IGSMiE PAN

NOWE KIERUNKI ROZWOJU DLA TECHNOLOGII MAGAZYNOWANIA ENERGII W BATERIACH

dr inż. Emil Hanc

Instytutu Gospodarki Surowcami Mineralnymi i Energią
Polskiej Akademii Nauk

Pracownia Geochemii Stosowanej i Inżynierii Środowiska

XXXVII Konferencja Energetyczna PAN, Zakopane, 2024

Agenda

Magazynowanie energii
Ogniwa elektrochemiczne

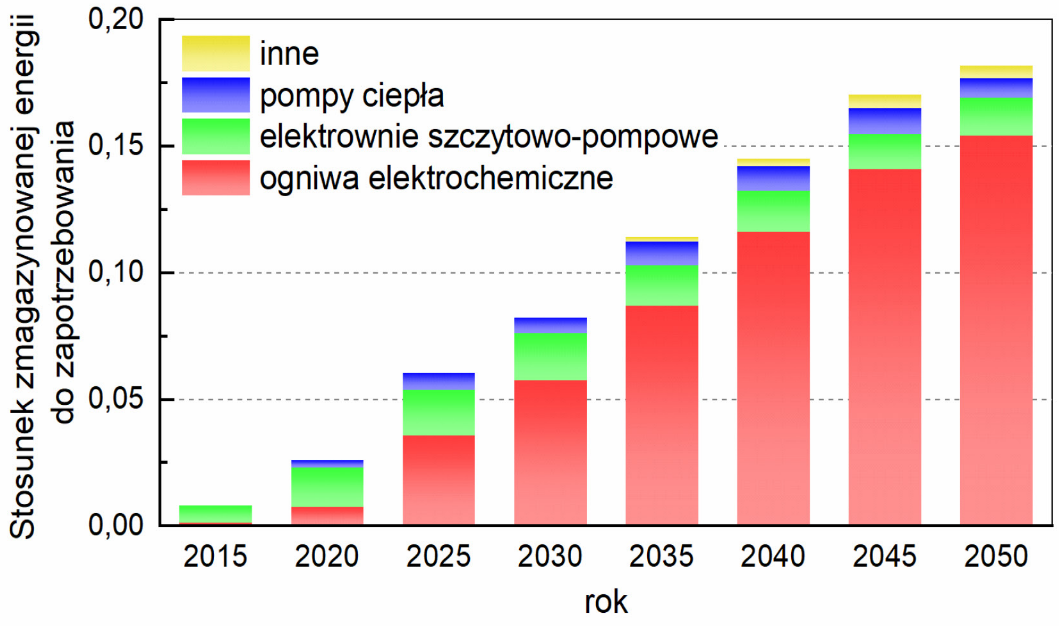
Ogniwa Li-ion
Komercyjne ogniwa
Limitacje technologii Li-ion

Nowe kierunki rozwoju
Alternatywy dla ogniw Li-ion

Ogniwa typu all-solid-state
Perspektywy

Kierunki komercyjne
Wizja

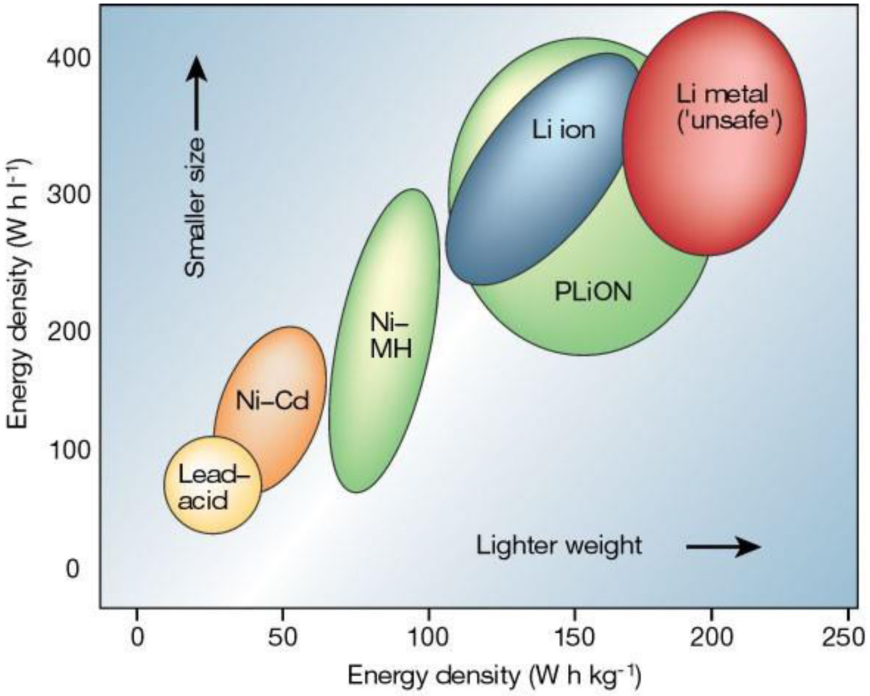
Magazynowanie energii



Magazynowanie energii ze źródeł odnawialnych jest szczególnym wyzwaniem a zarazem istotnym elementem zrównoważonej gospodarki energetycznej.

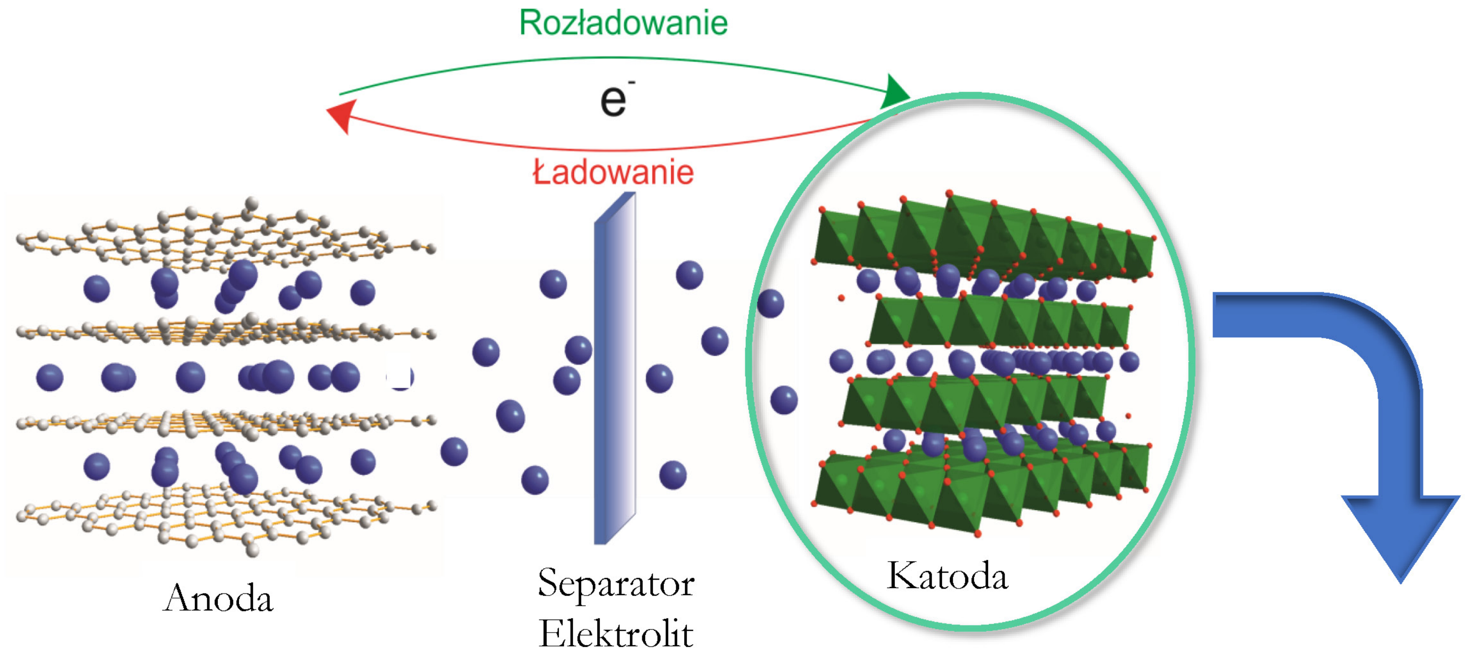
[C. Breyer, A. Azzuni, C. Breyer, *Energy Procedia* 2018, *155*, 237]
[O. Bamisile, B. Cai, H. Adun, M. Dagbasi, C. Ukwuoma, Q. Huang, N. Johnson, O. Bamisile, *Heliyon* 2024, 10, 19]

Ogniwa Li-ion



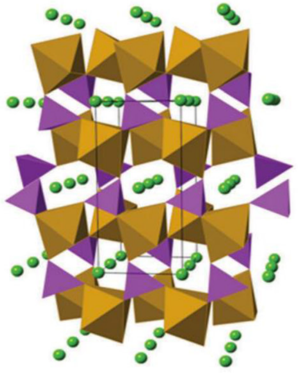
[J.-M. Tarascon, M. Armand, *Nature* 2001, 414, 359]

Zasada działania ogniwa Li-ion



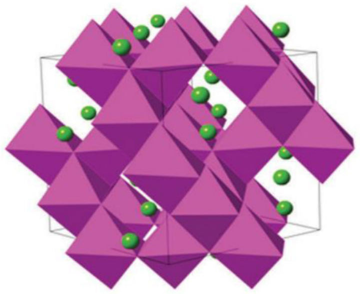
Materiały o strukturze spinelu

LMO LiMn$_2$O$_4$



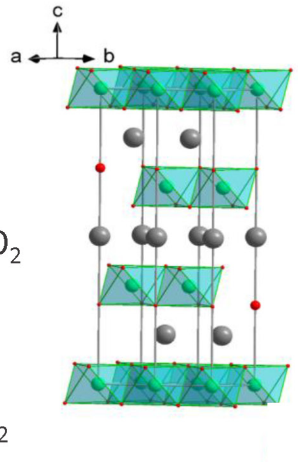
Materiały polianionowe

LFP LiFePO$_4$



Tlenki warstwowe

LCO LiCoO$_2$
NMC111(333) LiNi$_{0.33}$Mn$_{0.33}$Co$_{0.33}$O$_2$
NMC532 LiNi$_{0.5}$Mn$_{0.3}$Co$_{0.2}$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$_2$
NMC911(955) LiNi$_{0.9}$Mn$_{0.05}$Co$_{0.05}$O$_2$



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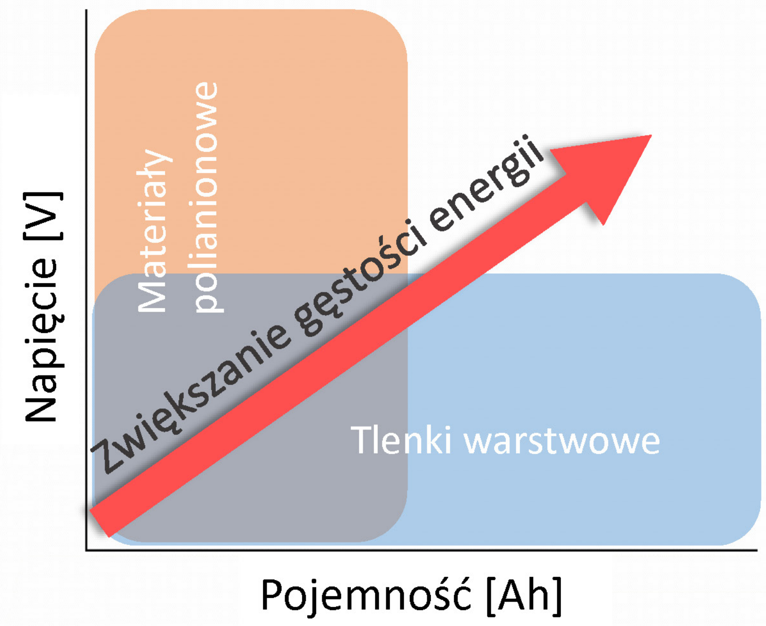
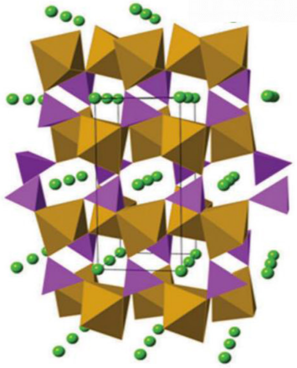


Rozwój ogniw Li-ion bazował na rozwoju materiału katodowego

Materiały o strukturze spinelu

LMO $LiMn_2O_4$



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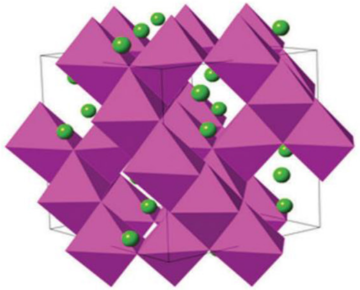

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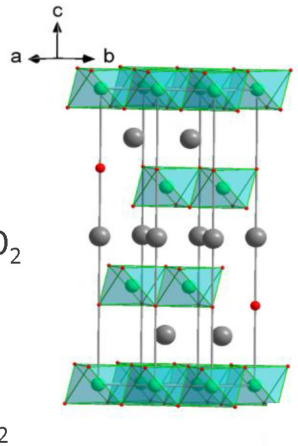
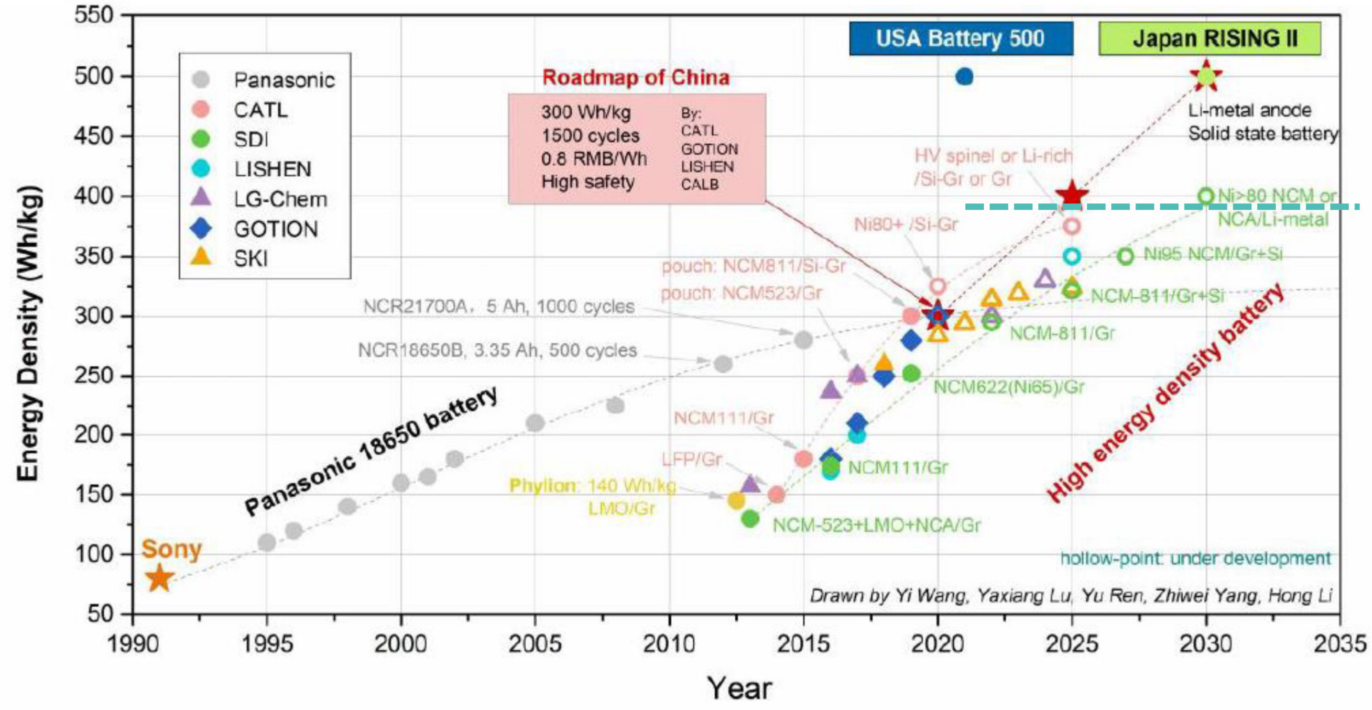
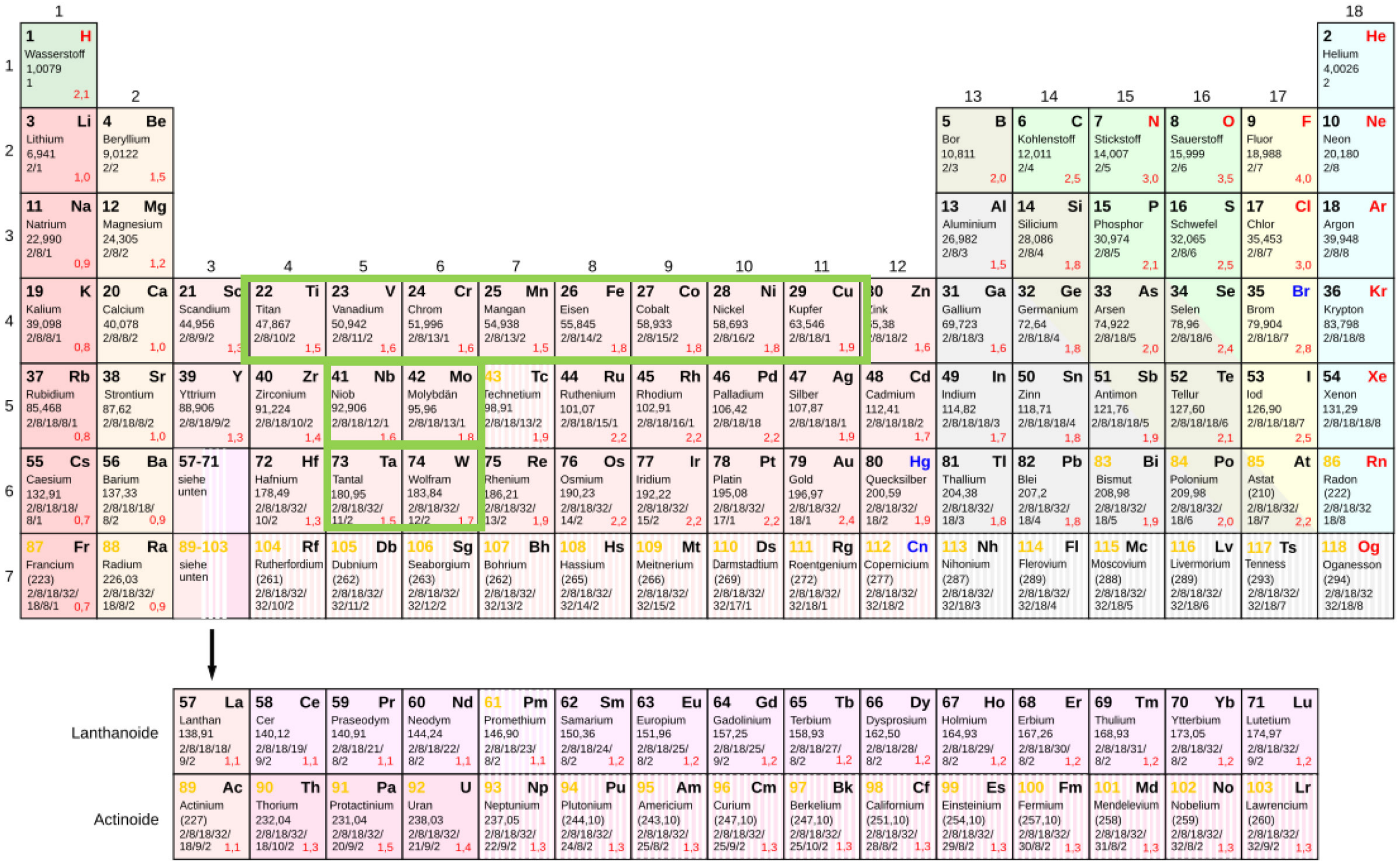


Technologia Li-ion rozwój



[Battery requirements for future automotive applications EG BEV&FCEV, 2019]
[Battery 2030+, Science Innovation Roadmap updated August 2023]

Jakie pierwiastki możemy stosować do katod?

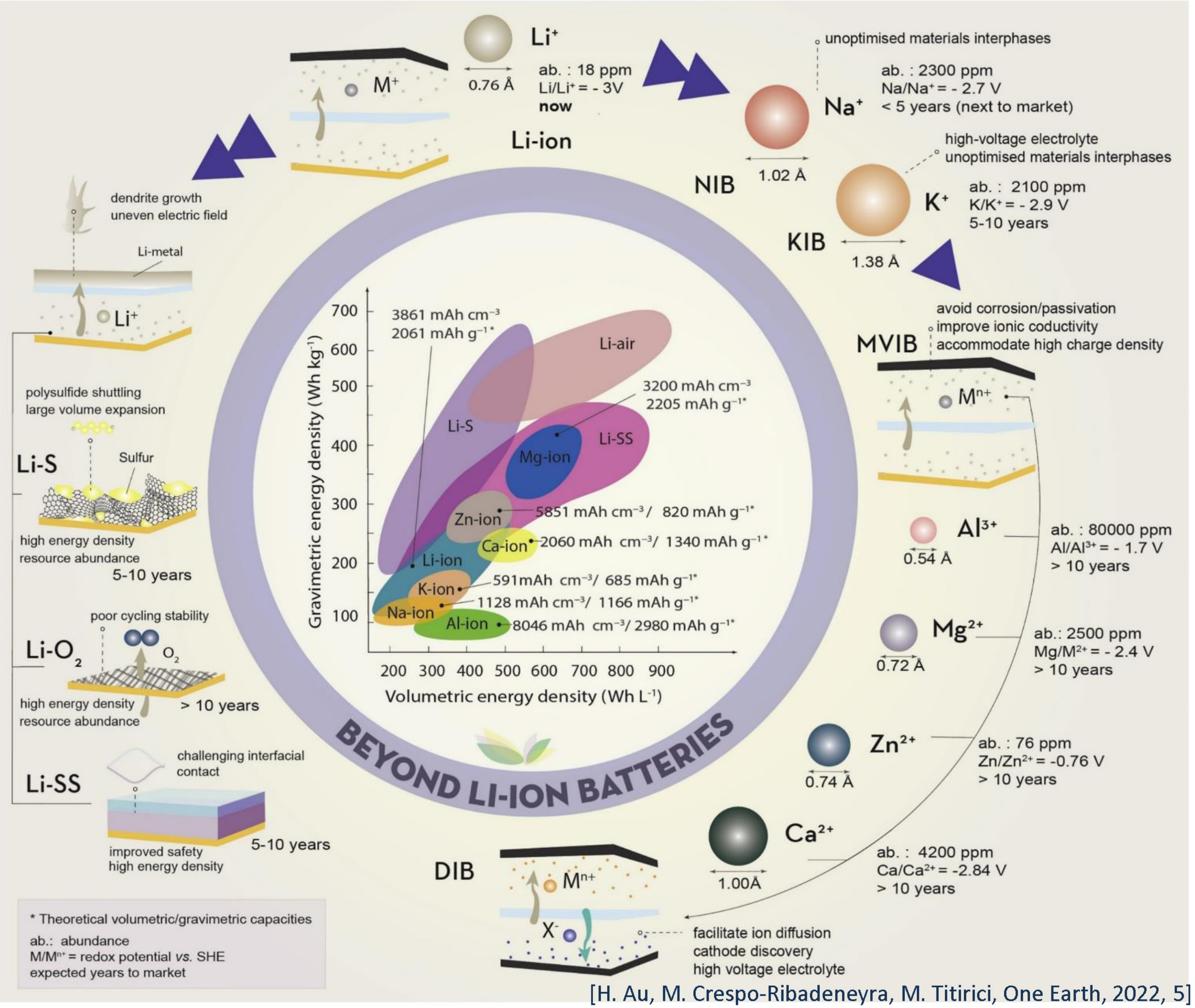


Co dalej?

- Dalszy prognozowany znaczy wzrost cen surowców litowych wymusza poszukiwania alternatywnych technologii, które umożliwiłyby eliminację litu oraz zminimalizowanie użycia surowców kopalnych.

Wizja

Alternatywy dla obecnej technologii Li-ion

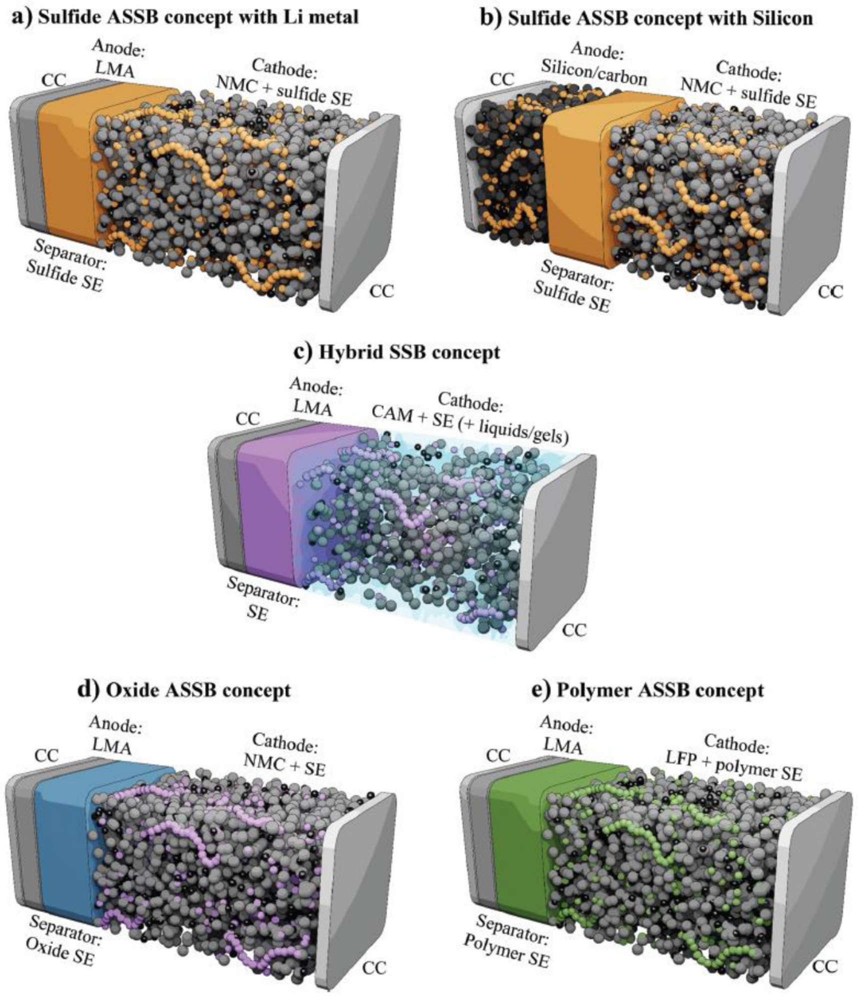


[H. Au, M. Crespo-Ribadeneyra, M. Titirici, One Earth, 2022, 5]

- solid-state
- Me-ion
- Me-S
- Me-air

Ogniwa typu solid-state

Nowa architektura ogniwa



Current collector	Anode active material	Anolyte	Separator	Catholyte	Cathode active material	Current collector
	▪ Lithium metal	▪ Solid	▪ Solid	▪ Solid	▪ LFP	
	▪ Silicon	▪ Oxide	▪ Oxide	▪ Oxide	▪ NMC	
	▪ Graphite	▪ Sulfide	▪ Sulfide	▪ Sulfide	▪ NCA	
	▪ LTO	▪ Polymer	▪ Polymer	▪ Polymer	▪ Sulfur	
		▪ (Liquid)		▪ (Liquid)	▪ High-voltage cathode, e. g. LMNO	

Ogniwa typu solid-state

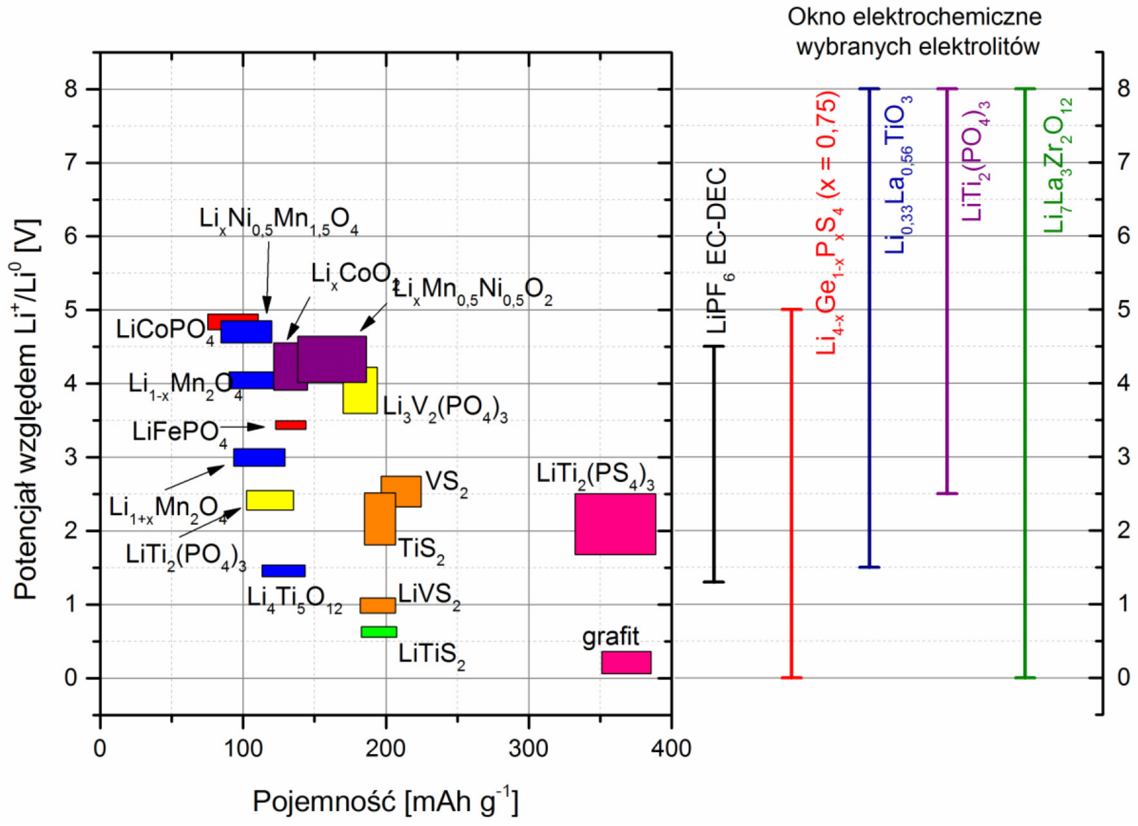
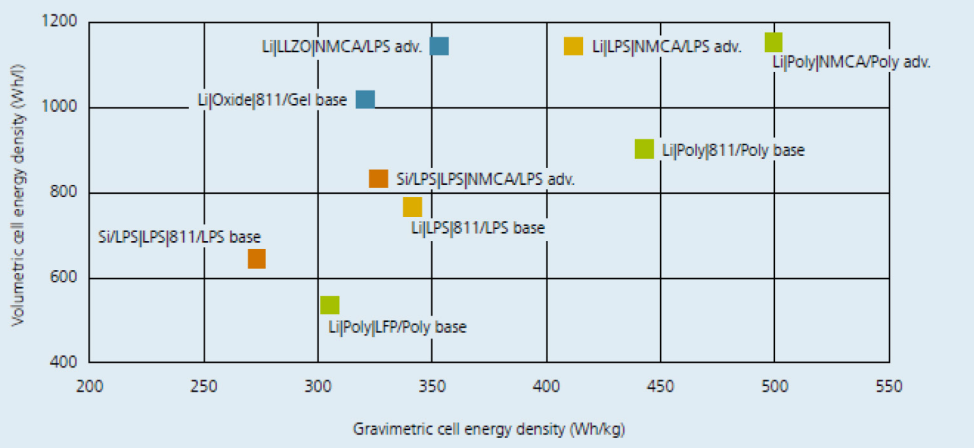


Figure 19: Calculated energy densities and specific energy for different SSB concepts in a base and an advanced configuration.



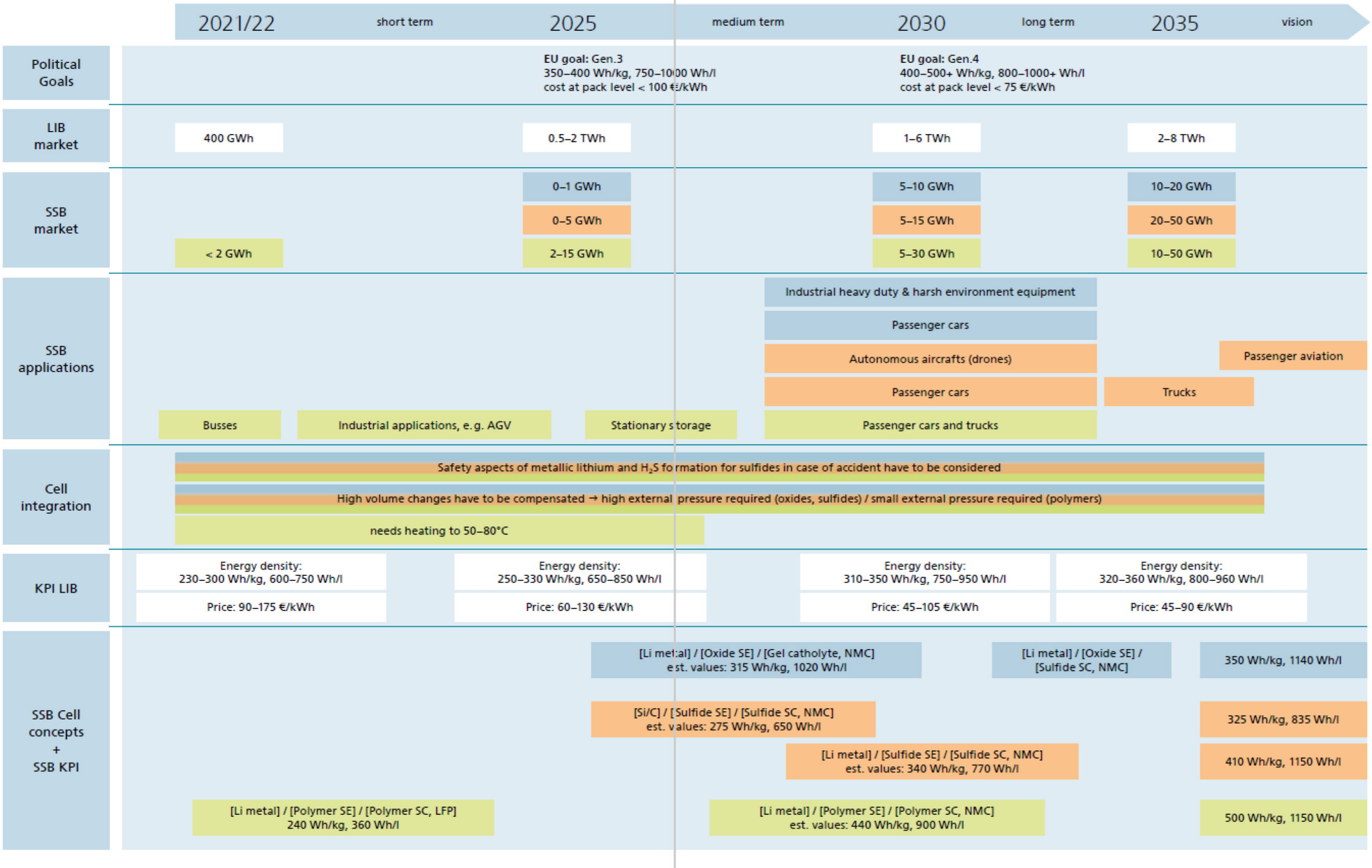
[Solid-State Battery Roadmap 2035+, 2023]

Ogniwa typu solid-state

Company	Time Horizon	Announcement	Source
ProLogium (Cells)	2022	1–2 GWh production capacity	[202]
ProLogium (Cells), Gogoro (OEM)	2022	2,5 kWh Prototype SSB for Scooter	[203]
ProLogium (Cells), VinFast (OEM), Mercedes-Benz (OEM)	2023	Market maturity for automotive application	[202, 204]
Quantum Scape (Cells)	2024	1 GWh production capacity	[137]
Quantum Scape (Cells), VW (OEM)	2025	Prototype in car	[205]
Quantum Scape (Cells)	2026	20 GWh production capacity	[137]
Qing Tao (Cells)	2020	1 GWh production capacity	[206]
Qing Tao (Cells)	2022	Factory with up to 10 GWh optional production capacity	[206]
SDI (Cells)	2020	Prototype Cell with in-situ Li metal anode	[136]
Panasonic (Cells), Toyota (OEM)	2021	Prototype in car	[205, 207]
Ampcera (Cells)	2021	Solid electrolyte commercially available	[205]
SDI (Cells)	2022	Construction of a pilot production plant	[208]
Solid Power, BMW (OEM), Ford (OEM)	Before 2025	Prototype in car	[209]
Panasonic (Cells)	2025	SSB development finished	[205]
Panasonic (Cells), Toyota (OEM)	2025	Market maturity for automotive application	[205, 207]
CATL (Cells)	2025	Development of Thiophosphate separator for sulfide SSB	[205]
Solid Power (Cells)	2026	100 Ah Si anode Cell	[149, 210]
SDI (Cells)	2027	SSB development finished	[205]
Solid Power (Cells)	2028	100 Ah Li metal Cell	[149, 210]
SKI (Cells)	2029	SSB development finished	[205]
Solid Power, BMW (OEM), Ford (OEM)	End of decade	Market maturity for automotive application	[209]
LGES (Cells)	2030+	SSB development finished	[205]
Bollore (Cells), Mercedes-Benz (OEM)	2020	Ceitavo Bus with 441 kWh LMP battery	[199]
Factorial Energy (Cells)	2021	Prototype 40Ah ASSB	[211]
WeLion New Energy Technology (Cells), NIO (OEM)	2022	SSB development finished	[205]
WeLion New Energy Technology (Cells)	2022	20 GWh production capacity, later on a expansion to 100 GWh	[212]
SES (Cells), GM (OEM)	2023	Prototype in car	[213]
Ionic materials (Cells) Nissan-Renault-Mitsubishi (OEM)	2025	Prototype in car	[213]
Hydro Quebec (Cells)	2025	SSB development finished	[214]
Ionic materials (Cells), Hyundai (OEM)	2030 +	Market maturity for automotive application	[213]
Blackstone Resources (Cells)	2022	500 MWh production, polycrystalline material	[199]
Stellantis (OEM)	2026	Prototype in car	[213]
StoreDot (Cells)	2028	Composite out of organic and inorganic materials	[215]
Honda (OEM)	2030	Market maturity for automotive application	[213]

[Solid-State Battery Roadmap 2035+, 2023]

Ogniwa typu solid-state

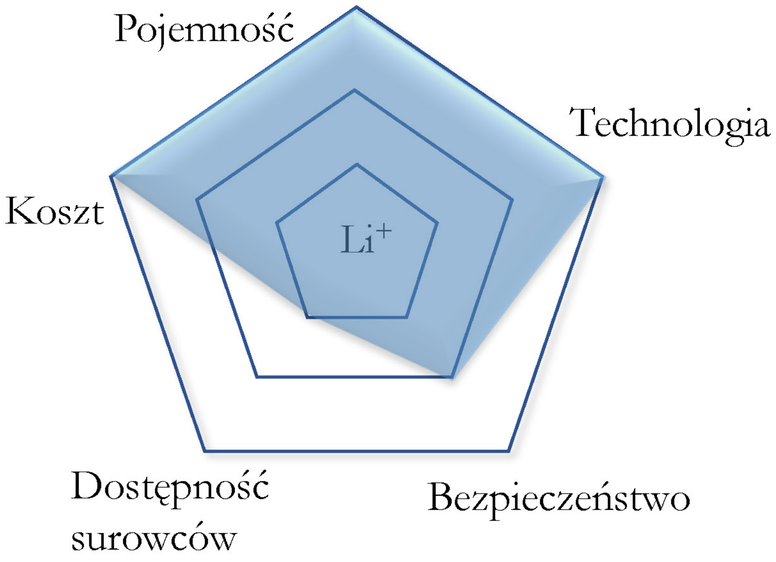


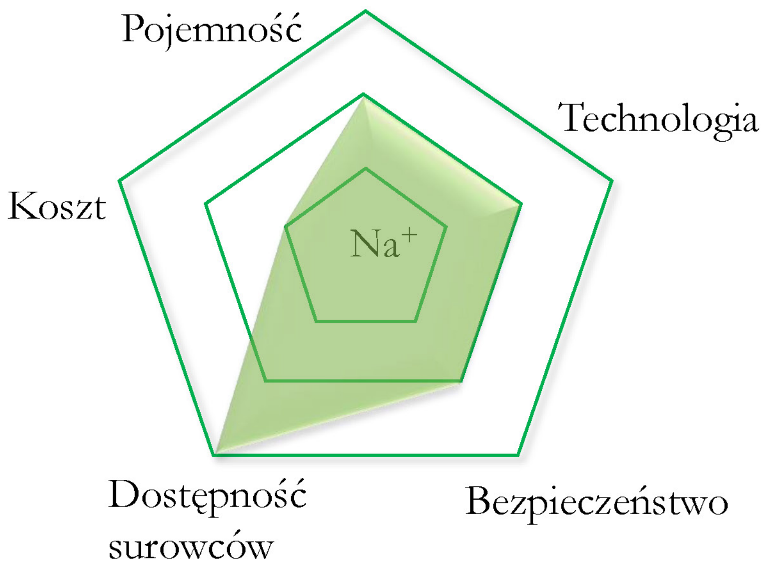
[Solid-State Battery Roadmap 2035+, 2023]

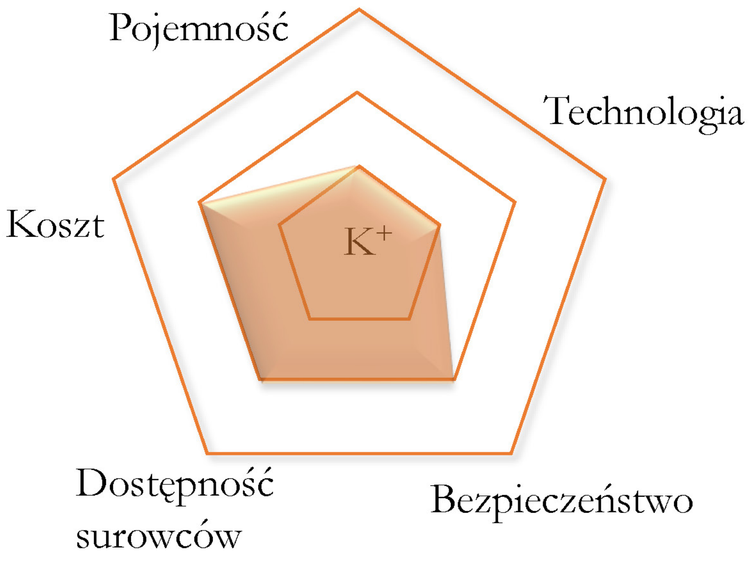
Technologia Me-ion

	Today & Short term	2025	Medium-/long term	2035	Vision
LIB	200–300 Wh/kg, 600–750 Wh/l 90–175 €/kWh		Continuous improvement	320–360 Wh/kg, 800–960 Wh/l 45–90 €/kWh	
SIB	140–160 Wh/kg, 250–300 Wh/l 80–120 €/kWh		Optimizing material combinations	> 200 Wh/kg, > 400 Wh/l < 40 €/kWh	

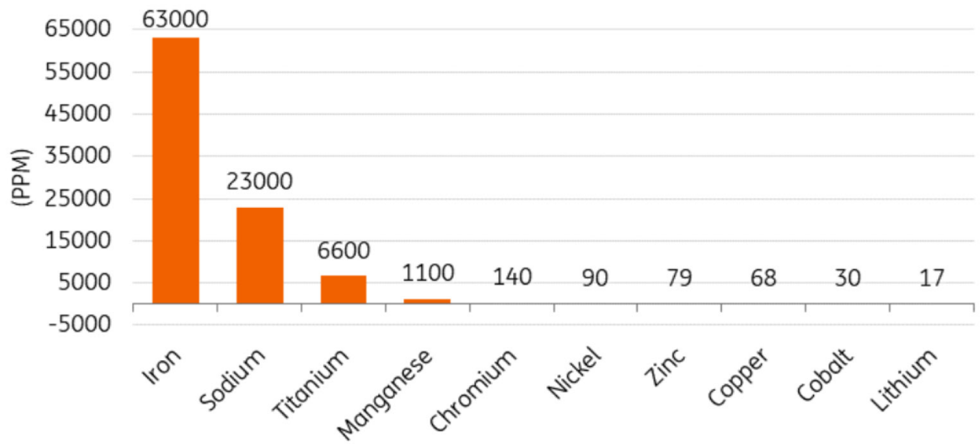
[Fraunhofer ISI, Alternative Battery Technologies Roadmap 2030+ , 2023]

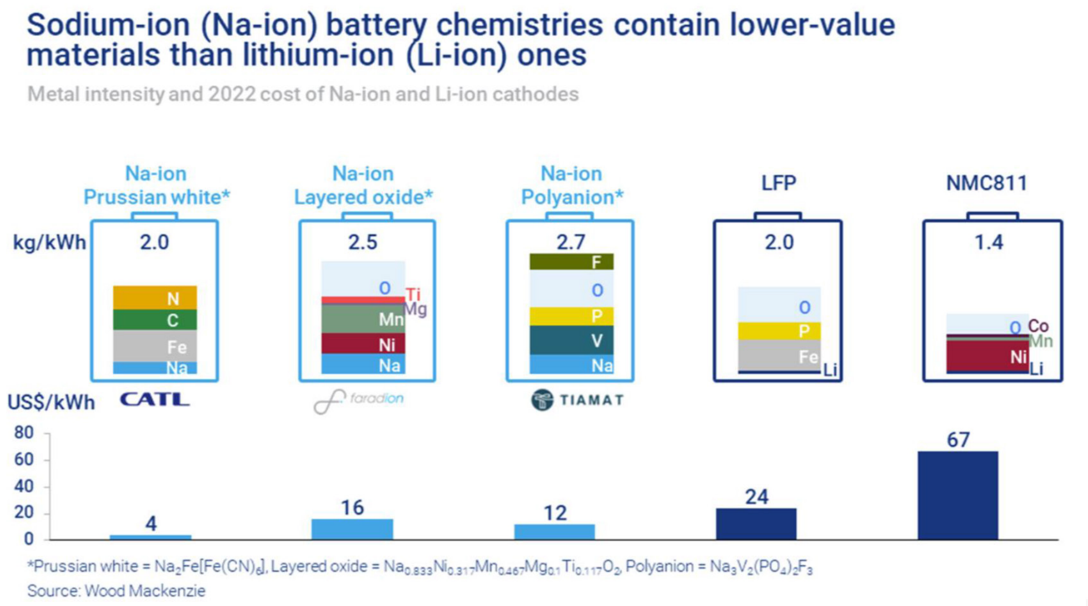


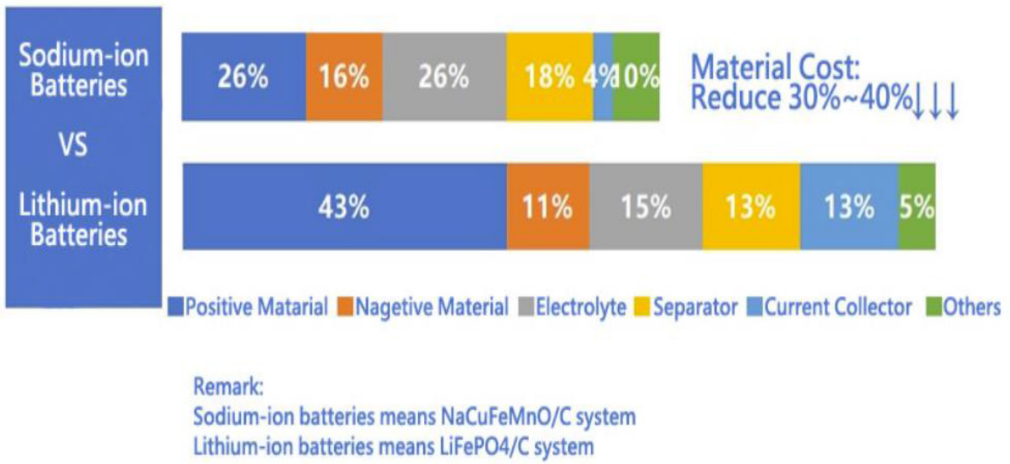




Technologia Na-ion



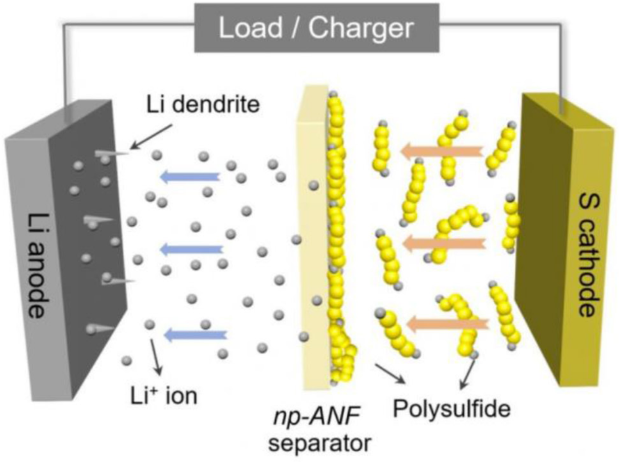


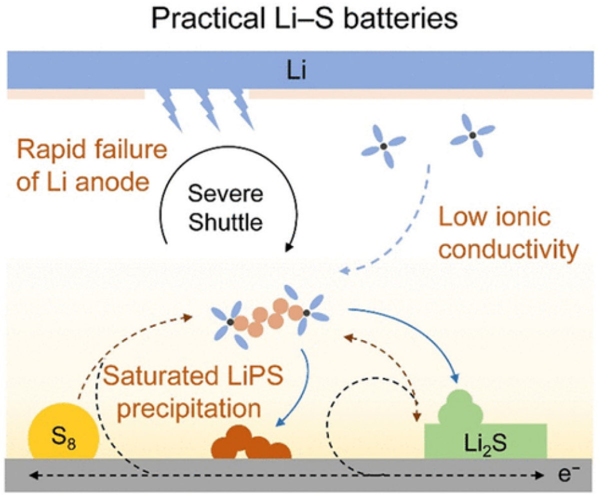


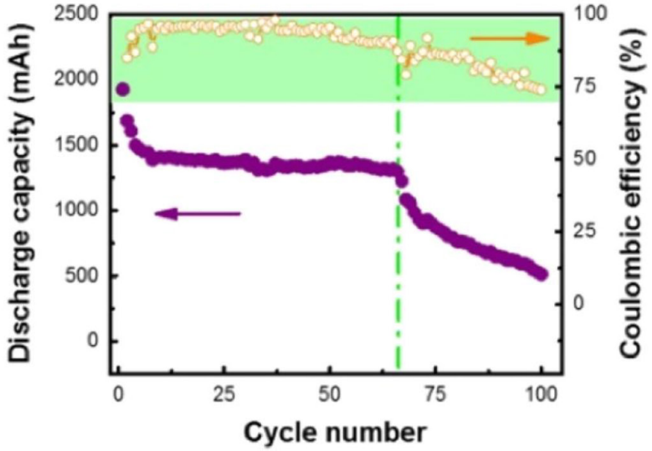
[P. Yadav, V. Shelke, A. Patrike, M. Shelke, Oxford Open Materials Science, 2023, 3(1)]
[M. He, A. Mejdoubi, D. Chartouni, M. Morcrette, P. Troendle, R. Castiglioni, *Journal of Power Sources*, 2023, 588]

Technologia Me-S

		Today & Short term 2025	Medium-/long term	2035 Vision
LIB		200–300 Wh/kg, 600–750 Wh/l 90–175 €/kWh	Continuous improvement	320–360 Wh/kg, 800–960 Wh/l 45–90 €/kWh
Me-S	Li-S	>300 Wh/kg, 300–450 Wh/l	Cycling stability and power density	550 Wh/kg, 700 Wh/l 50 €/kWh
Me-S	Na-S RT	>300 Wh/kg	Multiple challenges especially on cathode and anode side	>350 Wh/kg
Me-S	Na-S HT	180–268 Wh/kg, 300–414 Wh/l, long calendar and cycle lives 300–450€/kWh*	Cost reduction and safety improvements	220–300 Wh/kg, 320–440 Wh/l, long calendar and cycle lives <300 €/kWh*



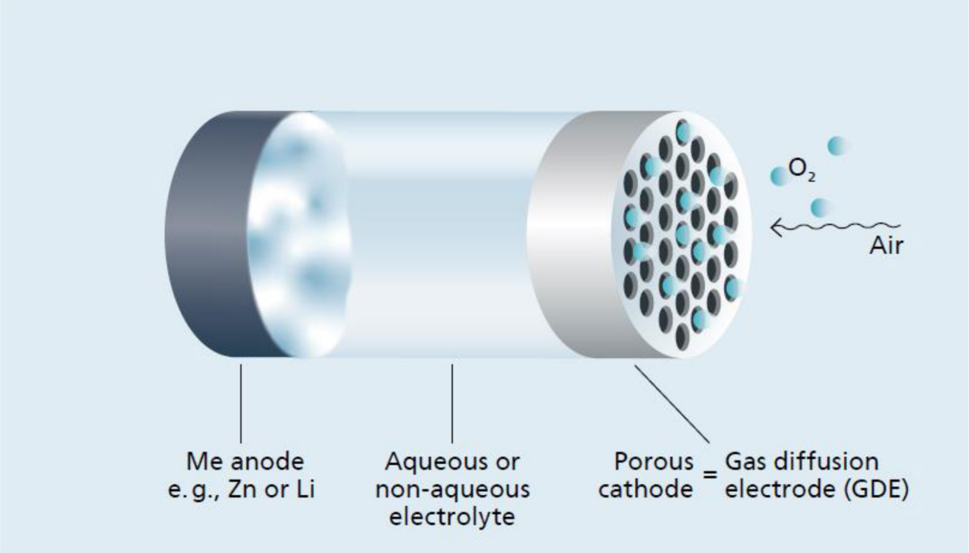




[Alternative Battery Technologies Roadmap 2030+ , 2023]

Technologia Me-air

		Today & Short term — 2025	Medium-/long term	2035 — Vision
LIB		200–300 Wh/kg, 600–750 Wh/l 90–175 €/kWh	Continuous improvement	320–360 Wh/kg, 800–960 Wh/l 45–90 €/kWh
Me-air	Li-air	<= 500 Wh/kg, but with a very low cycling stability	Safety, energy efficiency, unhealthy side reactions	theoretical: 3500 Wh/kg practical: 1230 Wh/kg
	Zn-air	100–200 Wh/kg, only flow design with pot. high cycling stability 100–150 €/kWh	No stable planar cell design, low power performance	200–300 Wh/kg, 2000–14000 cycles 10–100 €/kWh



[Alternative Battery Technologies Roadmap 2030+ , 2023]

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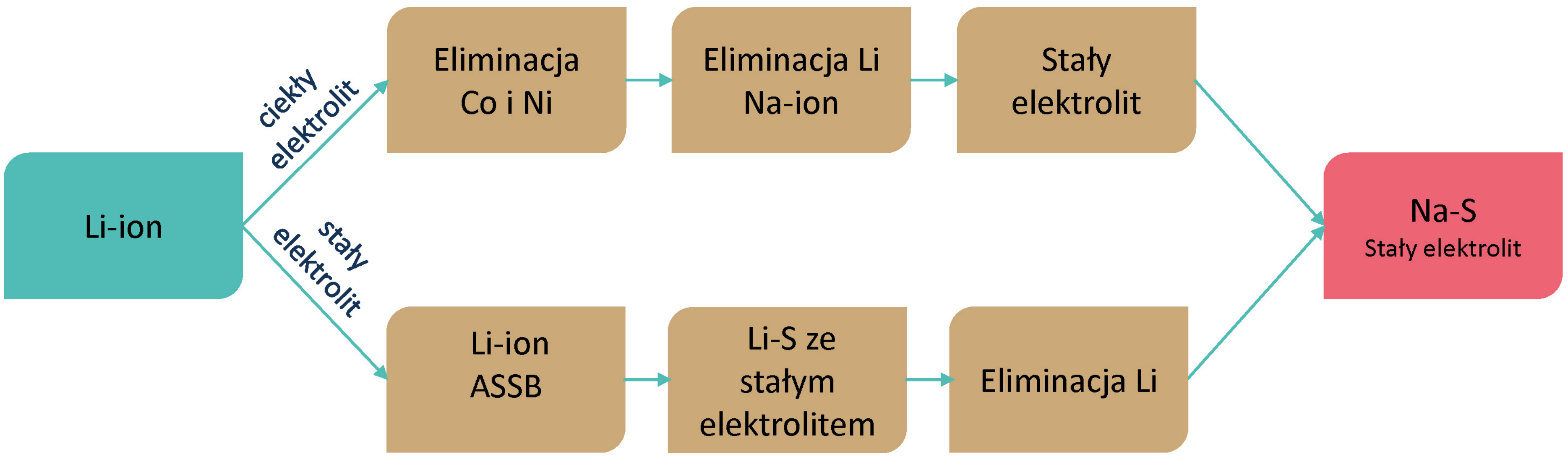
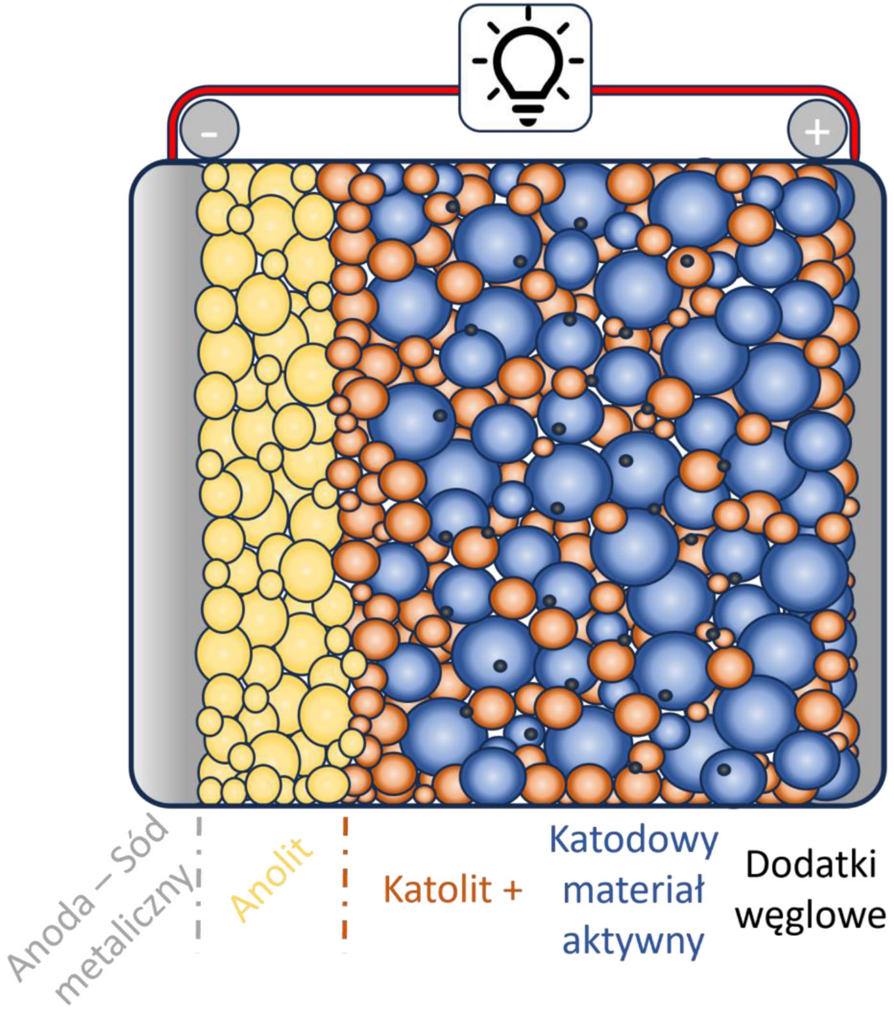


Elektrolity stałe dla ogniw Na-ion bazujące na $NaAlCl_4$



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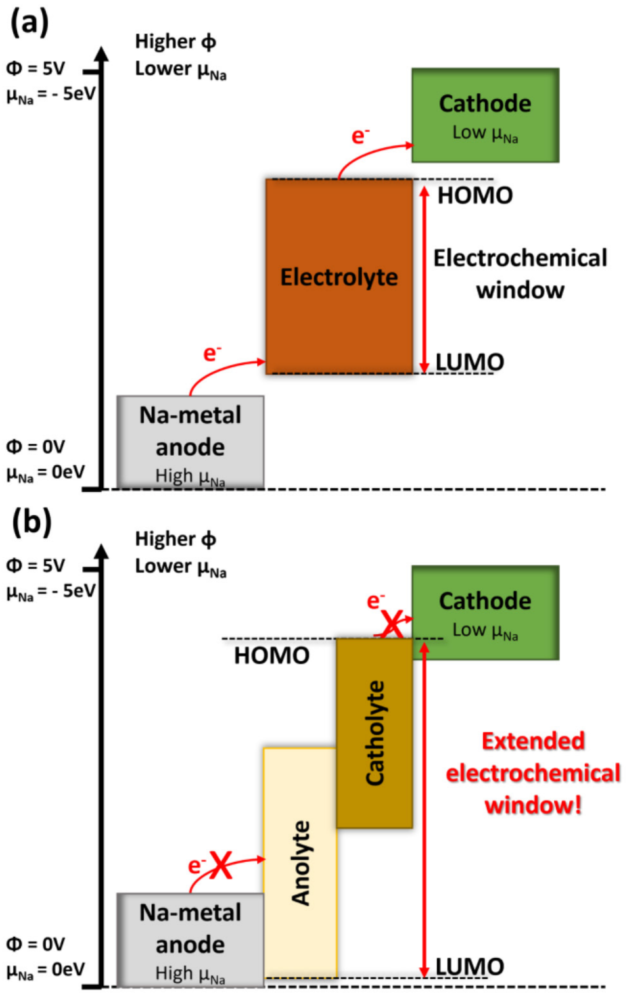

Obecnie znane stałe elektrolity sodowe oparte na halogenkach:

- wszystkie poznane oparte na Er, Y, Zr.
- niskie przewodnictwo

NARODOWE CENTRUM NAUKI

Prace zostały sfinansowane przez Narodowe Centrum Nauki w ramach projektu nr. 2023/51/D/ST11/01287

Dziękuję za uwagę!

IGSMiE PAN

dr inż. Emil Hanc
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