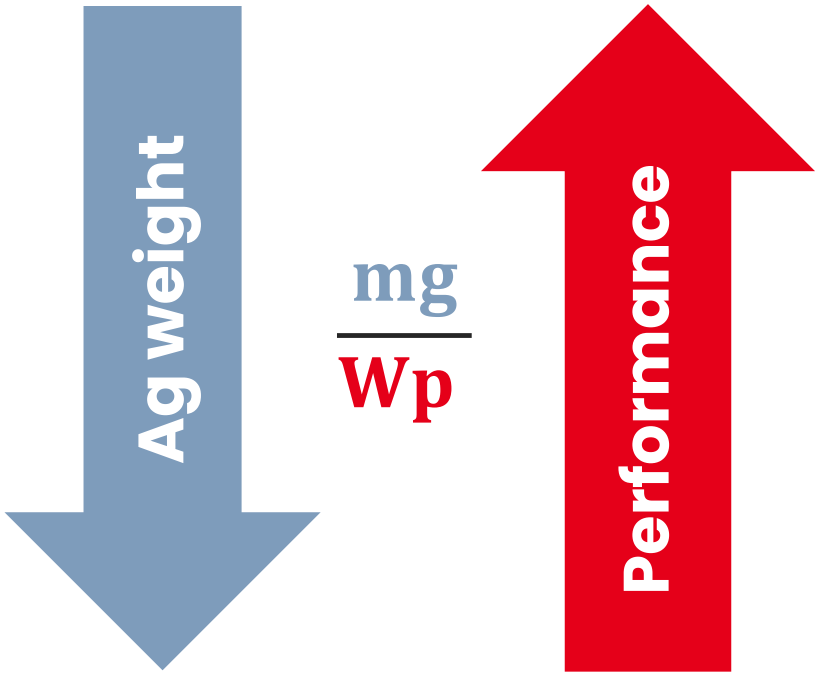
Sorting, dismantling and **recycling** (batteries, PV, magnets…)

Second life
Instrumentation of batteries, PV, electrolyzers fuel cell, PE for diagnostic

Increased lifespan
Battery, PV, Electrolyzer, fuel-cell, Power Electronics instrumentation for predictive maintenance

1. Reduction of critical raw materials in PV cells and modules : "How can we use less silver ?"

Duality of
increasing performance
and
reducing silver consumption
with novel cell and
module interconnection technologies



We must target 5mg Ag/Wp by 2030!

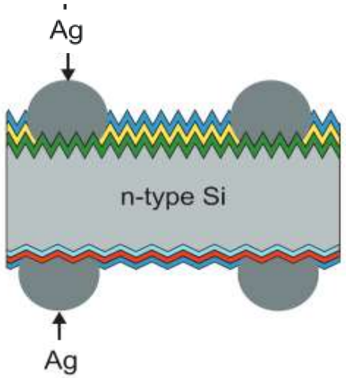
Innovations on heterojunction cell and module metallisation

- Cell metallisation with printing and plating using Cu,Al…
- Increasing efficiency with tandem cells
- Novel module interconnections

Evolutionary reduction of silver consumption by printing

Silver screen-printing process optimization

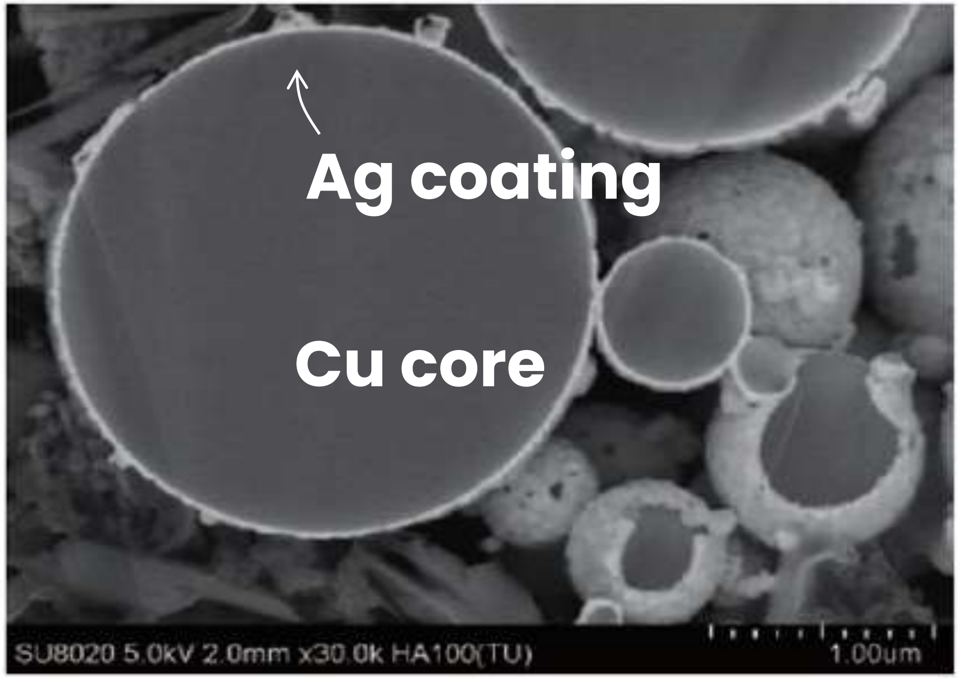
- Screen-printing process: screen angle and material design
- Cell metallisation design: thinner lines and increasing number of busbars



	Line width (µm)	Efficiency (%)	mg Ag / Wp
Ref.	55	22,47	28,8
Improved	44	22,39	19,2

=> 30% Ag reduction

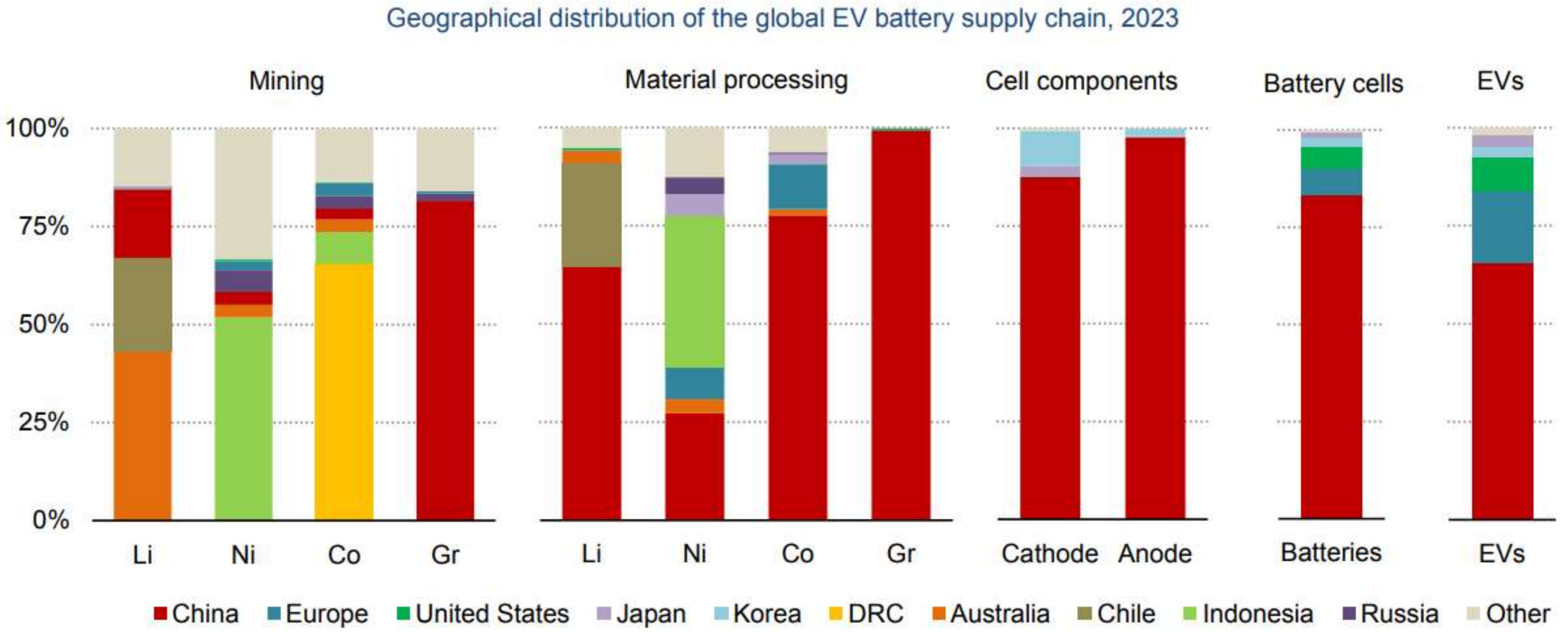
Metallisation pastes with Cu core particles coated with Ag



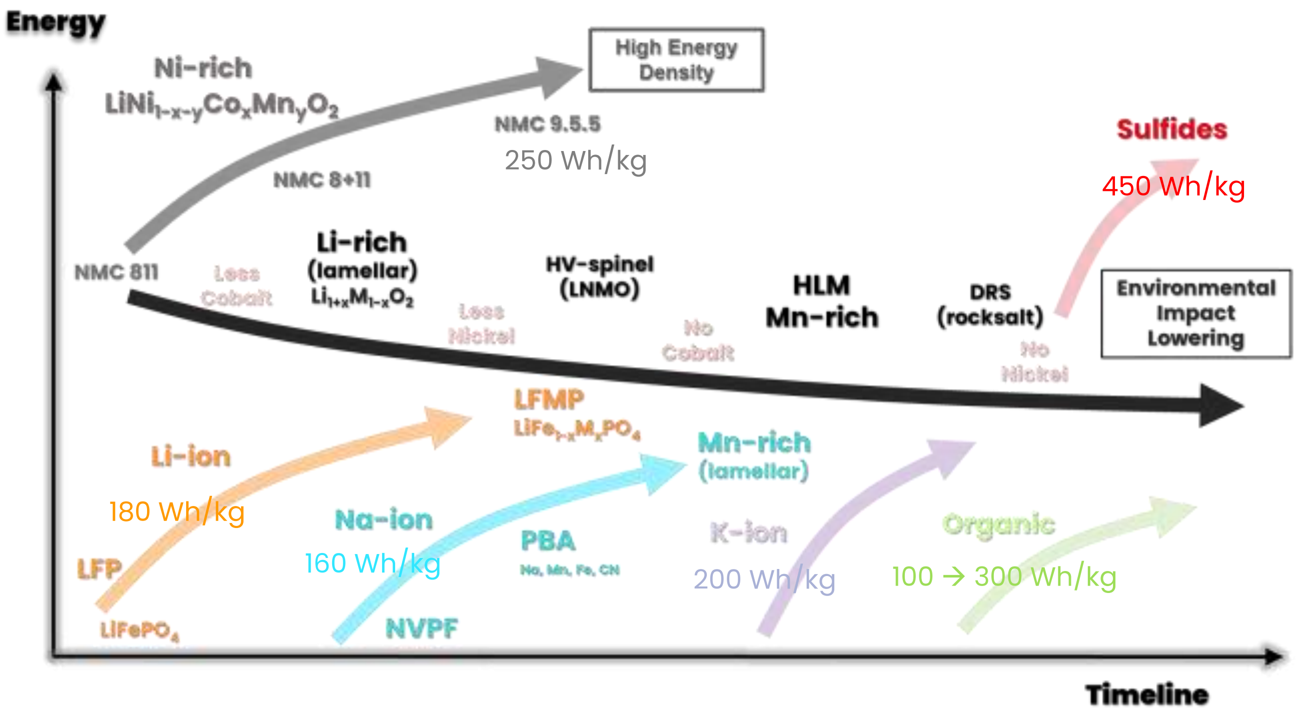
=> 40-65% Ag reduction

2. Reduction and substitution of CRM in batteries

Battery critical materials : Lithium, Cobalt, Nickel, Graphite



Battery roadmap



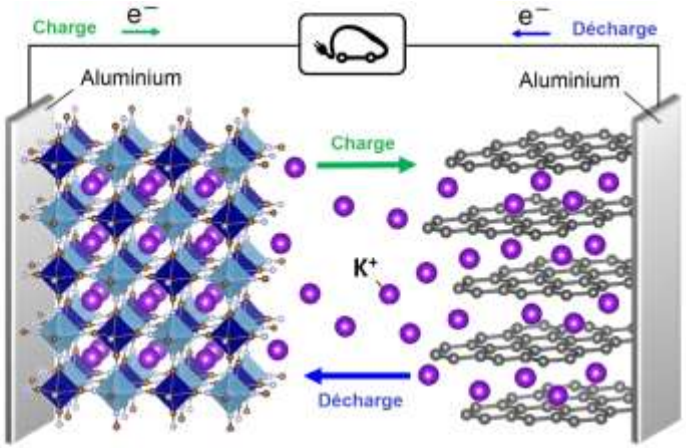
Common material challenge : understanding of degradation modes to increase lifetime

- **NMC batteries**
  - Material challenges :
    - ✓ Increase **Si** integration at anode
    - ✓ Reduce **nickel, cobalt** at cathode
- **Na-ion battery technology**
  - Cathode : NVPF or PBA or Mn-Rich
  - Anode: Hard carbon or $Na_2Ti_3O_7$
  - Material challenge: **vanadium** free
  - CEA Target >180Wh/kg
- **K-ion battery technology**
  - Cathode : PBA or layered Oxides
  - Anode : **Graphite**
  - Material challenge : Stable electrolyte design
  - CEA Target >200Wh/kg
- **Li-S battery technology**
  - Cathode : Sulfure
  - Anode **: Li-metal**
  - CEA Target > 450Wh/kg

CEA recent result on K-ion technologies

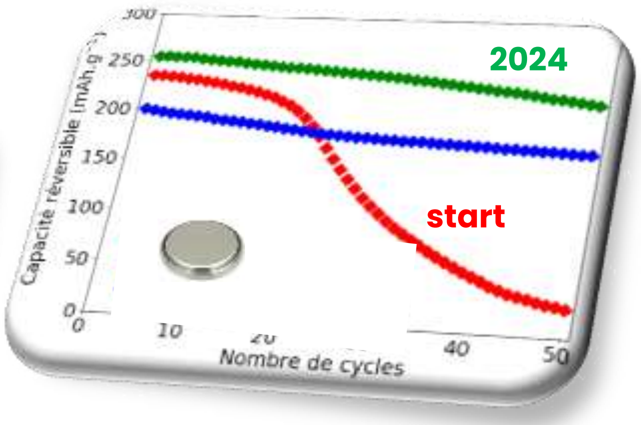
Advantages :
No Cu, Li, Ni, Co
Abundant of **K**
Low potential **K**
Safe 0V storage

Water based for :
- ✓ **Cathode synthesis**
- ✓ **Both electrodes coating**



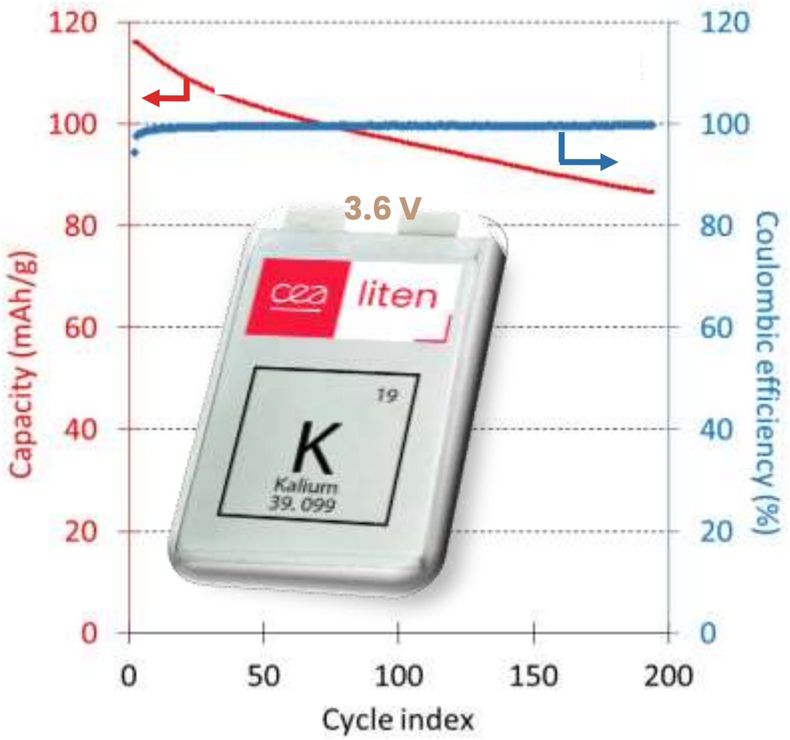
Prussian White
$K_2MnFe(CN)_6$

K-oriented Graphite



GEN 1 : PW/Graphite

<100 Wh/kg



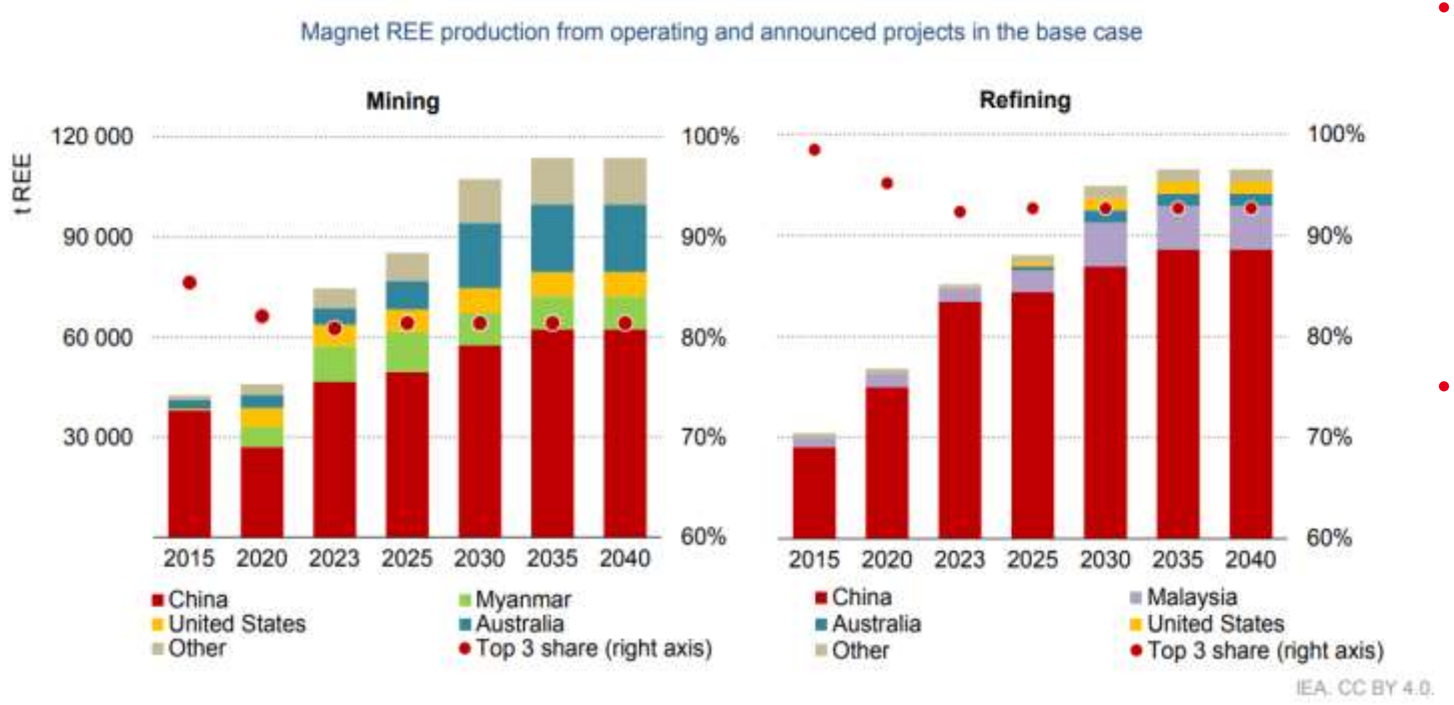
GEN 2 : *in preparation*

>200 Wh/kg

3. Reduction & substitution of rare earth in electric machines

Permanent magnet critical materials : (Heavy) Rare earth

Rare earth production will not fill the demand in 2035 !



Rare earth demand growth driven by electrification

- EV motors, typical content
  - >80% of EV motors use permanent magnets
  - **1-2 kg of magnets per motor**
  - 25% of Nd+Pr & 5% of Dy (wt. %)

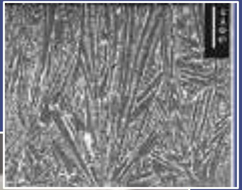
- Offshore wind turbines

  ~600 kg of magnet per MW for permanent magnet synchronous generators, ex for DD-PMSG:
  - Nd : ~180 kg/MW
  - Pr : ~35 kg/MW
  - Dy : ~17 kg/MW

Nd-Fe-B magnet manufacturing pilot line

Strip casting

As cast ribbons NdFeB

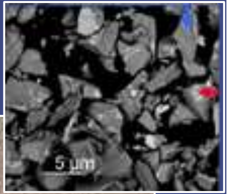


Alloy synthesis

Milling

Embrittled ribbons

Micron sized powder

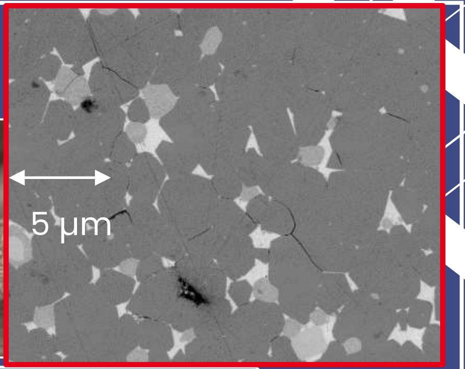


Hydrogen Decrepitating

Jet-milling

Sintering

dense magnets



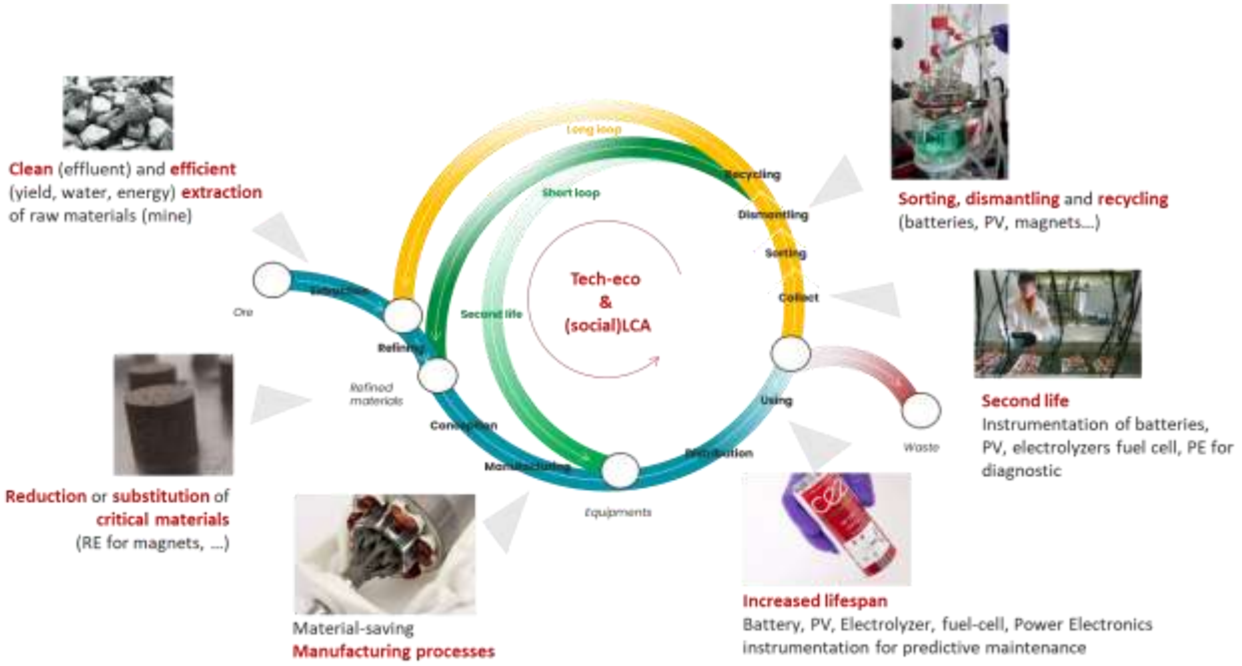
Pressing + Sintering

Conclusions

- Critical Raw Matrial challenges are an industrial reality :

  - ✓ The **reduction** or **substitution** of CRM
  - ✓ The increase of **technology performance** inducing a **reduction** of **CRM weight/Watt**
  - ✓ Material saving through innovative manufacturing process (e.g. reduce scraps)
  - ✓ ...

- Circular economy is a key lever to reduce the CRM demand



Improve the circularity of materials essential for low-carbon energy technologies, transfer solutions to the industry and therefore contribute to sovereignty for the energy transition