



NOWE KIERUNKI ROZWOJU DLA TECHNOLOGII MAGAZYNOWANIA ENERGII W BATERIACH

dr inż. Emil Hanc

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Polskiej Akademii Nauk

Pracownia Geochemii Stosowanej i Inżynierii Środowiska

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Agenda

2 /22

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

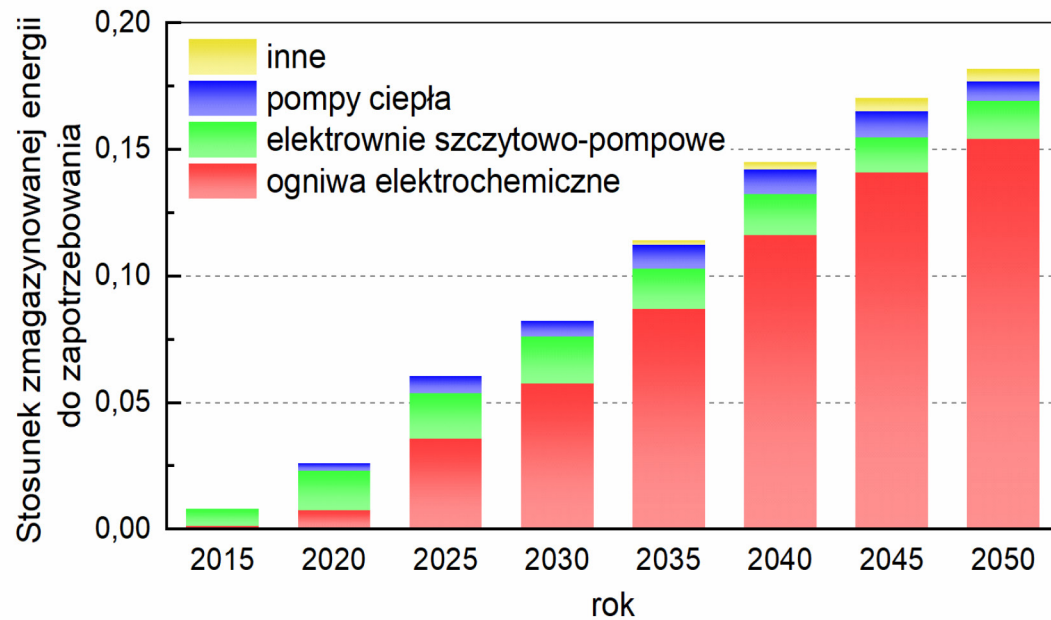
Perspektywy

Kierunki komercyjne

Wizja



Magazynowanie energii



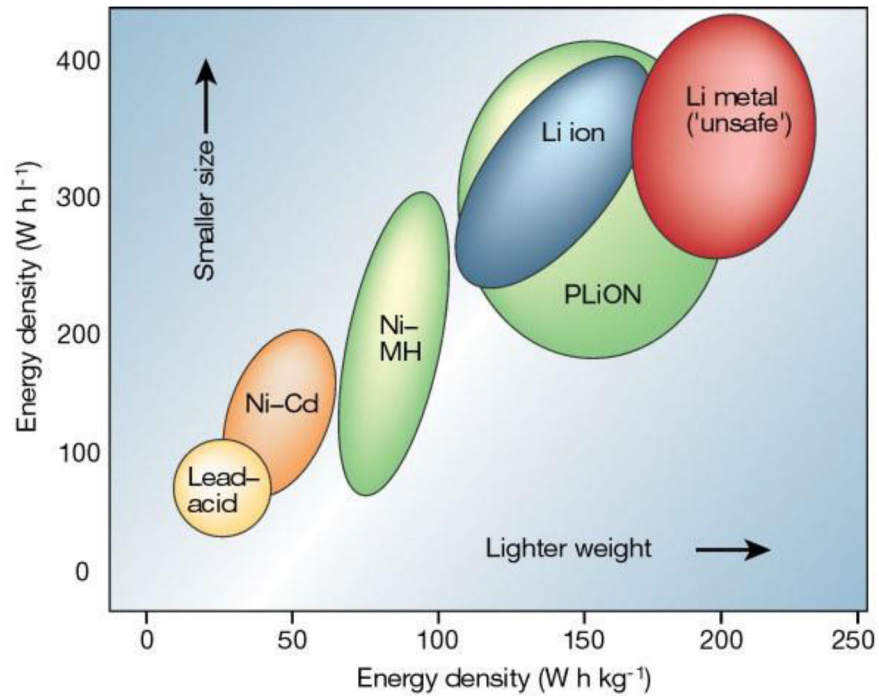
Magazynowanie energii ze źródeł odnawialnych jest szczególnym wyzwaniem a zarazem istotnym elementem zrównoważonej gospodarki energetycznej.

[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

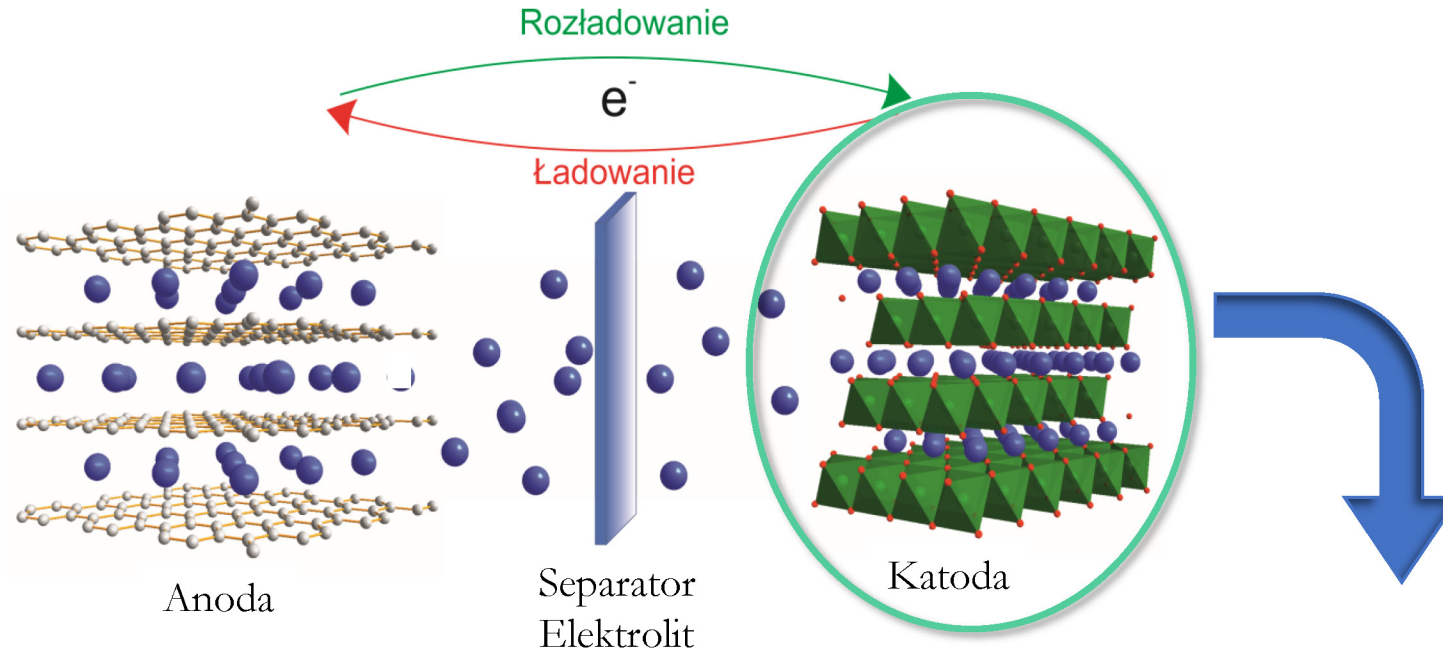


[J.-M. Tarascon, M. Armand, *Nature* 2001, 414, 359]



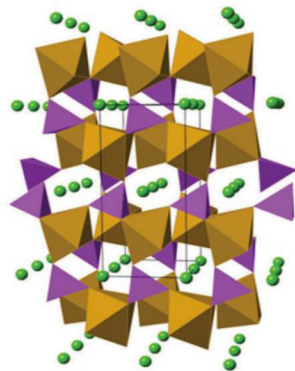


Zasada działania ogniwa Li-ion



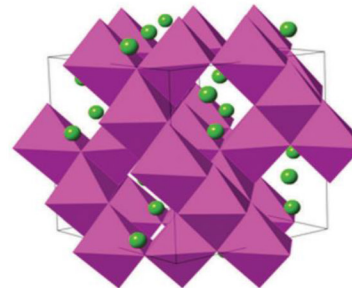
Materiały o strukturze spinelu

LMO LiMn_2O_4



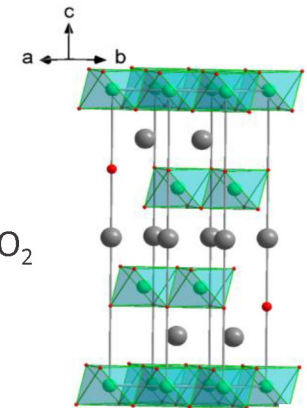
Materiały polianionowe

LFP LiFePO_4



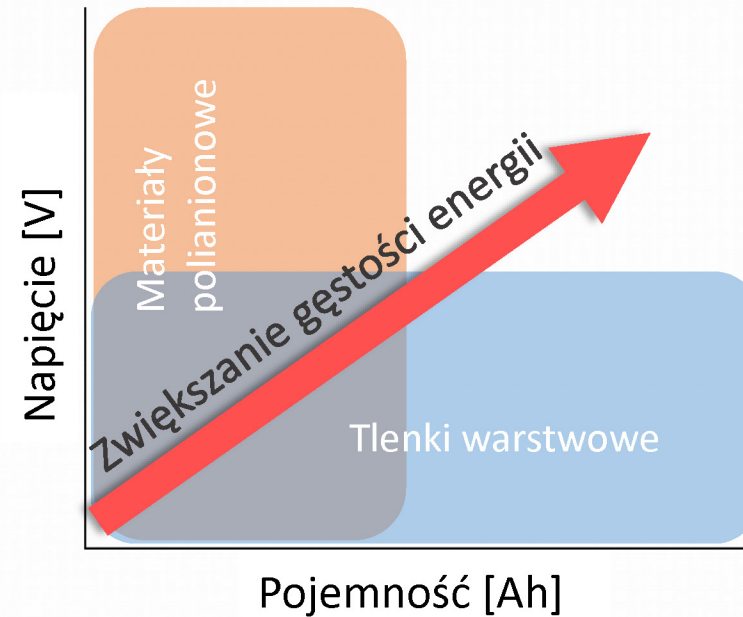
Tlenki warstwowe

LCO LiCoO_2
NMC111(333) $\text{LiNi}_{0.33}\text{Mn}_{0.33}\text{Co}_{0.33}\text{O}_2$
NMC532 $\text{LiNi}_{0.5}\text{Mn}_{0.3}\text{Co}_{0.2}\text{O}_2$
NMC622 $\text{LiNi}_{0.6}\text{Mn}_{0.2}\text{Co}_{0.2}\text{O}_2$
NMC811 $\text{LiNi}_{0.8}\text{Mn}_{0.1}\text{Co}_{0.1}\text{O}_2$
NMC911(955) $\text{LiNi}_{0.9}\text{Mn}_{0.05}\text{Co}_{0.05}\text{O}_2$





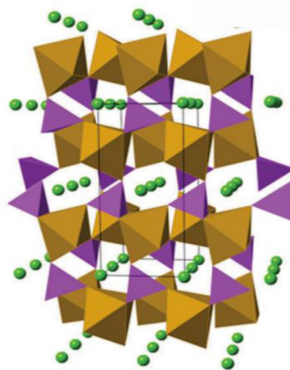
Zasada działania ogniwa Li-ion



Rozwój ogniw Li-ion bazował na rozwoju materiału katodowego

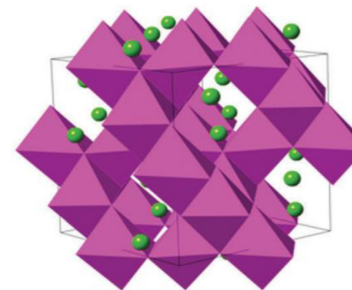
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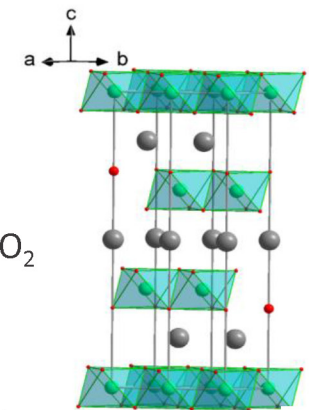
Materiały polianionowe

LFP LiFePO_4



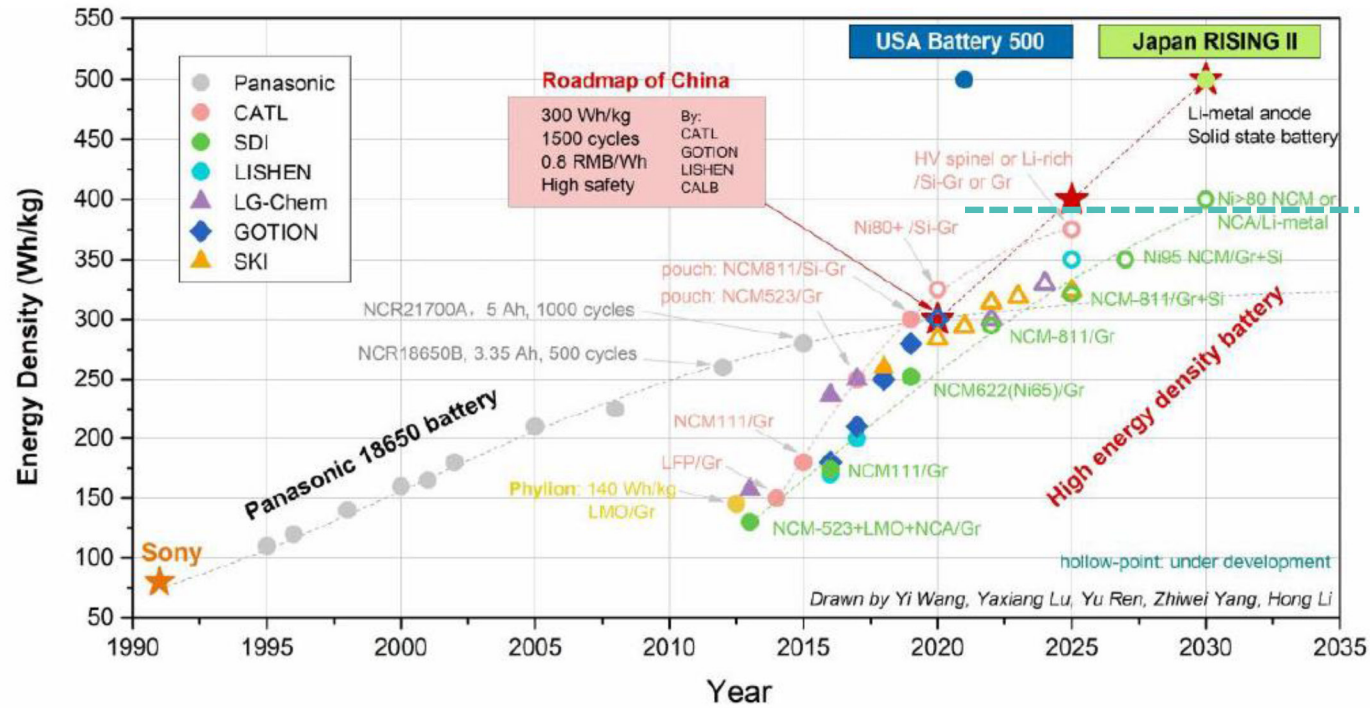
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Technologia Li-ion rozwój



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

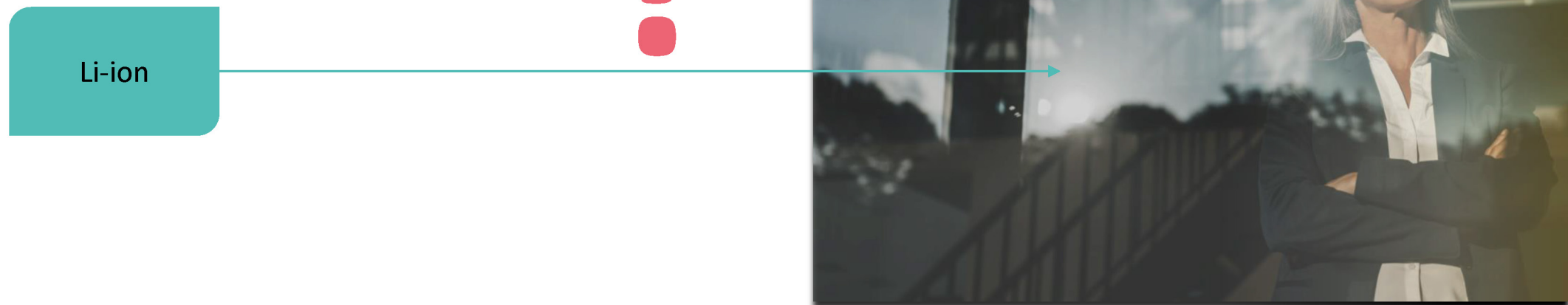


Co dalej?

9 / 22

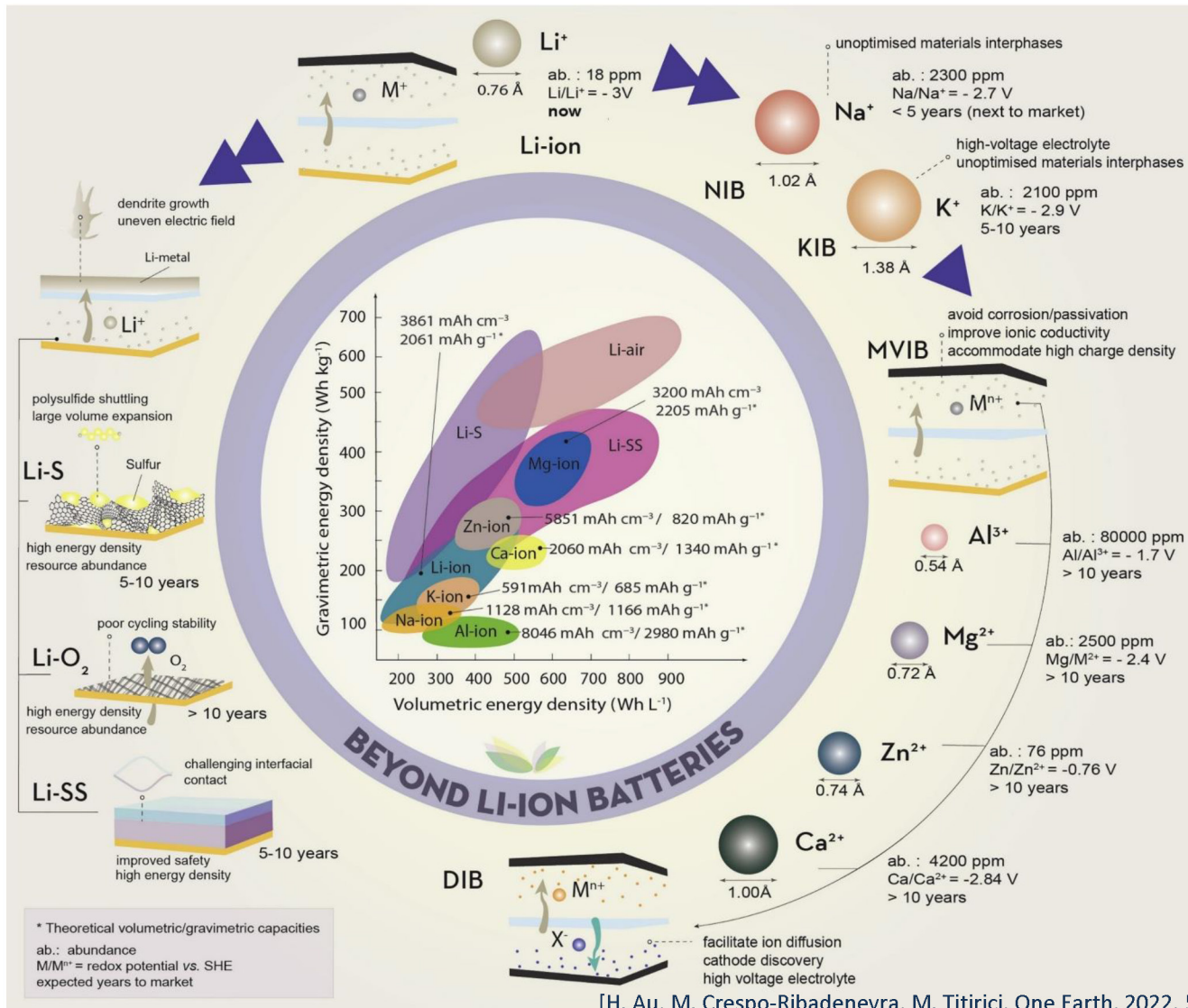
- Dalszy prognozowany znaczny wzrost cen surowców litowych wymusza poszukiwania alternatywnych technologii, które umożliwiłyby eliminację litu oraz zminimalizowanie użycia surowców kopalnych.

Wizja

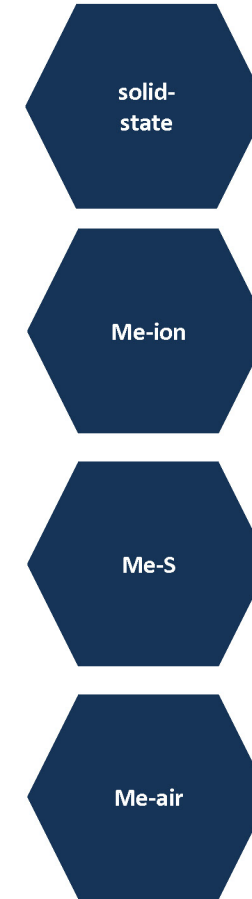




Alternatywy dla obecnej technologii Li-ion



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

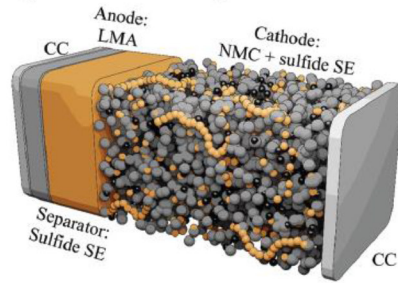




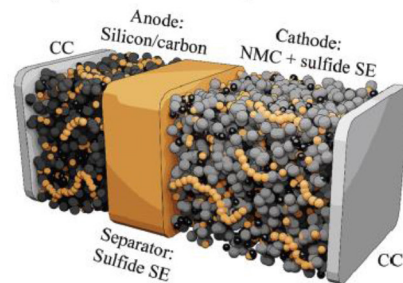
Ogniwa typu solid-state

Nowa architektura ogniwa

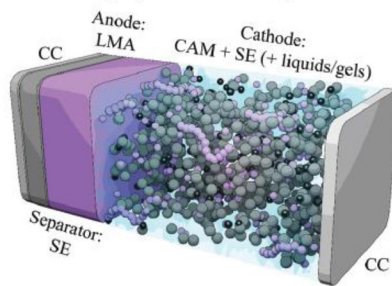
a) Sulfide ASSB concept with Li metal



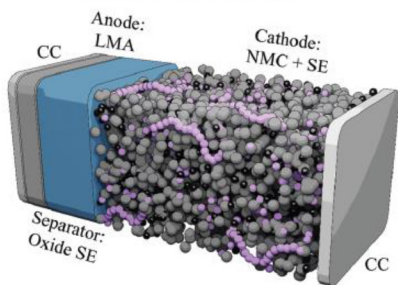
b) Sulfide ASSB concept with Silicon



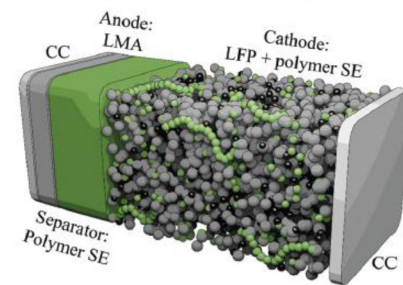
c) Hybrid SSB concept



d) Oxide ASSB concept



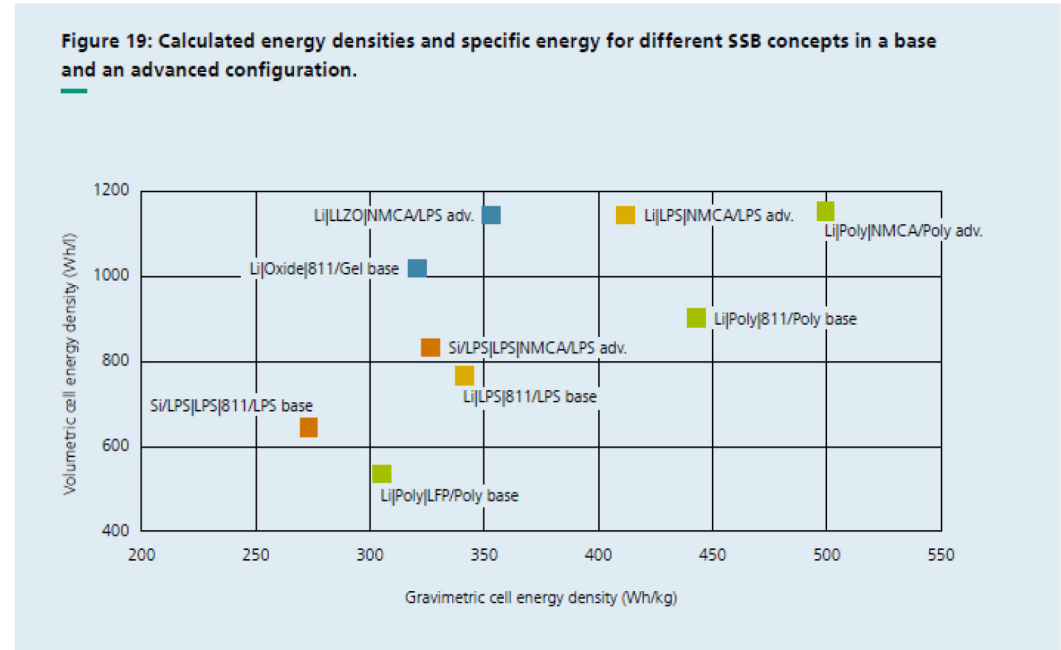
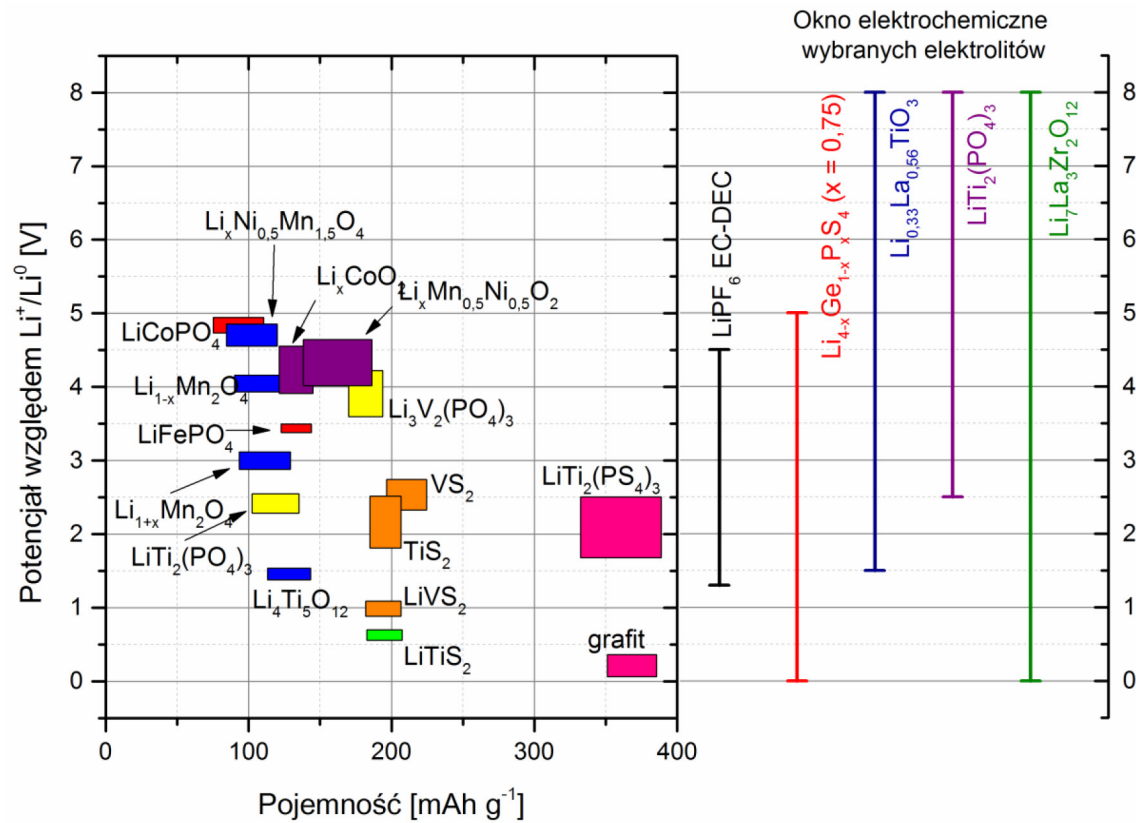
e) Polymer ASSB concept



	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



[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]
Bolloré (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]



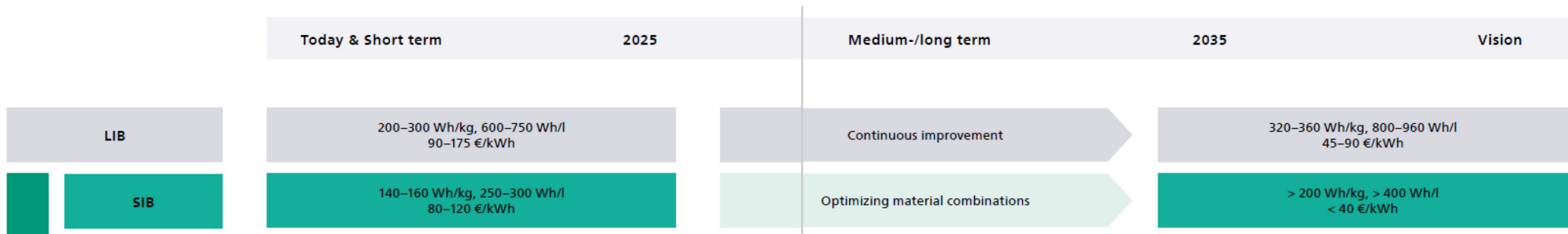
Ogniwa typu solid-state

	2021/22	short term	2025	medium term	2030	long term	2035	vision
Political Goals			EU goal: Gen.3 350–400 Wh/kg, 750–1000 Wh/l cost at pack level < 100 €/kWh			EU goal: Gen.4 400–500+ Wh/kg, 800–1000+ Wh/l cost at pack level < 75 €/kWh		
LIB market	400 GWh		0.5–2 TWh		1–6 TWh		2–8 TWh	
SSB market	< 2 GWh		0–1 GWh 0–5 GWh 2–15 GWh		5–10 GWh 5–15 GWh 5–30 GWh		10–20 GWh 20–50 GWh 10–50 GWh	
SSB applications	Busses	Industrial applications, e.g. AGV	Stationary storage		Industrial heavy duty & harsh environment equipment Passenger cars Autonomous aircrafts (drones) Passenger cars		Trucks Passenger aviation	
Cell integration	Safety aspects of metallic lithium and H ₂ S formation for sulfides in case of accident have to be considered							
	High volume changes have to be compensated → high external pressure required (oxides, sulfides) / small external pressure required (polymers)							
	needs heating to 50–80°C							
KPI LIB	Energy density: 230–300 Wh/kg, 600–750 Wh/l Price: 90–175 €/kWh		Energy density: 250–330 Wh/kg, 650–850 Wh/l Price: 60–130 €/kWh		Energy density: 310–350 Wh/kg, 750–950 Wh/l Price: 45–105 €/kWh		Energy density: 320–360 Wh/kg, 800–960 Wh/l Price: 45–90 €/kWh	
SSB Cell concepts + SSB KPI			[Li metal] / [Oxide SE] / [Gel catholyte, NMC] est. values: 315 Wh/kg, 1020 Wh/l		[Li metal] / [Oxide SE] / [Sulfide SC, NMC]		350 Wh/kg, 1140 Wh/l	
			[Si/C] / [Sulfide SE] / [Sulfide SC, NMC] est. values: 275 Wh/kg, 650 Wh/l				325 Wh/kg, 835 Wh/l	
					[Li metal] / [Sulfide SE] / [Sulfide SC, NMC] est. values: 340 Wh/kg, 770 Wh/l		410 Wh/kg, 1150 Wh/l	
			[Li metal] / [Polymer SE] / [Polymer SC, LFP] 240 Wh/kg, 360 Wh/l		[Li metal] / [Polymer SE] / [Polymer SC, NMC] est. values: 440 Wh/kg, 900 Wh/l		500 Wh/kg, 1150 Wh/l	

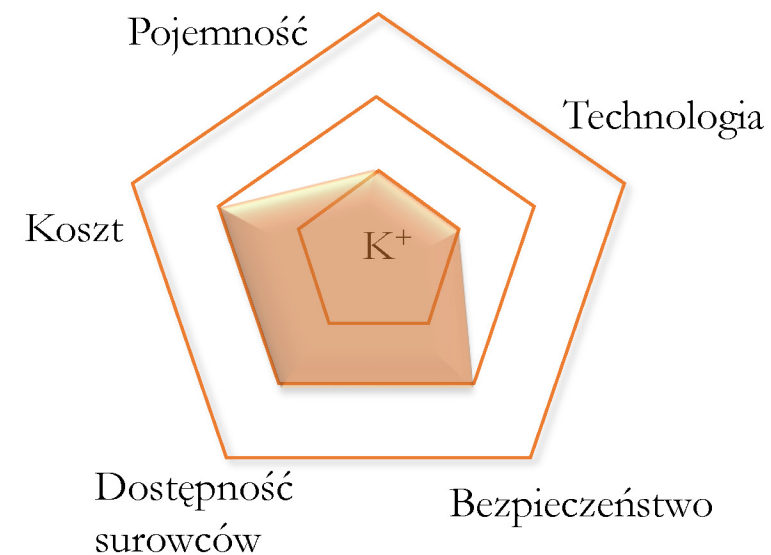
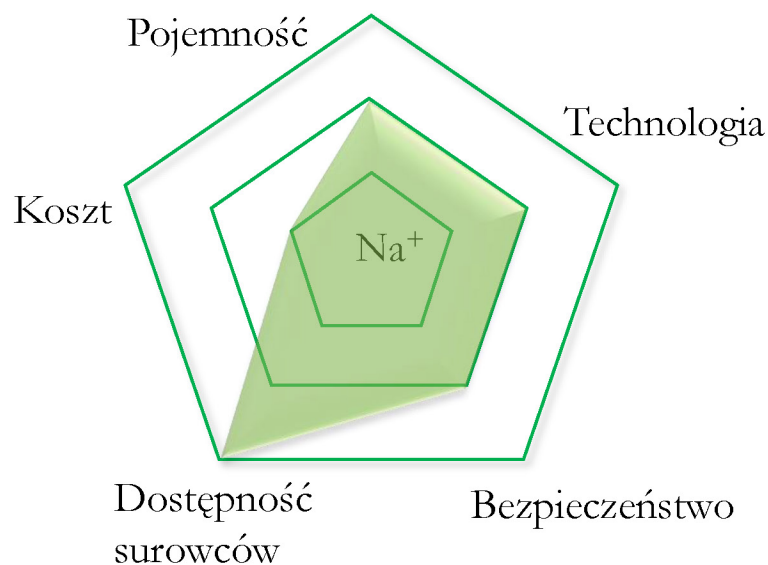
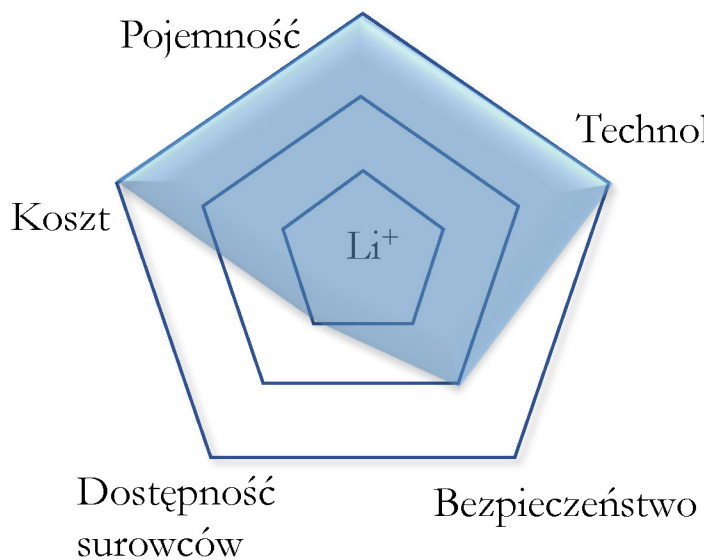
[Solid-State Battery Roadmap 2035+, 2023]



Technologia Me-ion

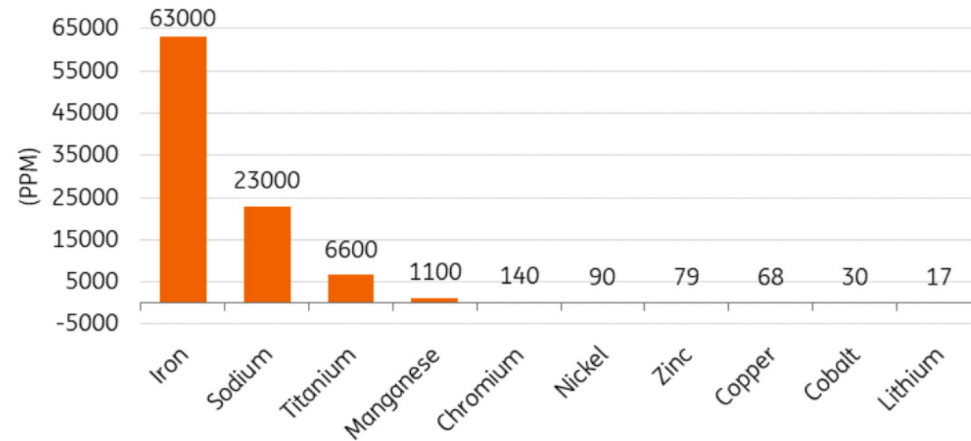


[Fraunhofer ISI, Alternative Battery Technologies Roadmap 2030+ , 2023]



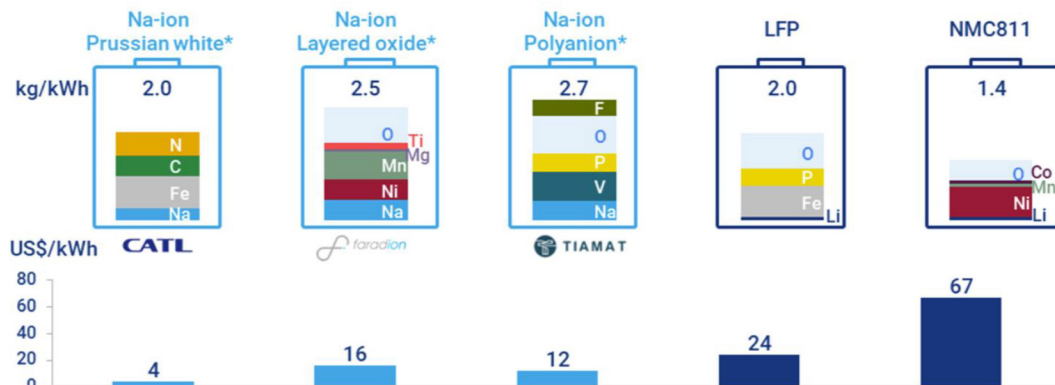


Technologia Na-ion

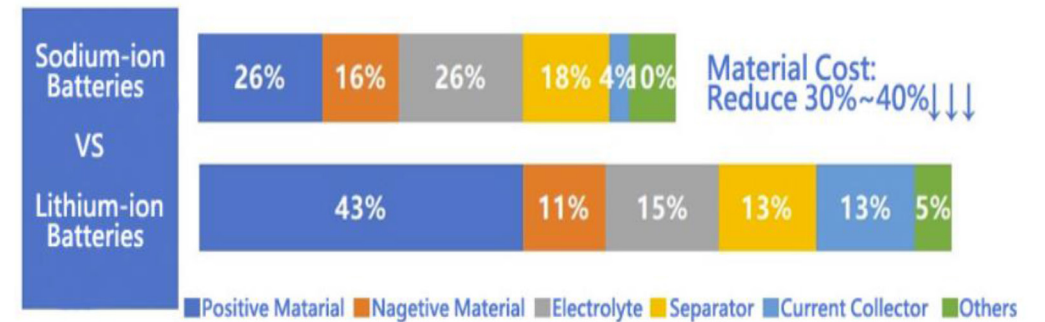


Sodium-ion (Na-ion) battery chemistries contain lower-value materials than lithium-ion (Li-ion) ones

Metal intensity and 2022 cost of Na-ion and Li-ion cathodes



*Prussian white = $\text{Na}_2\text{Fe}[\text{Fe}(\text{CN})_6]$, Layered oxide = $\text{Na}_{0.833}\text{Ni}_{0.317}\text{Mn}_{0.467}\text{Mg}_{0.1}\text{Ti}_{0.117}\text{O}_2$, Polyanion = $\text{Na}_3\text{V}_2(\text{PO}_4)_2\text{F}_3$
Source: Wood Mackenzie



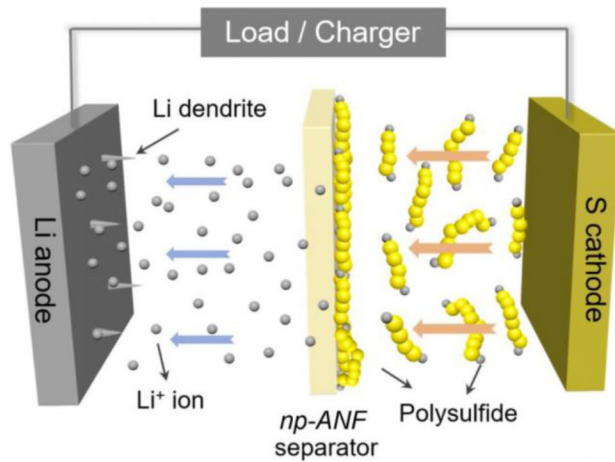
Remark:
Sodium-ion batteries means NaCuFeMnO/C system
Lithium-ion batteries means LiFePO4/C system

[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]

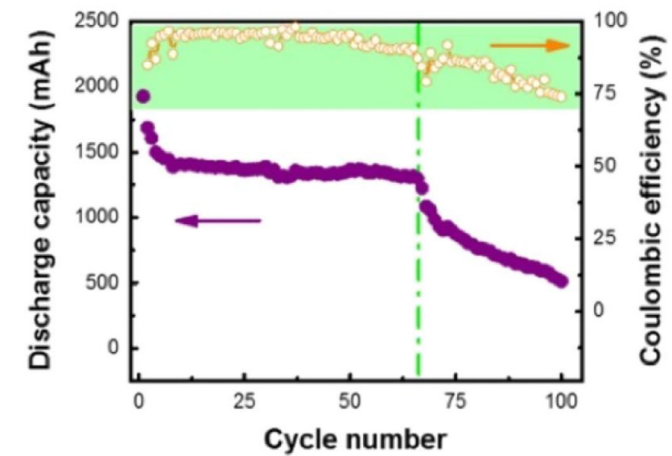
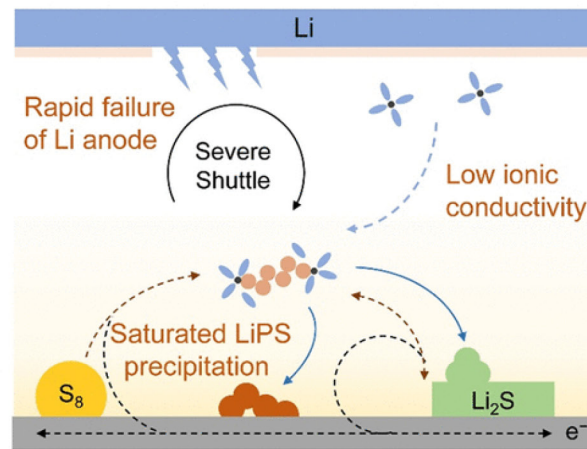


Technologia Me-S

		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
	Na-S RT		>300 Wh/kg	Multiple challenges especially on cathode and anode side		>350 Wh/kg
	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*



Practical Li-S batteries

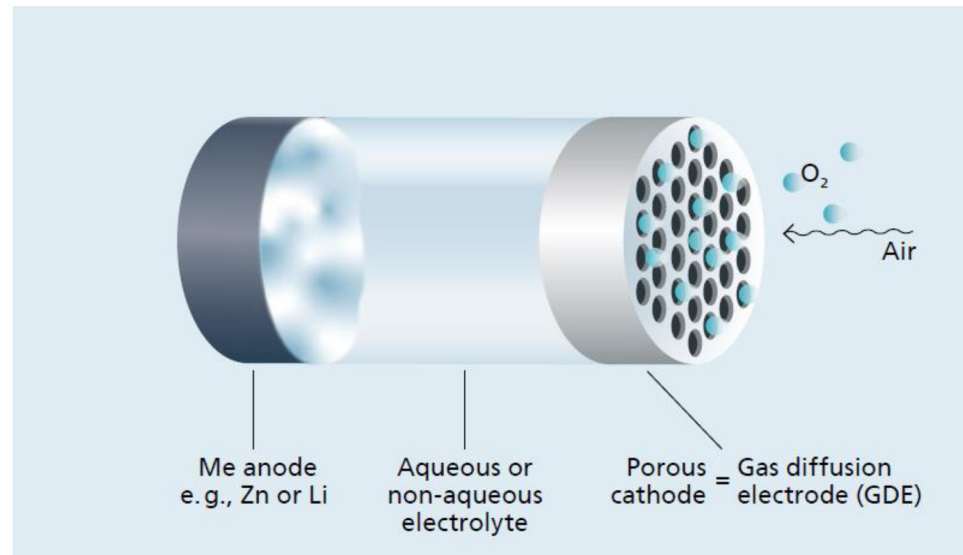


[Alternative Battery Technologies Roadmap 2030+ , 2023]



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]



Co dalej?

19 / 22

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

Wizja

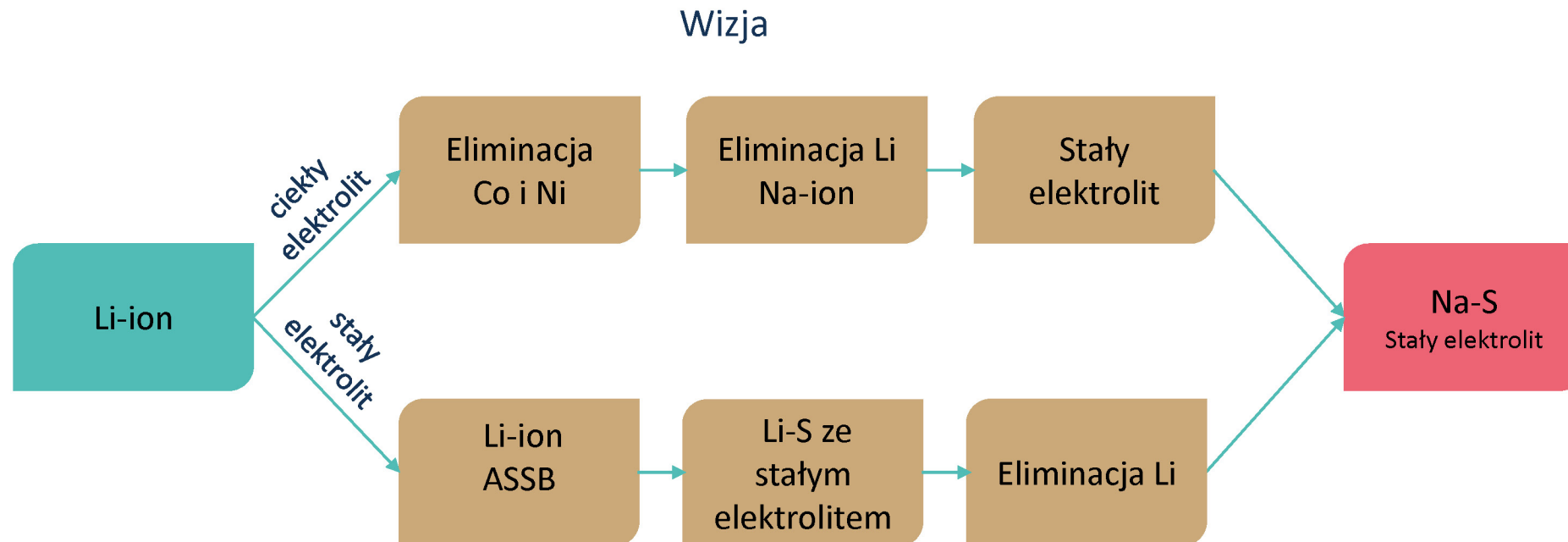




Co dalej?

20 /22

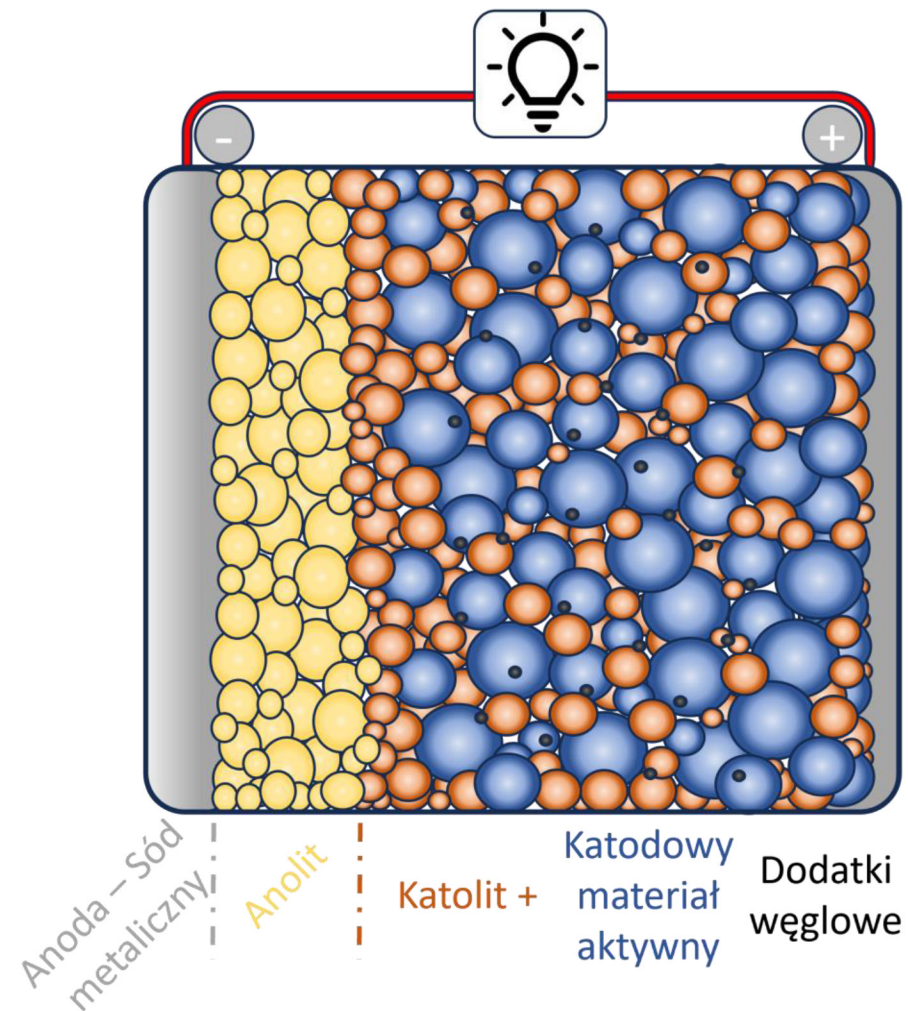
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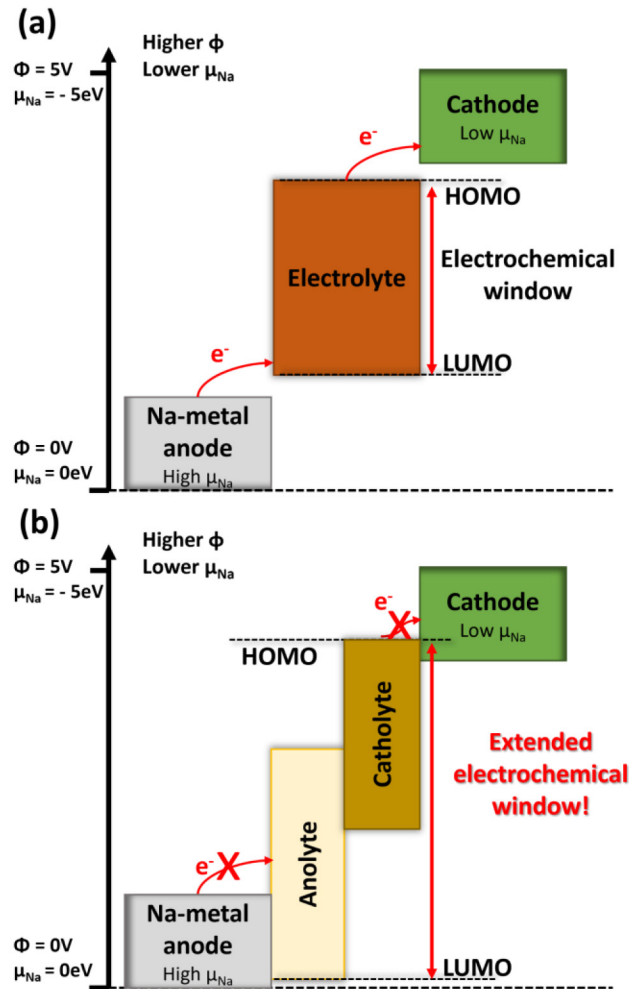
Elektrolity stałe dla ogniw Na-ion bazujące na NaAlCl_4

21 / 22





Elektrolity stałe dla ogniw Na-ion bazujące na NaAlCl_4



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

Instytut Gospodarki Surowcami Mineralnymi
i Energią PAN