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# Towards resource efficient manufacturing of Li-ion batteries: state-of-the-art and future trends

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## RESOURCE EFFICIENCY – USEFUL DEFINITIONS

Maximising of the supply of money, materials, staff, and other assets that can be drawn on by a person or organization in order to function effectively, with minimum wasted (natural) resource expenses

Using the Earth's limited resources in a sustainable manner while minimising environmental impact

Resource intensity is a measure of the resources (e.g. water, energy, materials) needed for the production, processing and disposal of a unit of good or service, or for the completion of a process or activity; it is therefore a measure of the efficiency of resource use

# Meanwhile, Li-ion industry is growing rapidly across the whole value chain

**Demand for raw materials is rising fast as the transportation and energy sectors' appetite for large lithium-ion batteries continues to grow.**

**Batteries are a key enabling technology for low emission mobility and for Energy storage. Recent forecasts indicate that the demand for batteries both in the EU and globally will grow expotentially in the next years**

**Source: EIT InnoEnergy**

# OUTLINE

1. Li-ion batteries – current state-of-the-art.

2. Resource efficiency – manufracturing

3. Resource efficiency – materials

4. Conclusions



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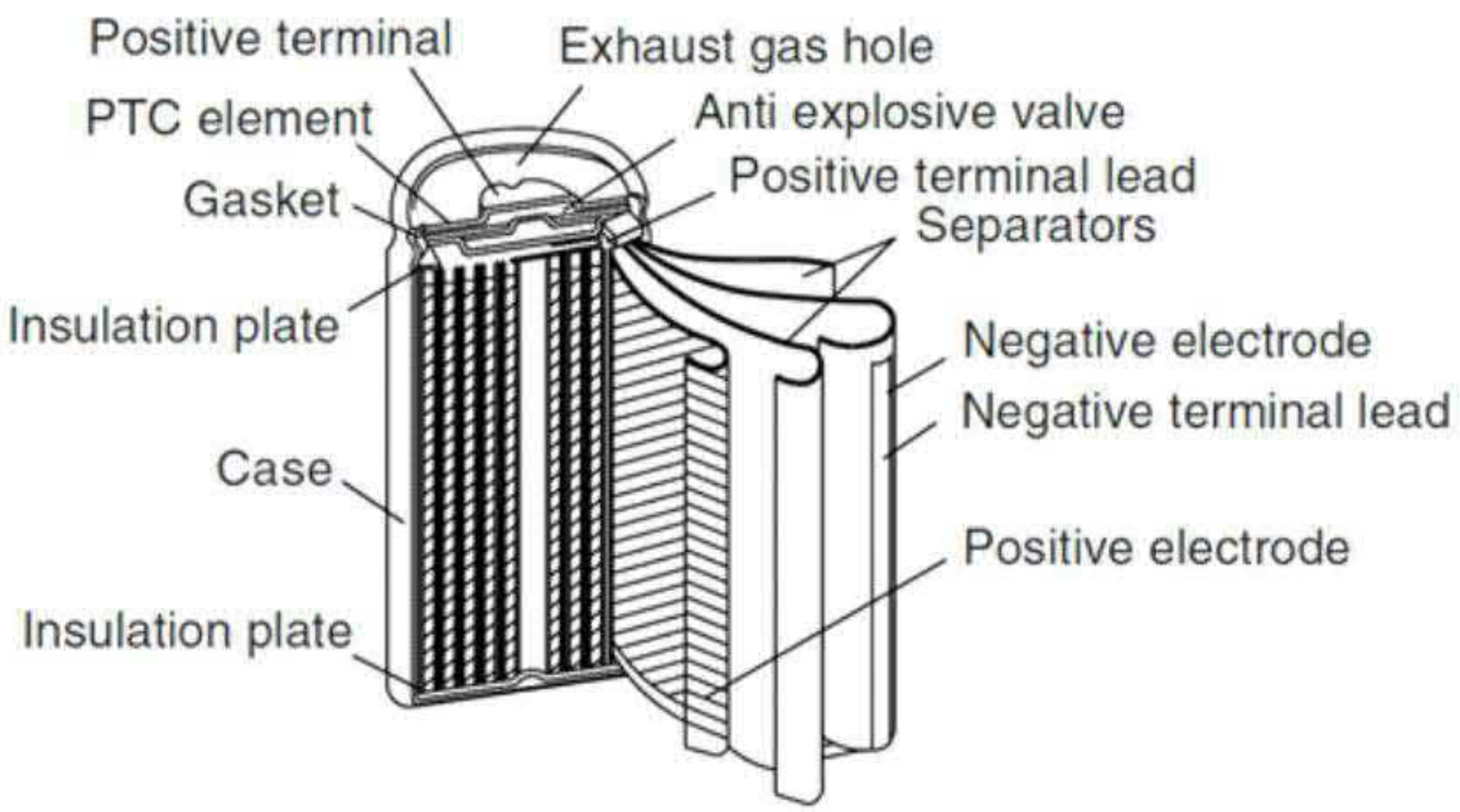
# STATE-OF-THE-ART

**What is a Li-ion battery composed of ?**

| Cell component | Materials |
|---|---|
| Cathode active material | Layered structures, *e.g.* $LiCoO_2$ (LCO)/$Li(Ni_xMn_yCo_{1-x-y})O_2$ (NMC)/$Li(Ni_{1-x-y}Co_xAl_y)O_2$ (NCA)<br>Spinel structures, *e.g.* $LiMn_2O_4$ (LMO)<br>Olivine structures, *e.g.* $LiFePO_4$ (LFP) |
| Cathode foil | Al |
| Anode active material | Carbonaceous materials (graphite, hard carbon), lithium titanate, or silicon-based materials |
| Anode foil | Cu |
| Binder | Polyvinylidine fluoride (PVDF)/polytetrafluoroethylene (PTFE)/polyvinyl alcohol (PVA)/carboxym |
| Electrolyte | Mixtures of ethylene carbonate (EC)/propylene carbonate (PC)/dimethyl carbonate (DMC)/ethyl fluoroethylene carbonate (FEC)/vinylene carbonate (VC) |
| Conductive additive | Acetylene black (AB) |
| Conductive salt | $LiPF_6$ |
| Separator | Polyethylene (PE)/polypropylene (PP) |
| Cell case | Varies (metal or laminate) |




Credit: Mitch Jacoby/C&EN; Binghamton University; The Japan Prize Foundation
John B. Goodenough (left), M. Stanley Whittingham, and Akira Yoshino will receive the 2019 Nobel Prize in Chemistry

- Intercalation chemistry (rocking chair mechanism)
- Only incremental improvements in energy density possible for conventional Li-ion batteries
- Raw materials' supply issues
- Do we have anything beyond Li-ion ?

- At least a dozen of different Li-ion chemistries are on the market. Some of the most common are listed below.
- Different technologies for different applications. Markedly different elemental composition (consequences in terms of raw material accessibility, toxicity, safety, recycling)
- The most important trend – eliminating cobalt (NMC111 – NMC523 – NMC622 – NMC811)
- Manufacturing is similar

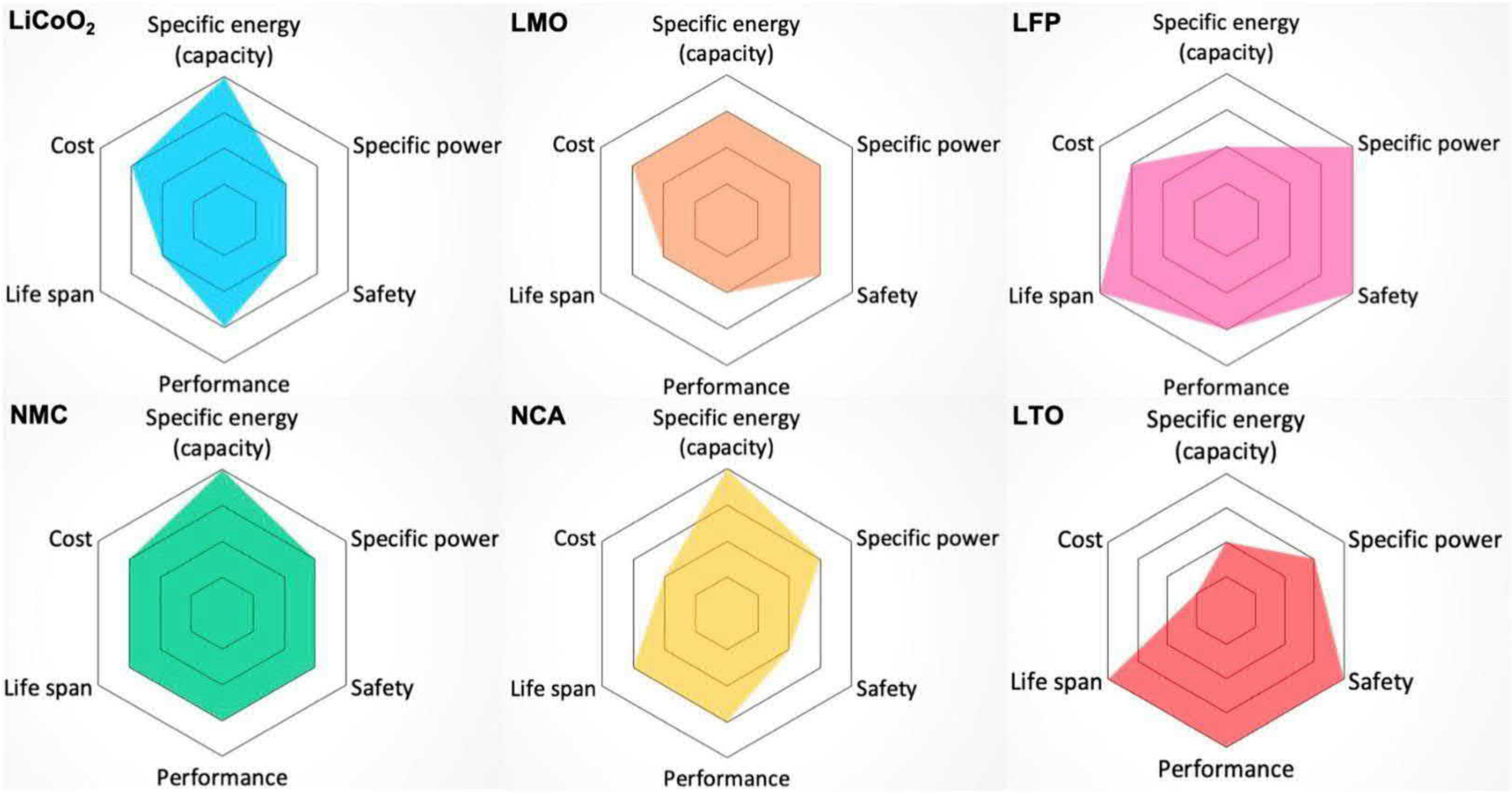
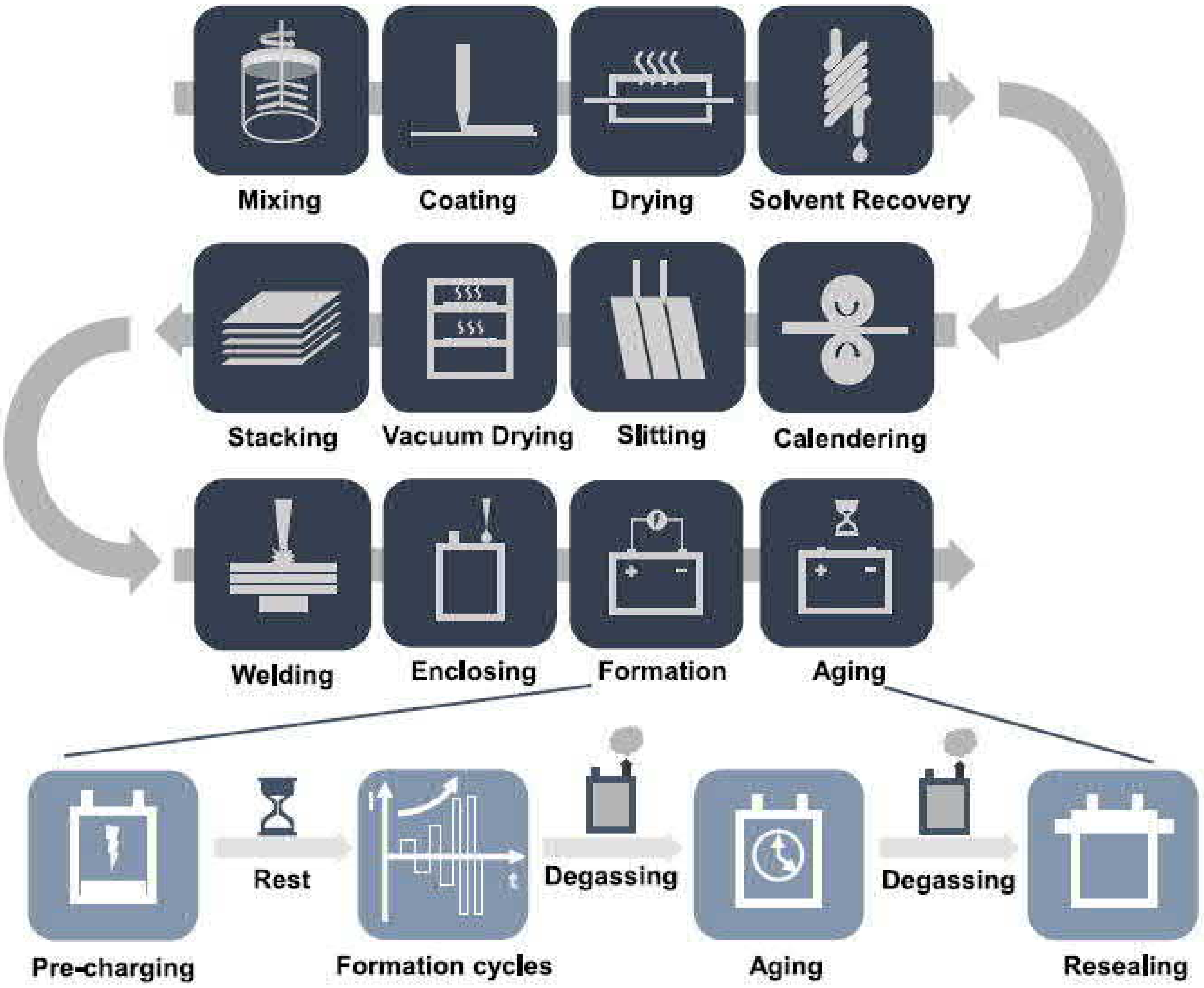



Image: MDPI

# Bottom line

- The cost of Li-ion batteries has dropped from over 1000 $/kWh in the early 2000s to less then 200 $/kWh currently
- At the same time energy density has been increased from 150 do neraly 300 Wh/kg
- „Beyond Li-ion” technologies are looming (solid state batteries, sodium-ion, Lithium-sulphur, lithium-air, multivalent batteries)
- Li-ion technologies (with incremental improvements) will most probably dominate for the next 10 years
- Trends for Li-ion: Ni-rich, Co-free cells, Si or Li as anode, new electrolytes
- Progress in Li-ion manufacturing lags behind, no substantial progres over the lat 30 years (manufacturing contributes about 25% of the Li-ion battery cost)

# RESOURCE EFFICIENCY - MANUFACTURING




From: y. Liu et al., iScience 24, 102332, April 23, 2021

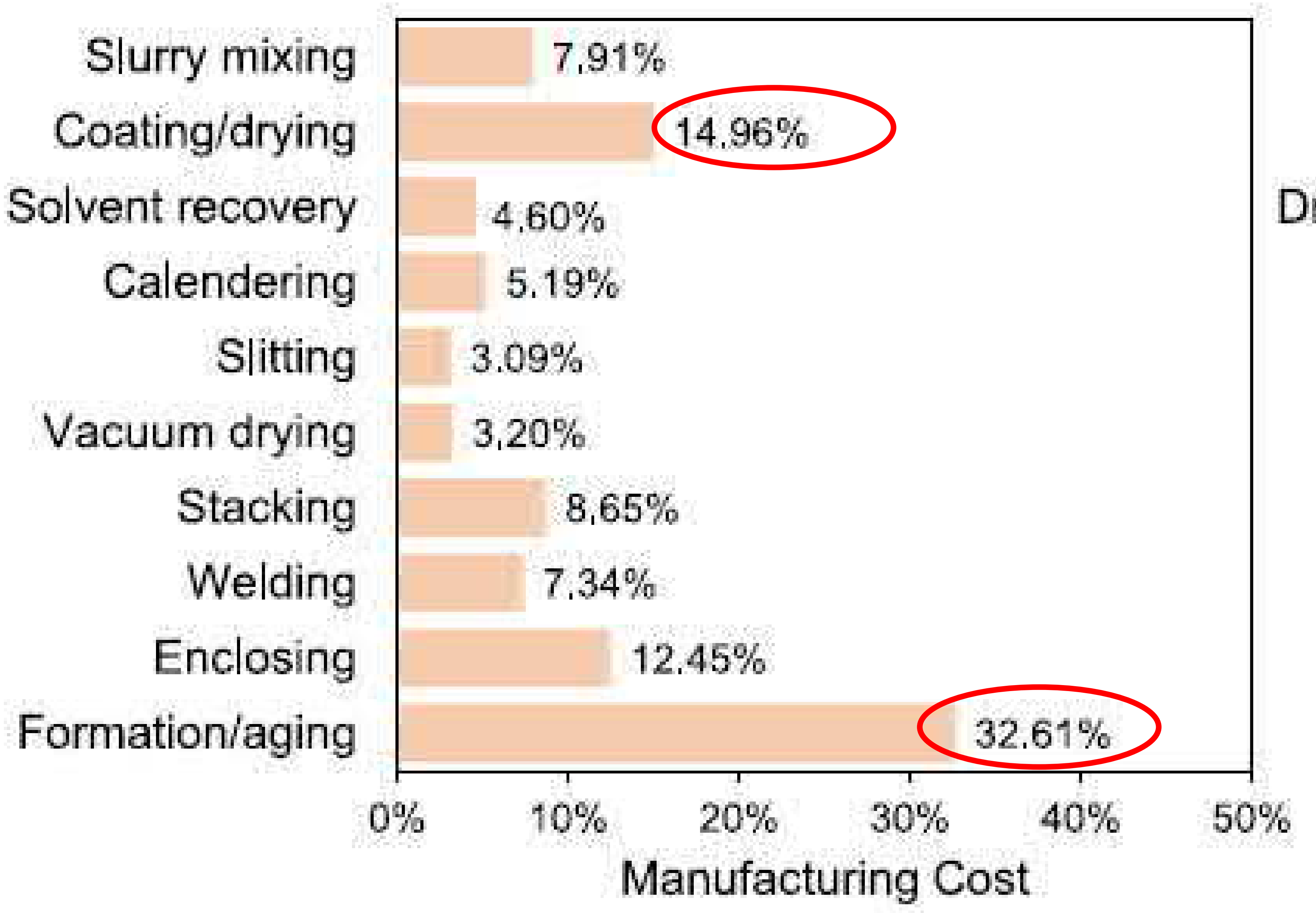
Currently typical Li-ion manufacturing workflow consists of three parts:

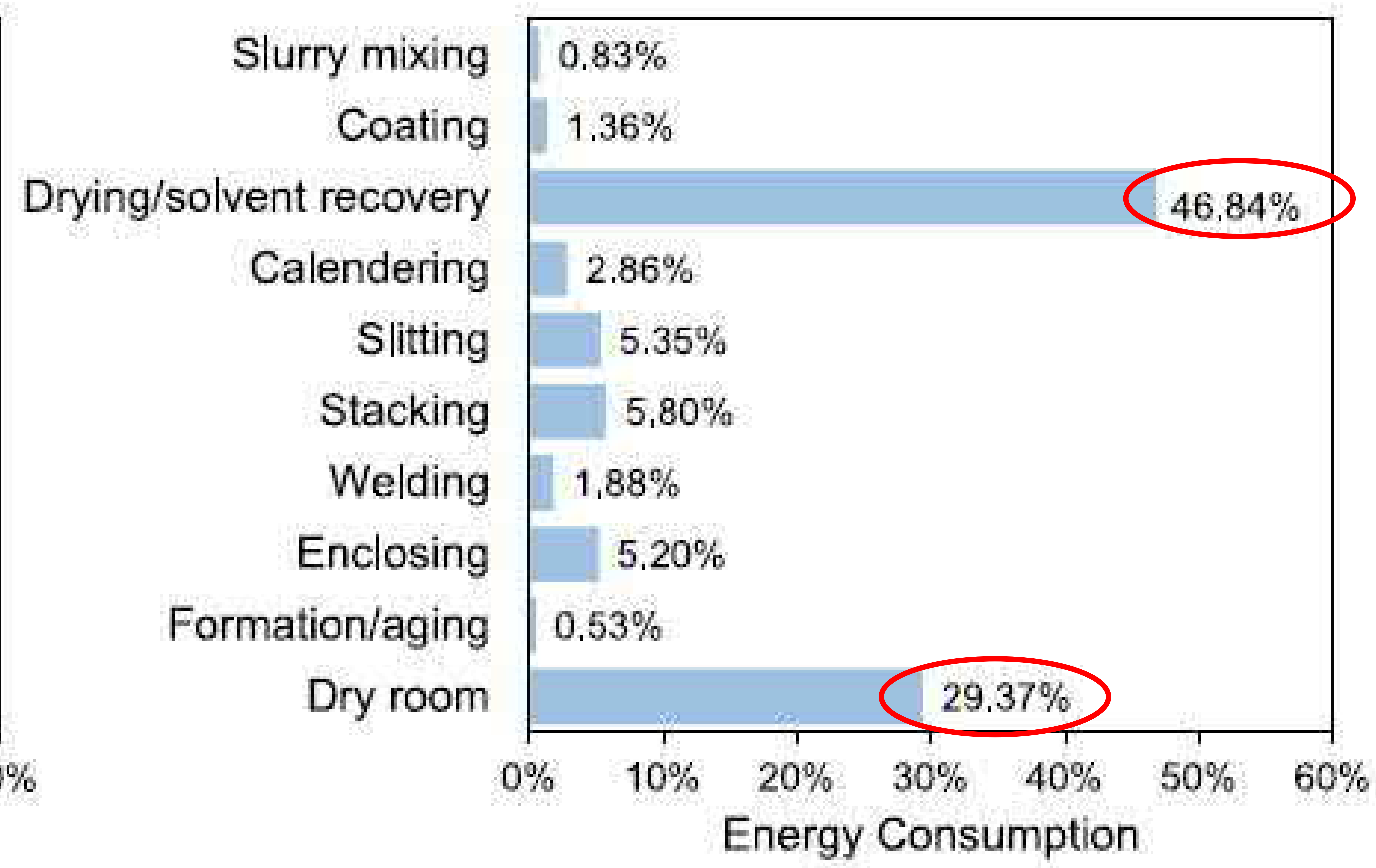
- electrode preparation,
- cell assembly,
- cell formation



**Where to look for efficiency enhancements ?**

# Cost and Energy consumption breakdown for Li-ion cel manufacturing




The estimation is based on a 67 Ah NMC622/graphite cell

The electrode coating, drying, cel formation and aging contribute to 48% of the entire manufacturing cost



From: y. Liu et al., iScience 24, 102332, April 23, 2021

# Steps that need the most research and innovation

## Coating, drying and solvent recovery

- Water-based cathode binder in place of toxic organic solvent (for cathodes that are not sensitive towards water)
- Highly concentrated cathode slurries in combination of extrussion proces (in place of casting by conventional slot die)
- Solvent-free electrode casting
- New drying techniques can reduce the drying time by 40%

## Vacuum drying

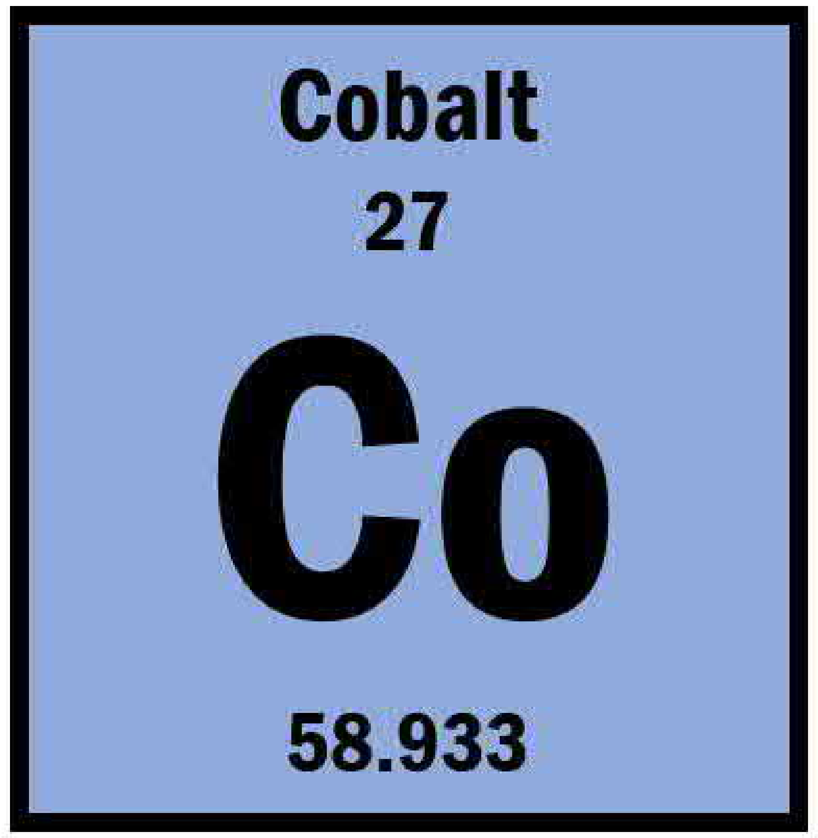
- Quick argon purging in place of long-term vacuum drying

## Formation and aging

- Acceleration of formation is of critical importance for cost reduction (today up to 32% of total cel cost)
- Decreasing the formation voltage window and increasing formation current

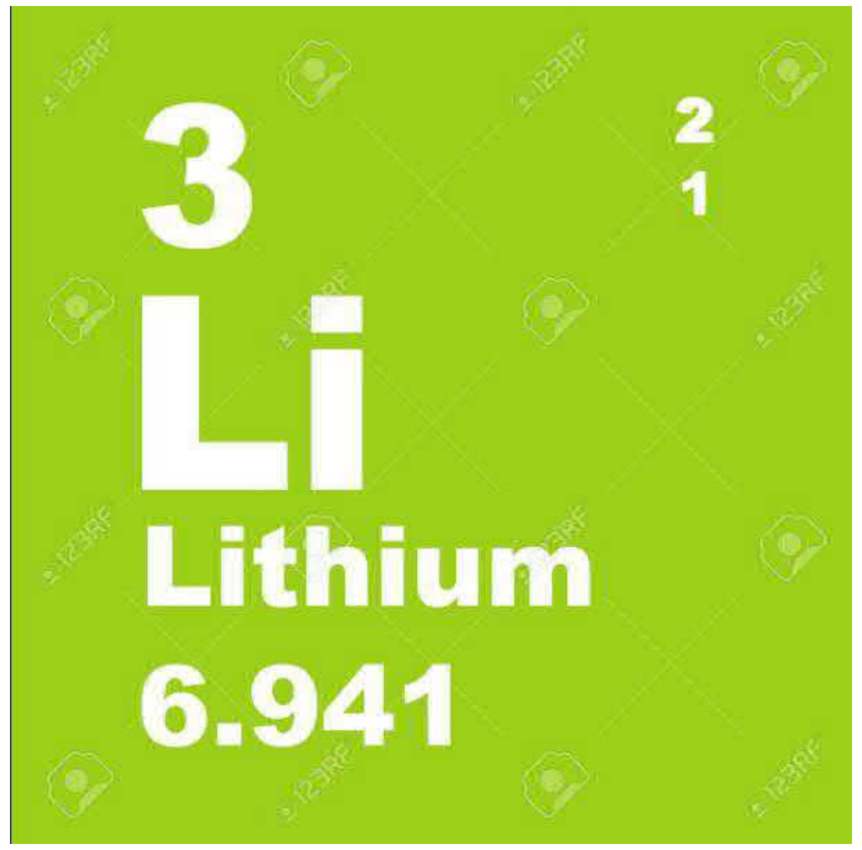
# RESOURCE EFFICIENCY - MATERIALS

- Among the materials used in Lithium-ion battery cells, three are currently listed as critical raw materials by the European Commission: cobalt, natural graphite and silicon metal.
- Although lithium is not in short supply, it has “an increasing relevancy for the Li-ion battery industry,” (EU Report on raw materials for battery applications, 2018)

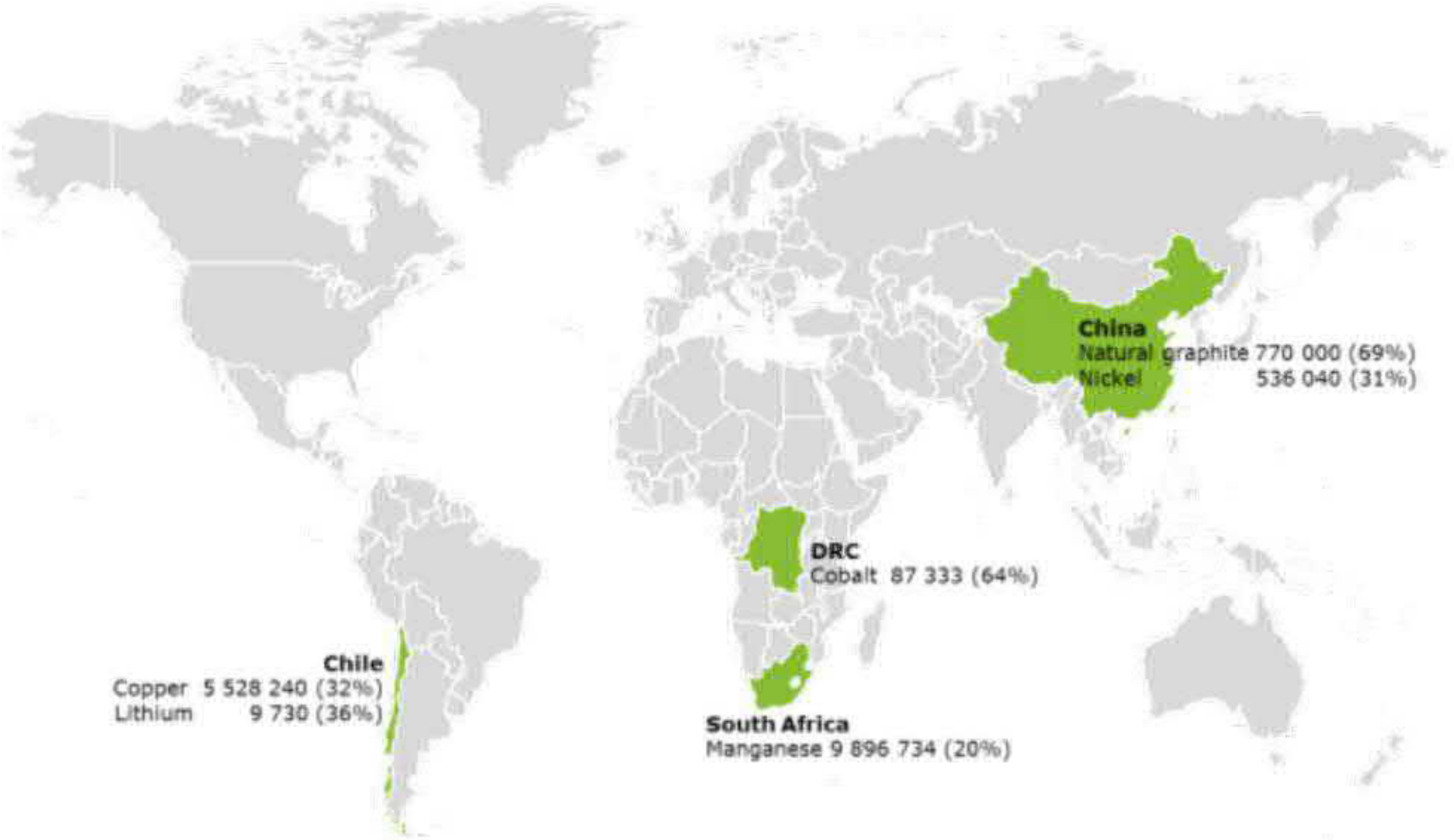





Graphite




Other elements: Mn, Ni, V, Cu, Al, Fe, P…




Countries accounting for largest share of global production of battery materials (tonnes, percent of global supply).

**Supply of critical raw materials for LIB is ensured by working along the three routes:**

- **sourcing from third countries;**
- **developing domestic sourcing and promoting recycling of battery materials**
- **reuse of batteries.**

From: Report on Raw Materials for Battery Applications, European Commission Staff Working Document, 2018



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Countries accounting for largest share of EU supply of battery materials (tonnes, percent of EU supply)

Currently, sourcing of raw materials is mainly driven by prices. EU production of certain material may not yet be competitive, even if the deposits exist



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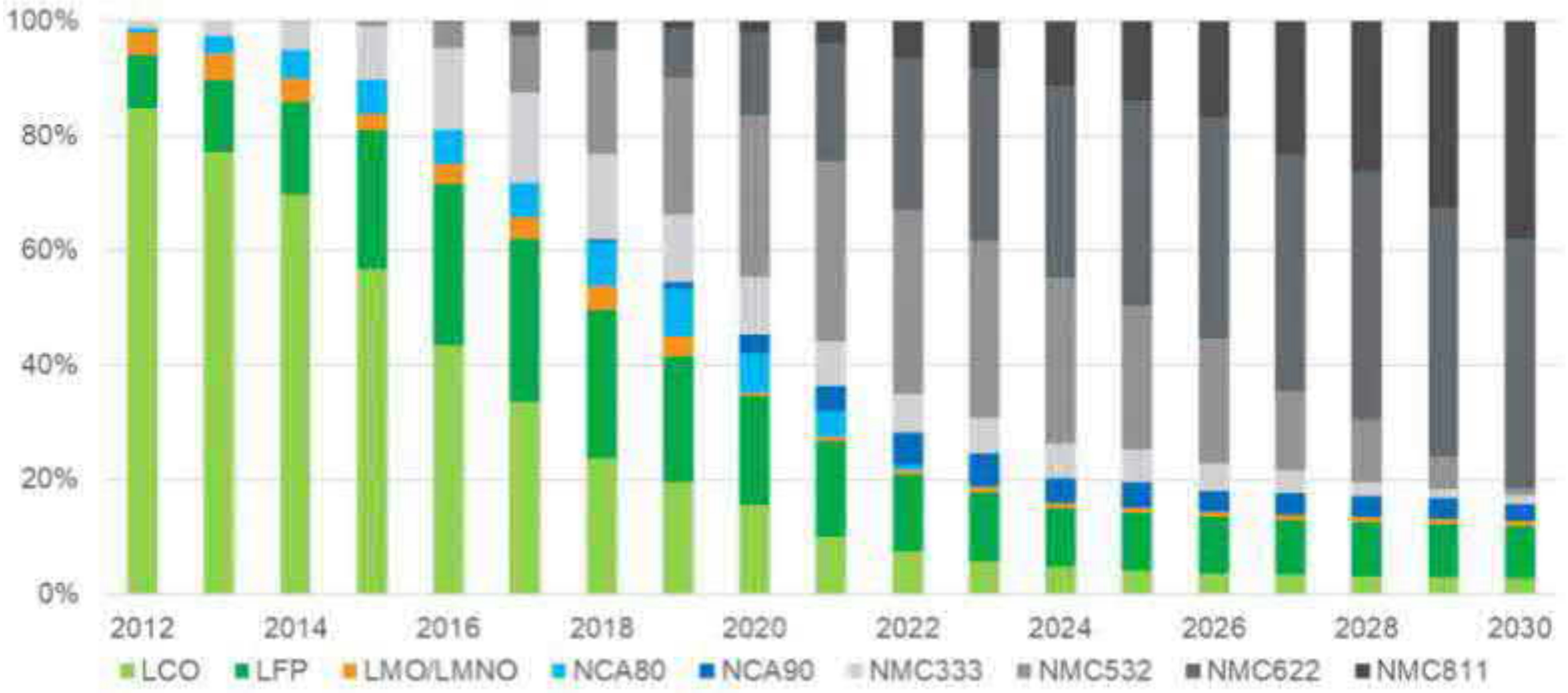
From: Report on Raw Materials for Battery Applications, European Commission Staff Working Document, 2018

# Evolution of cobalt content in lithium batteries: past and future



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# Next generation lithium battery concepts – raw material perspective

- ✓ Lithium-sulphur (Li-S)
- ✓ Solid state  lithium batteries (SSLB)
- ✓ Sodium-ion (Na-ion)
- ✓ Multialent batteries
- ✓ Lithium-air (Li-air)

| Cell generation | Cell chemistry | |
|---|---|---|
| Generation 5 | • $Li/O_2$ (lithium-air) | > 2025 ? |
| Generation 4 | • All-solid-state with lithium anode<br>• Conversion materials (primarily lithium-sulphur) | |
| Generation 3b | • Cathode: HE-NCM, HVS (high-voltage spinel)<br>• Anode: silicon/carbon | ~ 2025 |
| Generation 3a | • Cathode: NCM622 to NCM811<br>• Anode: carbon (graphite) + silicon component (5-10%) | ~ 2020 |
| Generation 2b | • Cathode: NCM523 to NCM622<br>• Anode: carbon | current |
| Generation 2a | • Cathode: NCM111<br>• Anode: 100% carbon | current |
| Generation 1 | • Cathode: LFP, NCA<br>• Anode: 100% carbon | current |

Battery technology denominations according to Nationale Platform, Elektromobilitat, adobpted by JRC

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# RECYCLING IS CRITICAL

- Recycling battery materials reduces dependencies and cost in terms of raw materials
- Goal is to recover as much material as possible – preferably all of it – for direct reuse to produce new electrodes
- Currently, the lithium battery recycling industry in Europe is mainly concentrating on lithium batteries from spent electronics and portable instruments
- Chemistry of these batteries is varying a lot, challenging the processing and recovery of the materials
- Recycling industry must prepare for future challenges of large amounts of large EV batteries available to be recycled (bigger scale processing units)

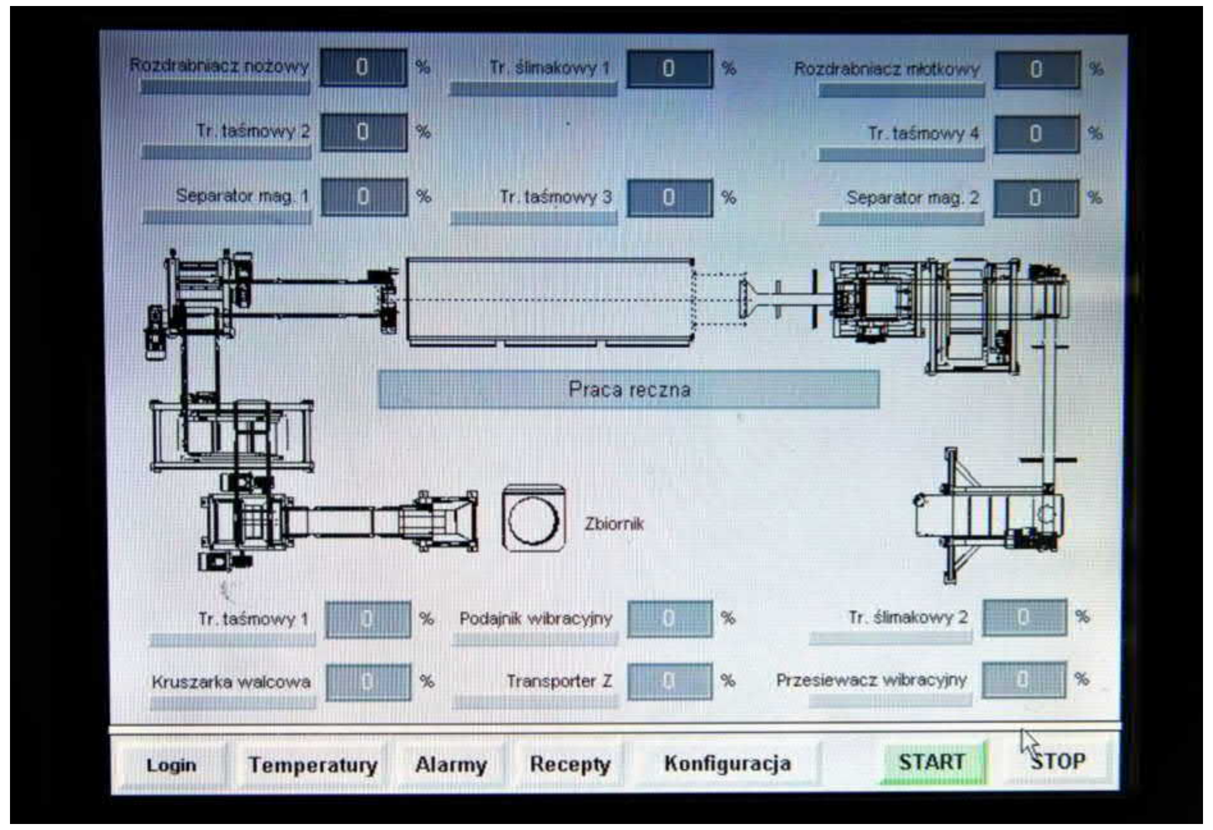


Strategic Research Agenda for Batteries 2020, European Commission, European Technology and Innovation platform

# Further progress in recycling technologies is necessary

## Below: pilot battery recycling facility co-developped by Łukasiewicz-IMN

Line for processing lithium ion and nickel metal hydride batteries at the Waste Disposal Plant Inneko in Gorzów Wielkopolski




Touch panel for remote control of the secondary lithium-ion and nickel-hydride battery processing

Processing of the secondary lithium-ion and nickel-hydride batteries results in the following material fractions:

1) polymers from secondary battery housings and PCB chips;
2) magnetic steel from cells;
3) electrode mass containing elements such as Co, Ni, C,Li, Mn, Cu, Al;
4) fraction of Al and Cu metal foil (from battery electrodes).

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# CONCLUSIONS

- Li-ion is a mature family of technologies both in terms of manufacturing and chemistry/materials
- Innovation in manufacturing is needed for further energy and cost reduction, with special focus on a small numer of energy intensive operations
- Critical raw materials utilization must be reduced:
    - NMC cathode materials must further evolve towards lesser Co content
    - More efforts towards next-generation lithium battery systems with fewer critical elements (Li-S ?)
- Further progres in Li-ion battery recycling is critical



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# Thank you for your attention

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