Sustainability challenges in lithium-ion battery value chain

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Introduction

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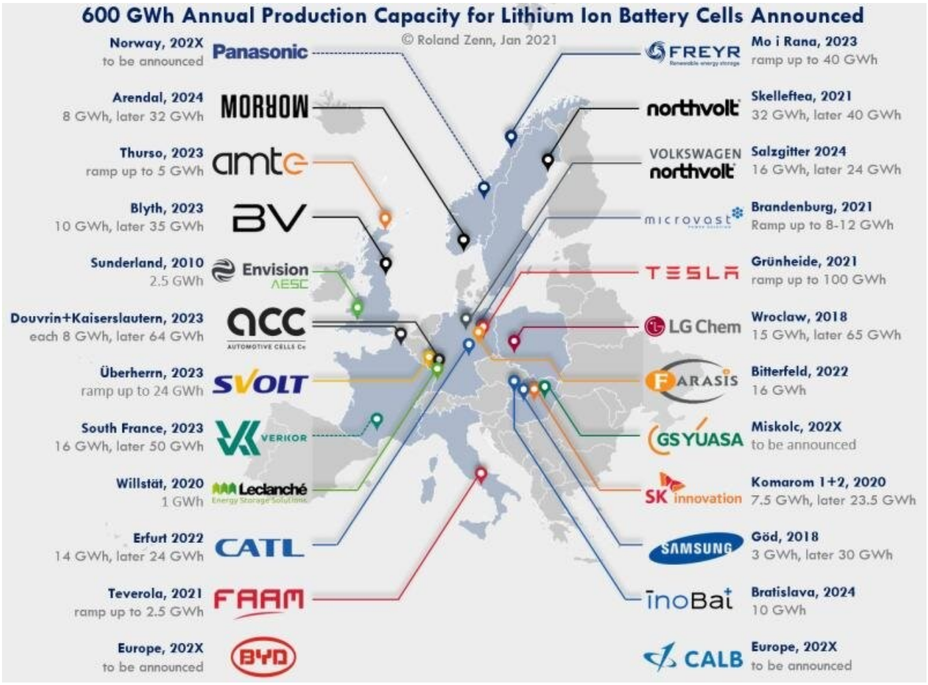
- The demand for lithium-ion batteries is growing rapidly due to the increasing popularity of electric vehicles, portable devices, and energy storage from renewable energy sources, particularly household electricity generated by wind power and solar cells.
- This means **increasing battery capacity need**, and new Gigafactories are being built in Europe.
- In addition to Gigafactories, **several investment plans for the manufacture of battery precursors and battery chemicals** have also been published.

Kuva: Finnish Minerals Group



Key challenges in the sustainability of Li-ion battery value chain

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- Use of critical raw materials in batteries (especially Li, Co, and graphite)
- Use of primary minerals in the batteries
- Formation of sodium sulfate during the coprecipitation
- Harmful (even toxic) solvents in the battery cell lines
- Halogen-containing binders and electrolytes
- Low recycling efficiencies and recovery rates

Replacement of critical raw materials in batteries

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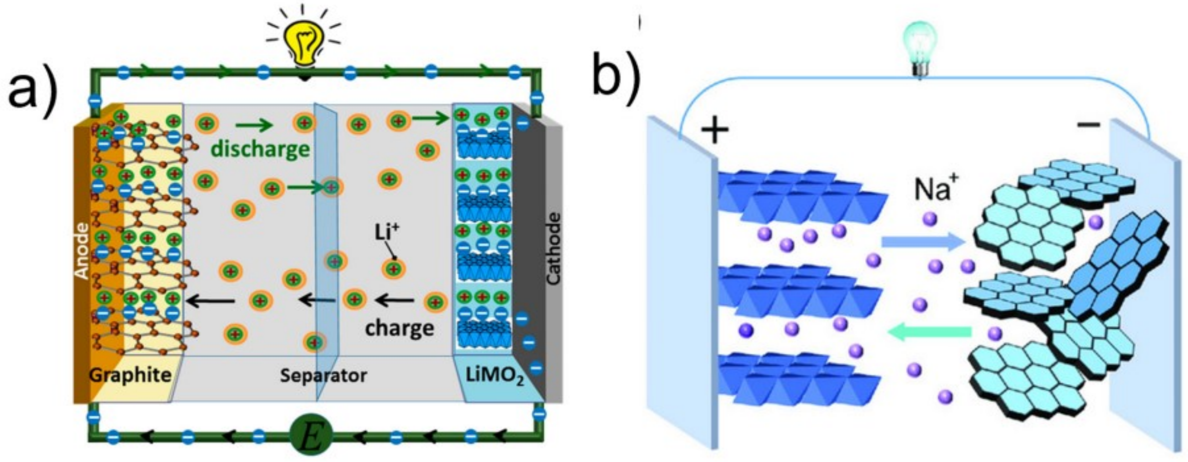
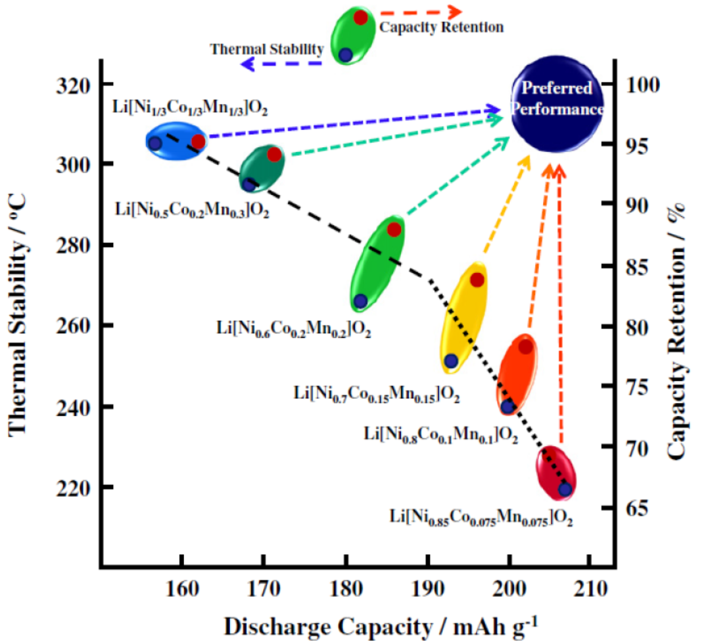
- Development of parallel battery technologies to Li-ion batteries, such as Na-ion

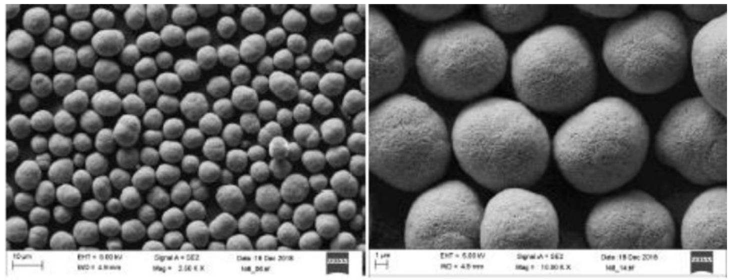


- Co-free cathodes for lithium-ion batteries (e.g. LNMO or LNO)



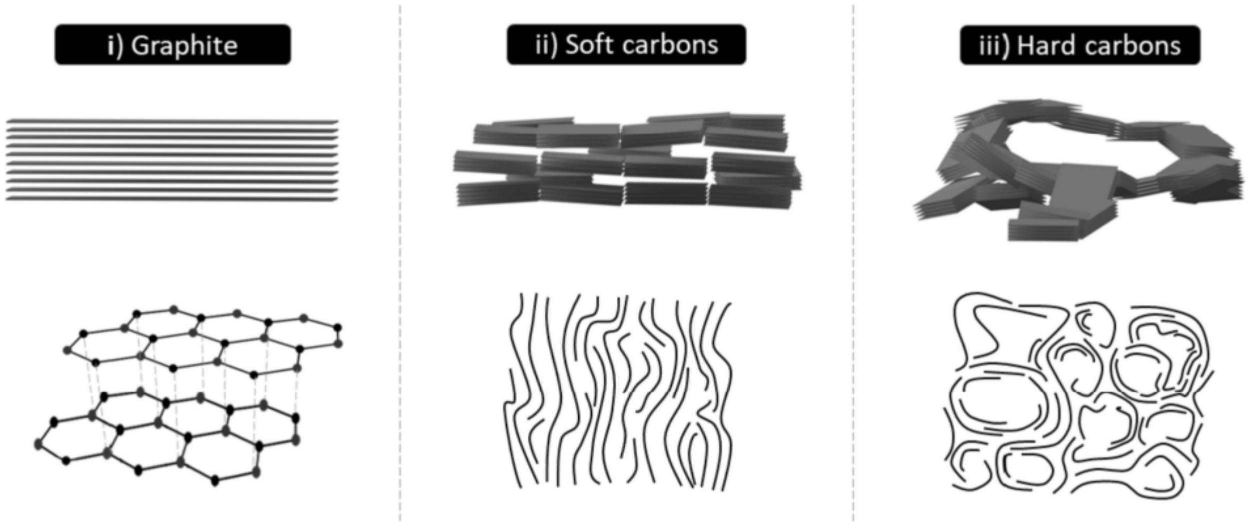
Noh et al. 2013, J. Power Sources

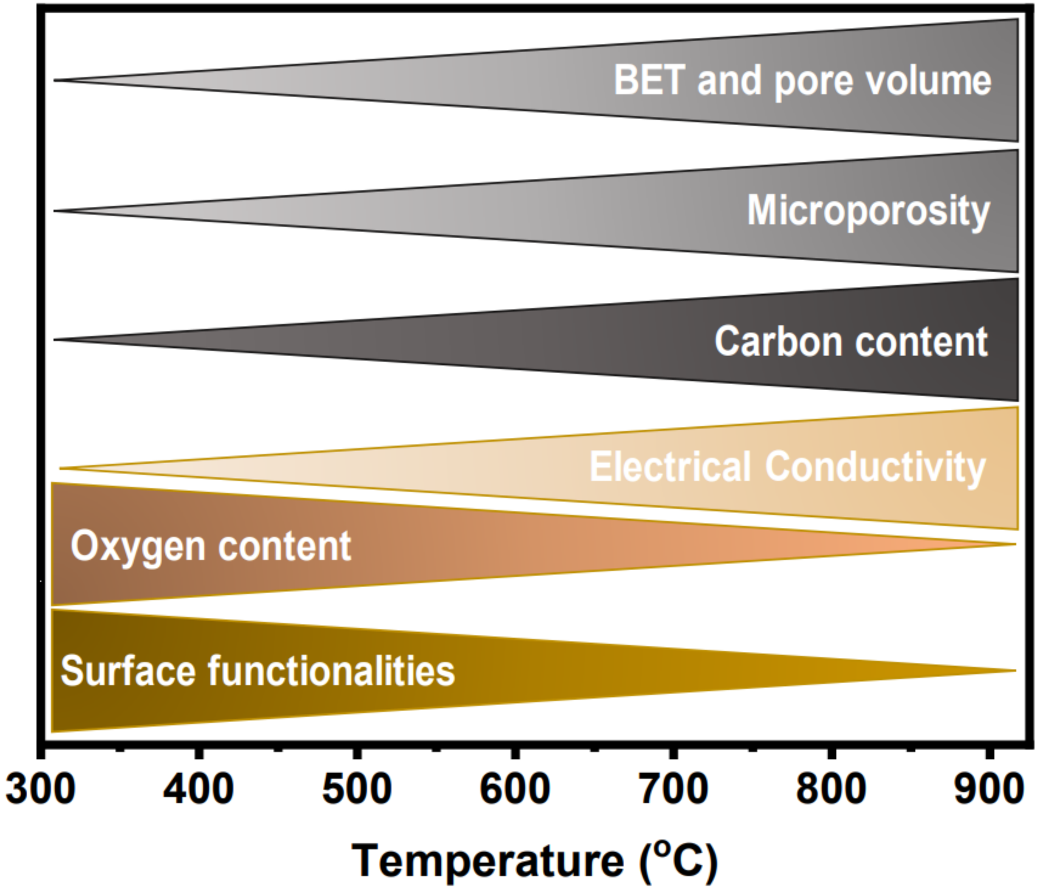
Cathode	$LiNi_{0.5}Mn_{1.5}O_4$	$LiCoO_2$	$LiMn_2O_4$	$LiFePO_4$	$LiCo_{1/3}Ni_{1/3}Mn_{1/3}O_2$
Energy Density (Wh kg^{-1})	650	518	400	495	576
Discharge Voltage (V)	4.7	3.7	3.9	3.4	3.7
Specific capacity (mAh g^{-1})	138	140	100	145	155



Replacement of critical raw materials in batteries

- Replacement of graphite anode by biomass-based carbon materials



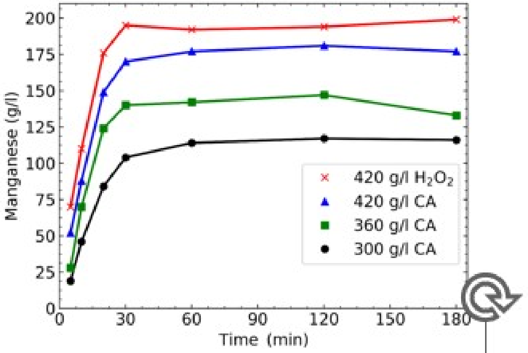


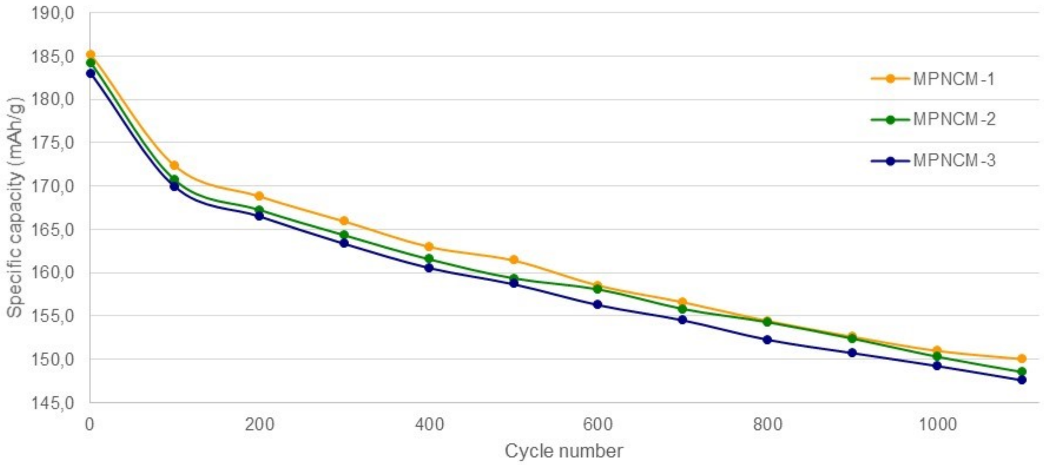
Molaiyan, P.; Dos Reis, G.S.; Karuppiah, D.; Subramaniyam, C.M.; García-Alvarado, F.; Lassi, U. Recent Progress in Biomass-Derived Carbon Materials for Li-Ion and Na-Ion Batteries—A Review. Batteries 2023, 9, 116. https://doi.org/10.3390/ batteries9020116

Increased amount of recycled (secondary) materials

- The growing need for batteries will significantly increase the need for both primary battery minerals and recycled materials.
- However, these secondary materials alone are not enough to cover even the current need for battery materials (estimation 3-10 wt% of all material flows).
- Therefore, **we need responsible mining and sustainable battery mineral/chemical processing**.

Effect of S/L on manganese concentration at 60 °C.





Kauppinen, T; Vielma, T; Salminen, J; Lassi, U (2020) ChemEngineering 4 (2), 40. https://doi.org/10.3390/chemengineering4020040

https://www.boliden.com/sustainability/case-studies/purification-of-manganese-from-anode-sludge-at-kokkola

Sustainable solutions for sodium sulfate

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- Alkaline sodium sulfate is produced in the coprecipitation of NMC precursors (using NaOH as precipitant for metal sulfate solutions) but also during hydrometallurgical battery recycling processes
- Recycling is typically done with sulfuric acid leaching followed by precipitation of metals by NaOH

- Some potential solutions:

*Crystallization of sodium sulfate (Glauber salt)

*Conversion of sodium sulfate to sulfuric acid and NaOH via electrodialysis

*Use of sodium sulfate in neutral electrolytic pickling

*Use of sodium sulfate as alkali-activator for AAMs

*Conversion of sodium sulfate to chemicals for further use

Replacement of harmful (even toxic) solvents in the battery cell lines

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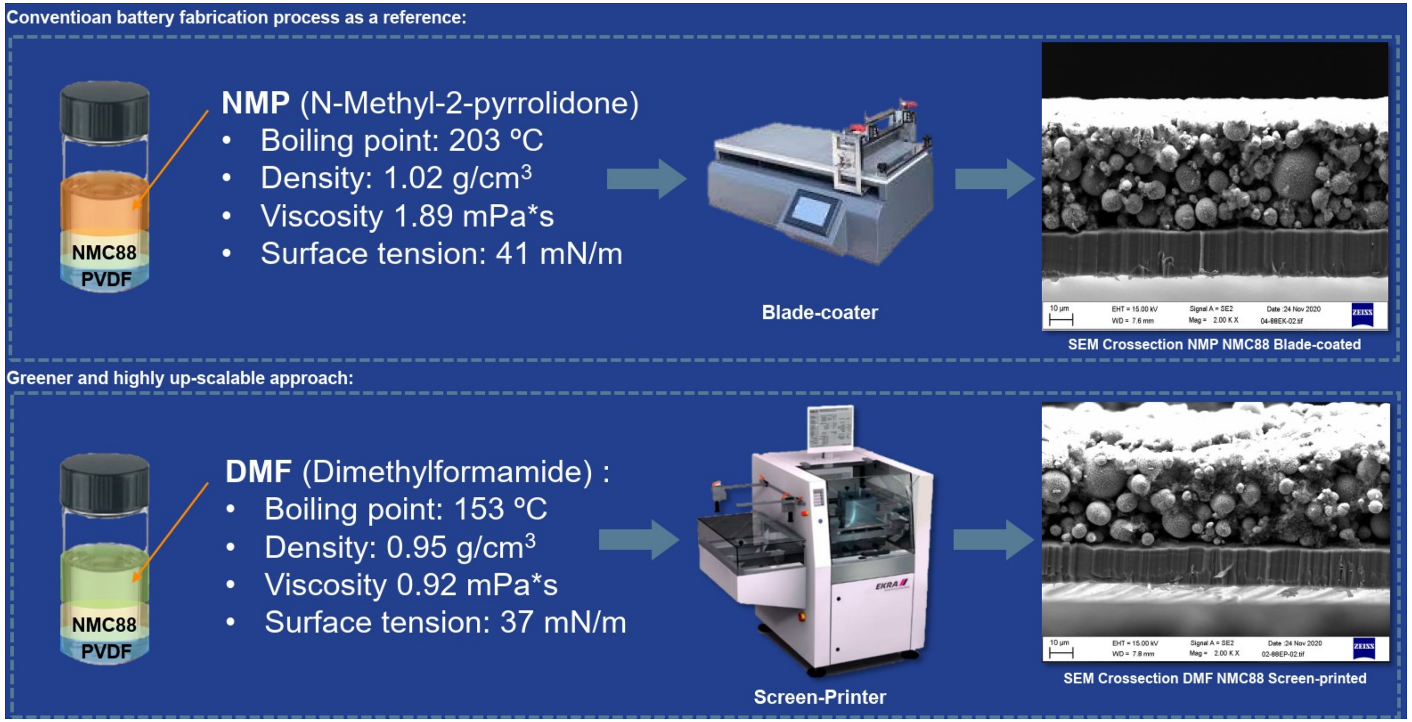

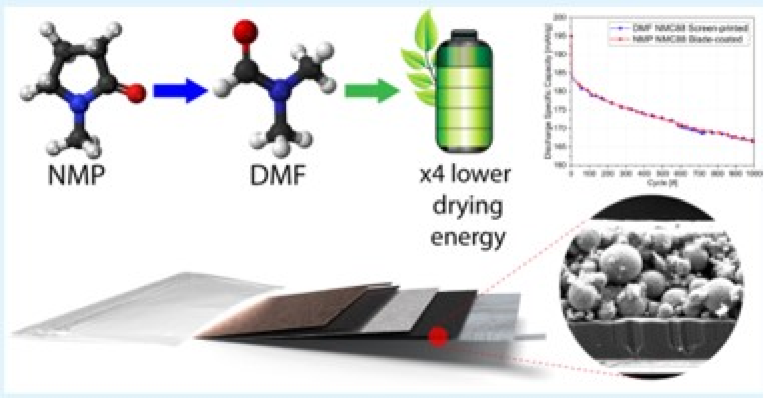

Sliz, Molaiyan, Fabritius, Lassi (2022) Printed electronics to accelerate solid-state battery development, https://doi.org/10.1088/2632-959X/ac5d8e
Sliz et al. (2022) Applied Energy Materials, https://doi.org.10.1021/acsaem.1c2923

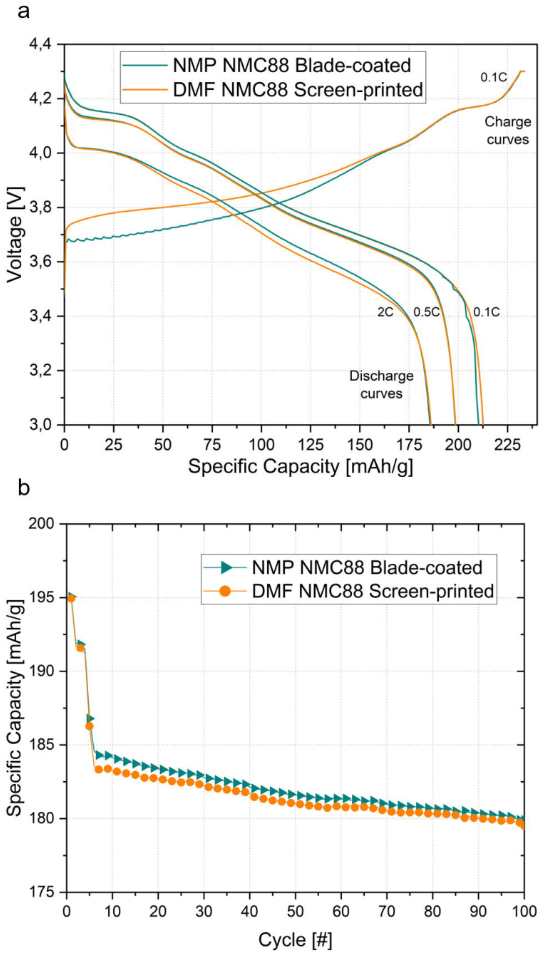

Figure 5. Electrical analysis of the fabricated batteries. a) Specific capacity vs voltage at various charge-discharge current (0.1C, 0.5C, 2C) for differently fabricated cathodes. b) Specific capacity during charging-discharging (1C/1C) process for differently fabricated cathodes.

Replacement of halogen-containing binders and electrolytes

- PVDF is the most commonly used binder for lithium-ion batteries. It poses a risk of HF emissions in the case of accident. Some water-based binders are available, but unfortunately not suitable for NMC cathodes.
- E.g. for LFP batteries water-based binders, such as carboxymethyl cellulose (CMC) can be used

- Electrolyte salt, $LiPF_6$ (lithium·phosphate·fluorine) is mostly used in LIBs. It is claimed that solid-state batteries (with solid electrolyte) would be more sustainable and replacement of halogens is possible.
- However, it seems that most of solid electrolytes (both polymer-based and inorganic ones) contain halogen salt
- Thus, electrolytes (also for solid-state batteries) poses a potential risk of HF emissions.

Conclusions

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- Battery chemistries are changing and enable more sustainable LIBs in the future (replacement of CRMs, such as Co and graphite)
- Increased capacities for precursor production require new sustainable solutions for sodium sulphate (waste solution from battery precursor production)
- Use of secondary materials increases, but will not be enough without primary mining
- Battery cell lines needs to be more sustainable
- Reduced use or replacement of toxic solvents and halogen-containing binders and electrolyte salts in cell assembling, material-efficient coating without comprimising cell performance

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