

Reducing Nickel Dependency: High-Voltage Performance of $\text{Na}_{0.8}\text{Cu}_x\text{Fe}_y\text{Mn}_z\text{O}_2$ Layered Oxides for Sustainable Sodium-Ion Batteries

Dominik Stepien¹, Archana Kumar¹, Martin Aaskov Karlsen², Philipp Adelhelm^{1,3,4}



¹Institut für Chemie, Humboldt-Universität zu Berlin.

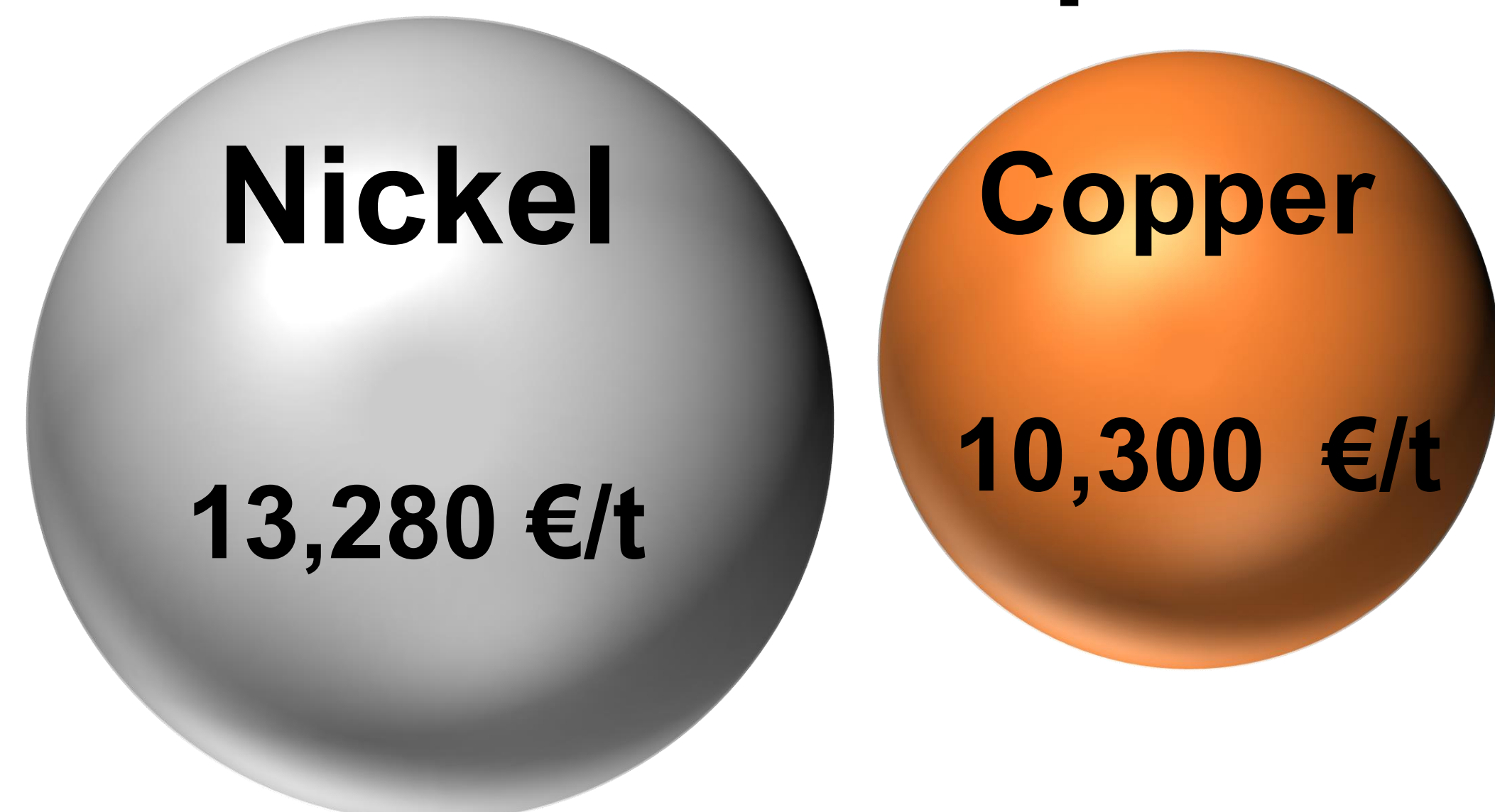
²Deutsches Elektronen-Synchrotron (DESY), Hamburg.

³Joint research group Operando Battery Analysis (CE-GOBA), Helmholtz-Zentrum Berlin.

⁴Center for the Science of Materials Berlin (CSMB), Humboldt-Universität zu Berlin.

Sodium-ion batteries are emerging as a strategic alternative to Li-ion systems, yet current layered oxide cathodes still rely on nickel-containing chemistries such as NFM111. Ni is classified as a critical raw material in Europe, with persistent supply risks projected beyond 2030. Here, we investigate $\text{Na}_{0.8}\text{Cu}_x\text{Fe}_y\text{Mn}_z\text{O}_2$ layered oxides as Ni-free cathode materials, conceptually analogous to Ni-Fe-Mn systems. We aim to retain competitive performance while improving cost efficiency, sustainability, and European supply-chain resilience.

Raw material price



Based on sulfate precursor and wt.% of each metal (SMM; 28.12.2025)

EU supply risk: Cathode metals

Possible European providers

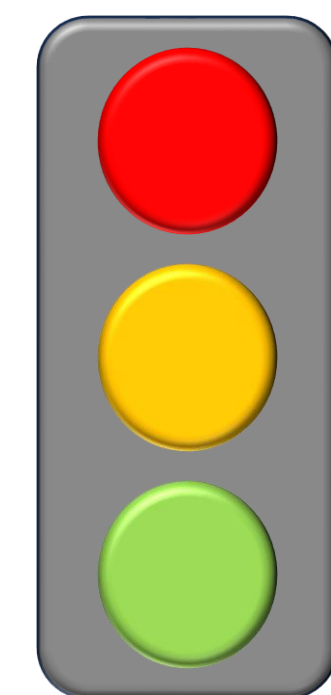
Cu

Manica (IT): Copper sulfate
Aurubis (DE/BE/BG): Copper cathode
Boliden (SE/FI): Copper cathodes
KGHM (PL): Copper cathodes

➤ Cu and Fe can be sufficiently supplied within Europe, supported by established mining, refining, and chemical precursor production capacities.

Fe

LKAB (SE): Iron ore
Olmix Nordenham (DE): Iron sulfate
Ferrodo (DE/EU): Iron sulfate



Ni
Mn
Cu, Fe
Mn

Mn

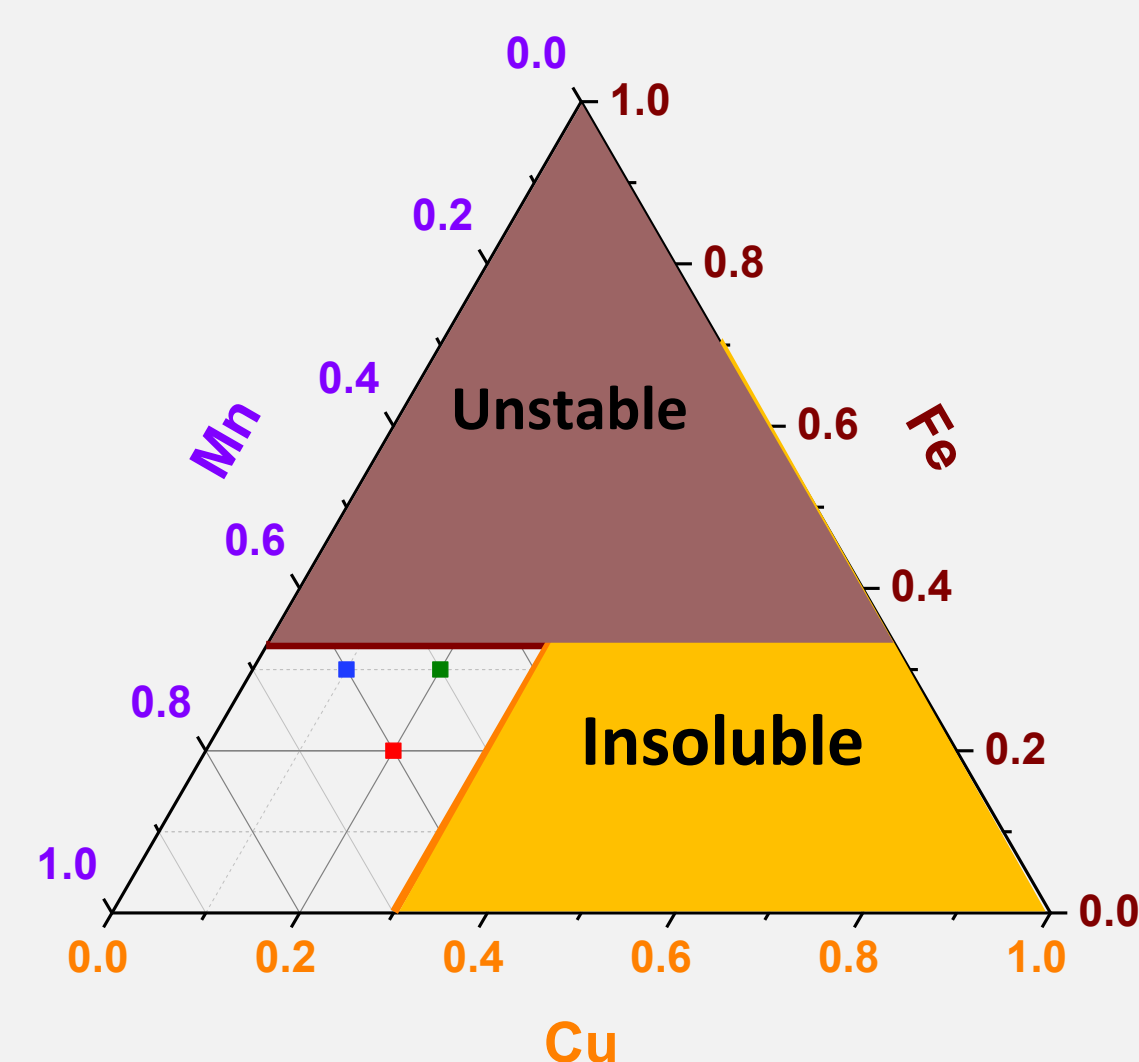
Chvaletice Project (CZ): Mangan sulfate

➤ EU risk reduction, though not fully EU self-sufficiency.

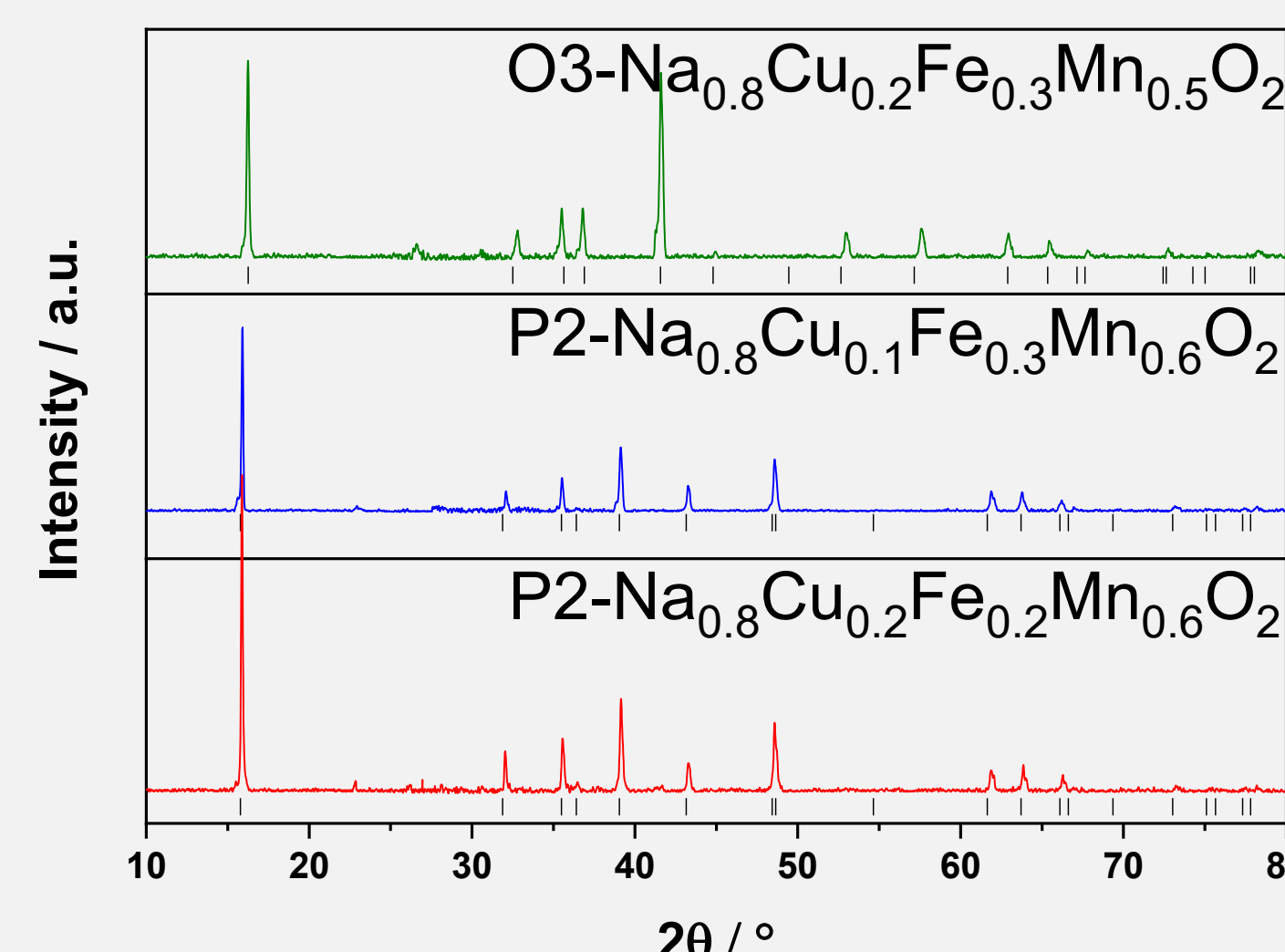
Ni

Boliden (FI): Ni sulfide concentrate

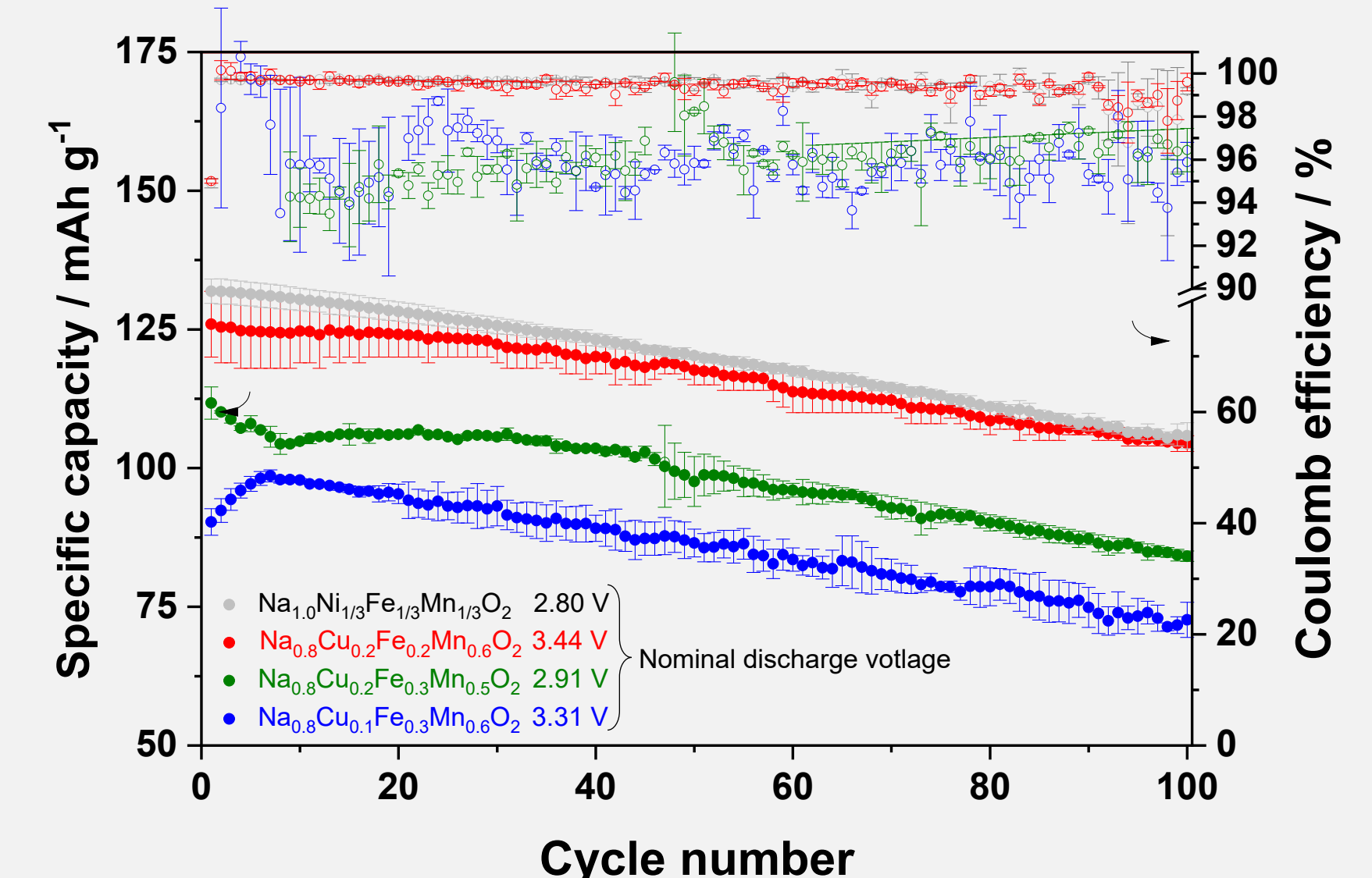
➤ Cannot cover EU Ni demand.



➤ Three compositions with increased Cu and Fe contents were selected to enhance energy density by accessing higher-voltage redox reactions.

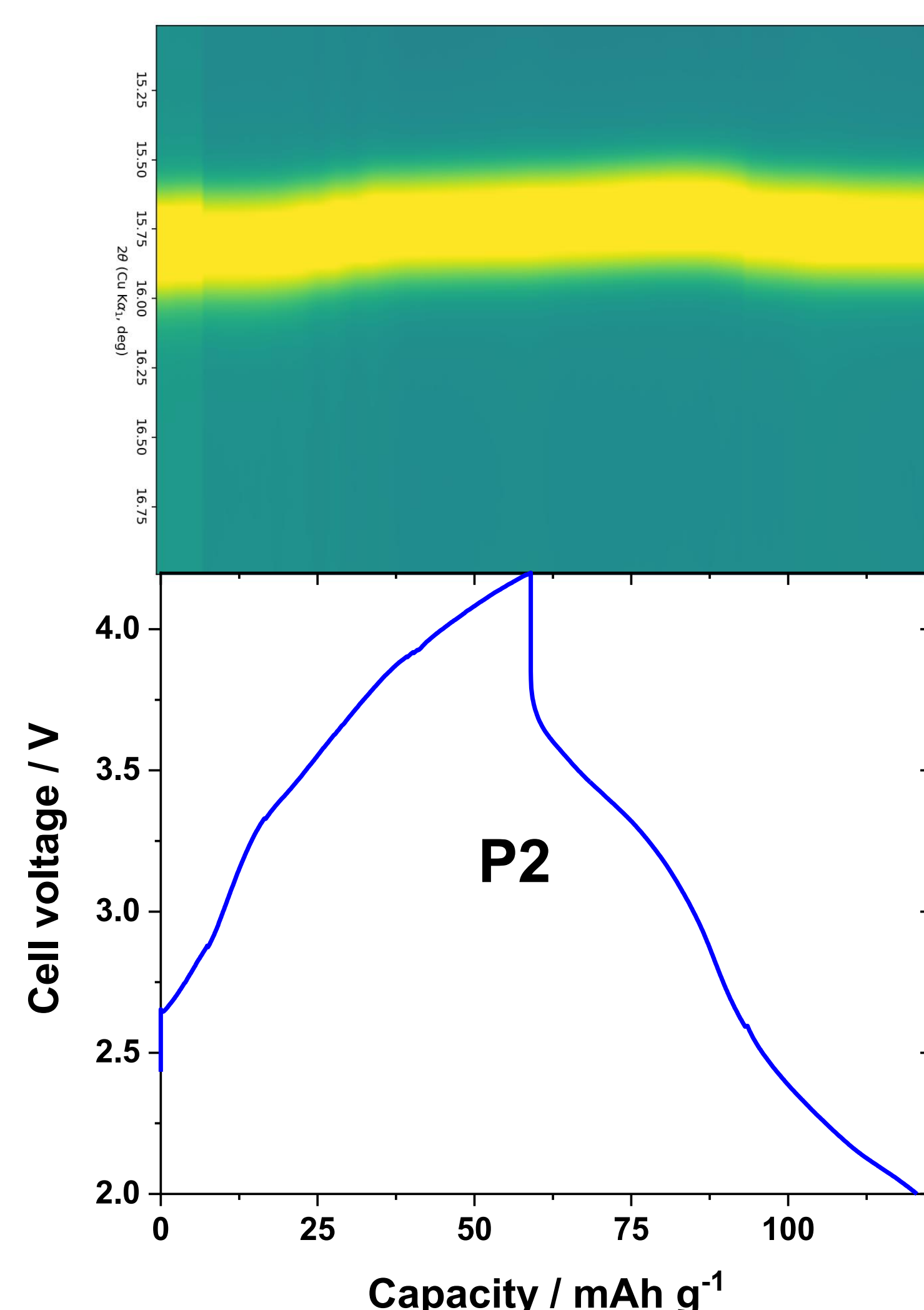


➤ An increased Mn content ($\text{Mn}_{0.6}$) promotes P2, whereas lower Mn content ($\text{Mn}_{0.5}$) stabilizes O3.

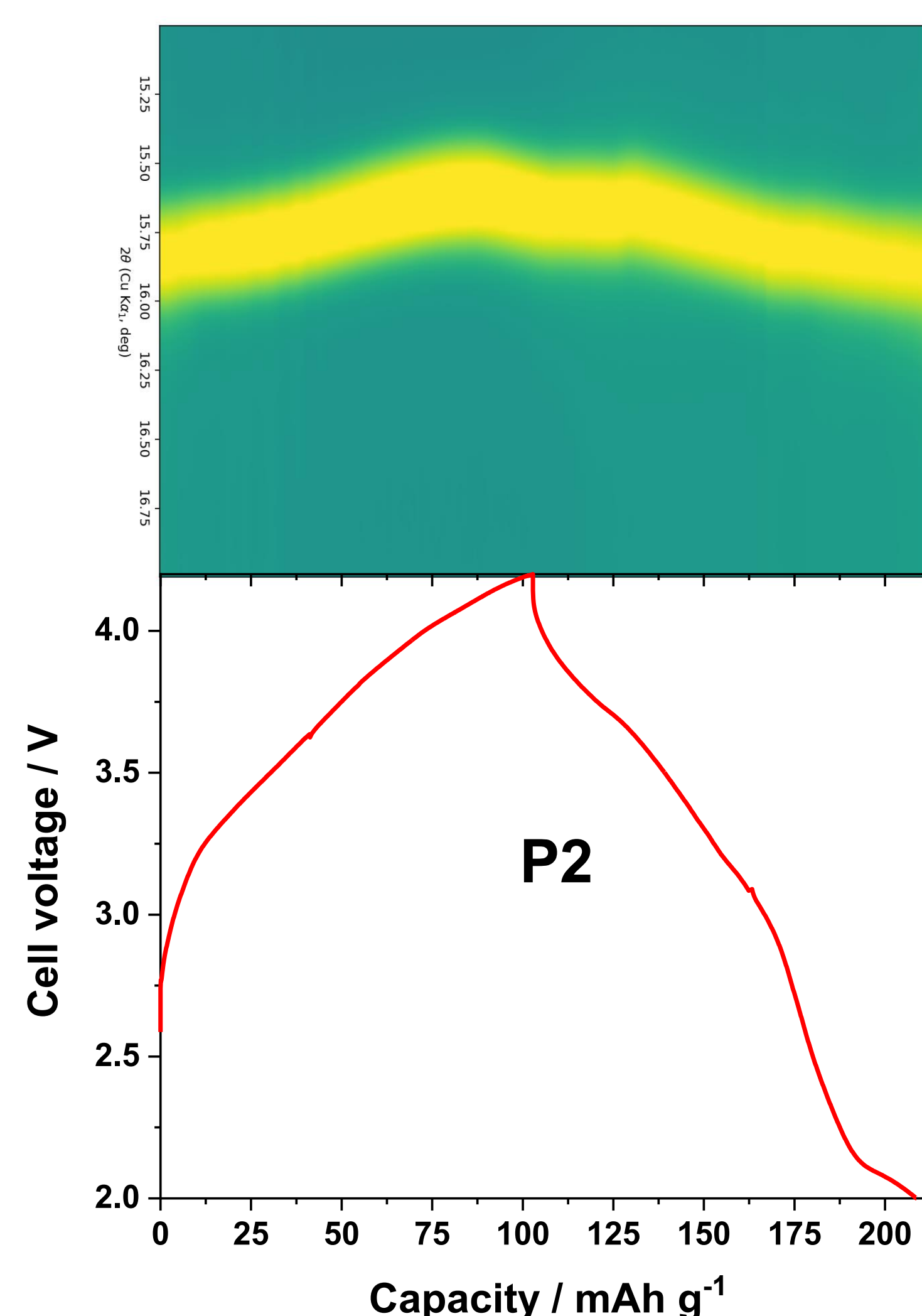


P2- $\text{Na}_{0.8}\text{Cu}_{0.2}\text{Fe}_{0.2}\text{Mn}_{0.6}\text{O}_2$ exhibits the most favorable balance of structure and electrochemical performance, reaching a level competitive with NFM111.

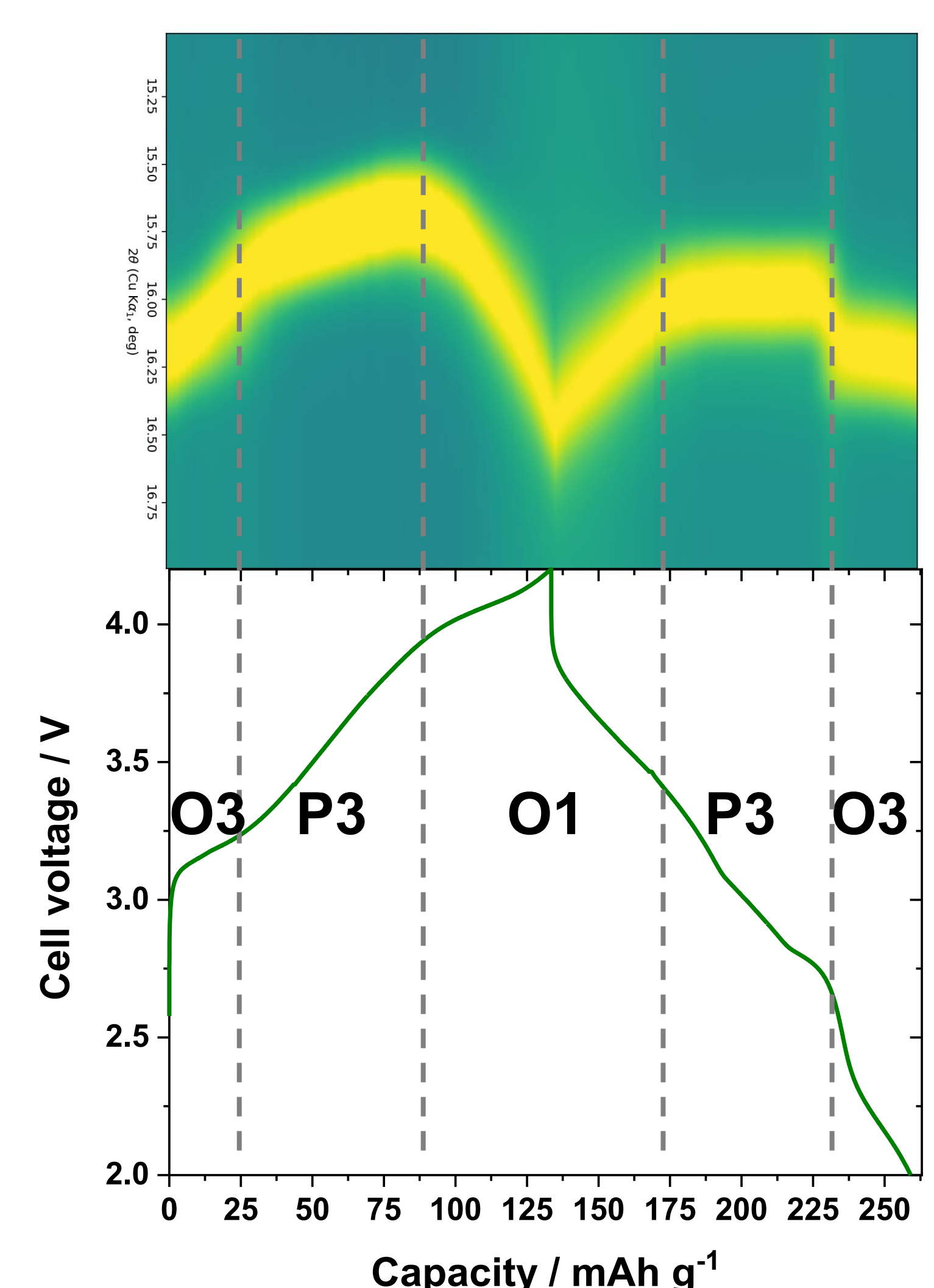
P2- $\text{Na}_{0.8}\text{Cu}_{0.1}\text{Fe}_{0.3}\text{Mn}_{0.6}\text{O}_2$



P2- $\text{Na}_{0.8}\text{Cu}_{0.2}\text{Fe}_{0.2}\text{Mn}_{0.6}\text{O}_2$



O3- $\text{Na}_{0.8}\text{Cu}_{0.2}\text{Fe}_{0.3}\text{Mn}_{0.5}\text{O}_2$



➤ The O3 composition shows O3 → P3 → O1 transitions associated with higher structural stress and faster capacity decay, while the P2 materials display solid-solution behavior with reduced stress.

Na layered oxide cathodes based on the Cu-Fe-Mn system represent a promising route toward a resilient European supply chain for sodium-ion batteries. In particular, P2- $\text{Na}_{0.8}\text{Cu}_{0.2}\text{Fe}_{0.2}\text{Mn}_{0.6}\text{O}_2$ demonstrates electrochemical performance on par with commercially available NFM111.



BMFTR funded project:
ENTISE (03XP0579C)
Contact: dominik.stepien.2@hu-berlin.de



Federal Ministry
of Research, Technology
and Space



Batterieforschung
DEUTSCHLAND