The future direction of lithium-ion battery chemistry

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Sydney ICC

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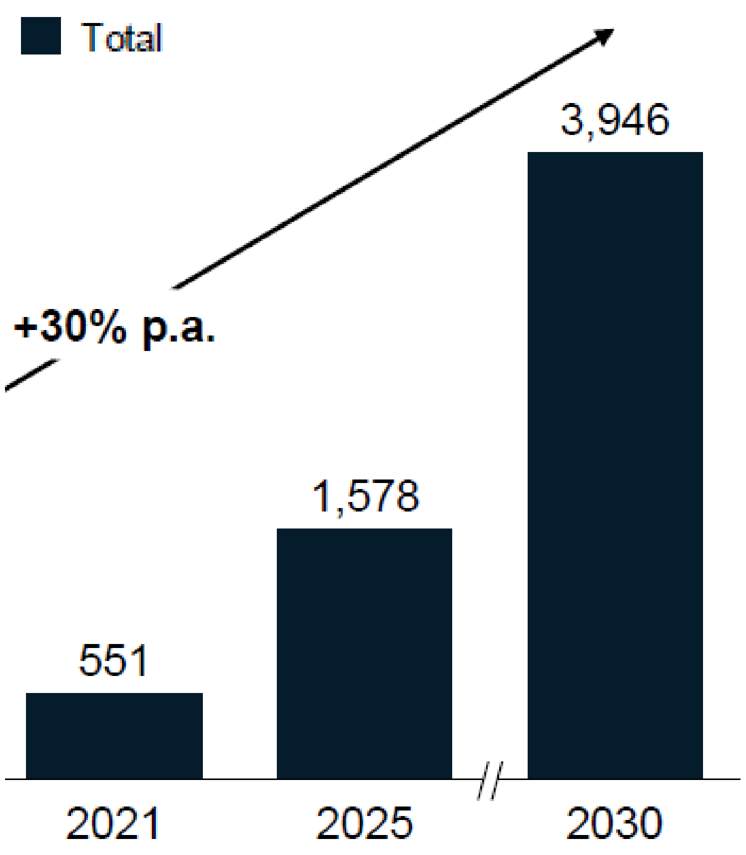
EXHIBITION · TRAINING · NETWORKING

Global lithium-ion battery cell demand (GWh)

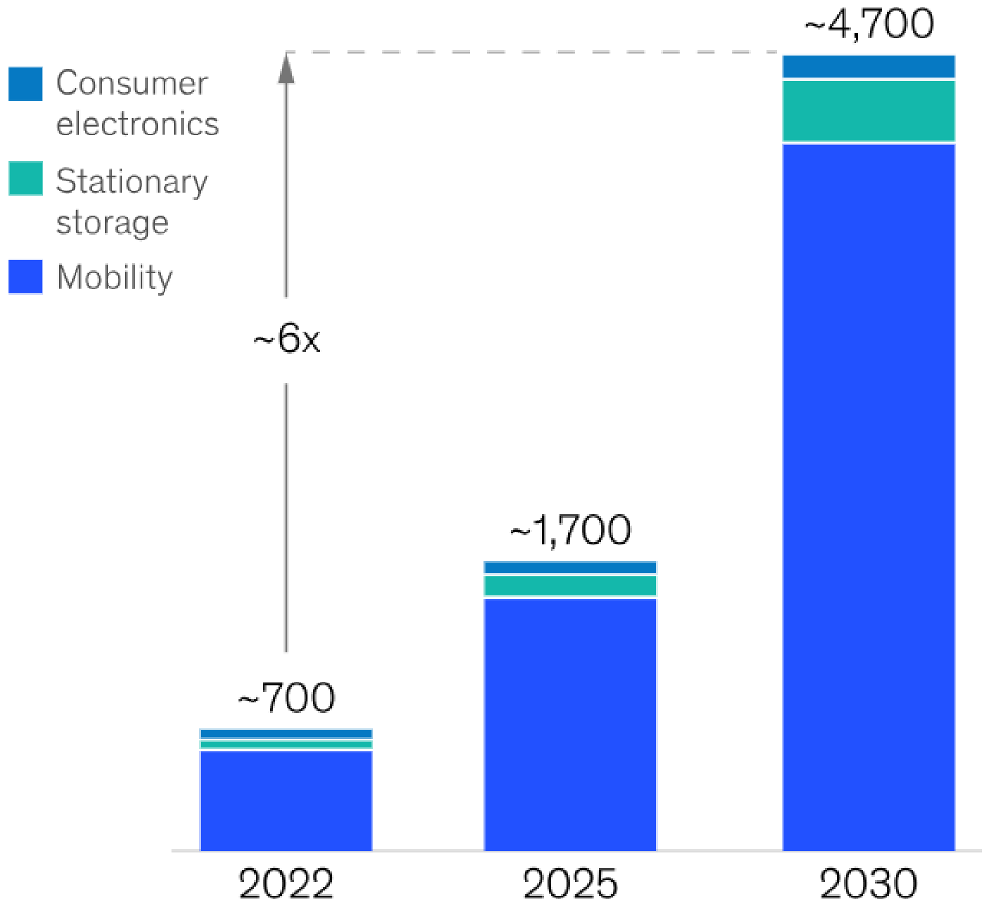
Driven by electrification of transport and energy storage

2022 Projection



Source: *HIS; WEF; McKinsey Battery Demand Model 2022*

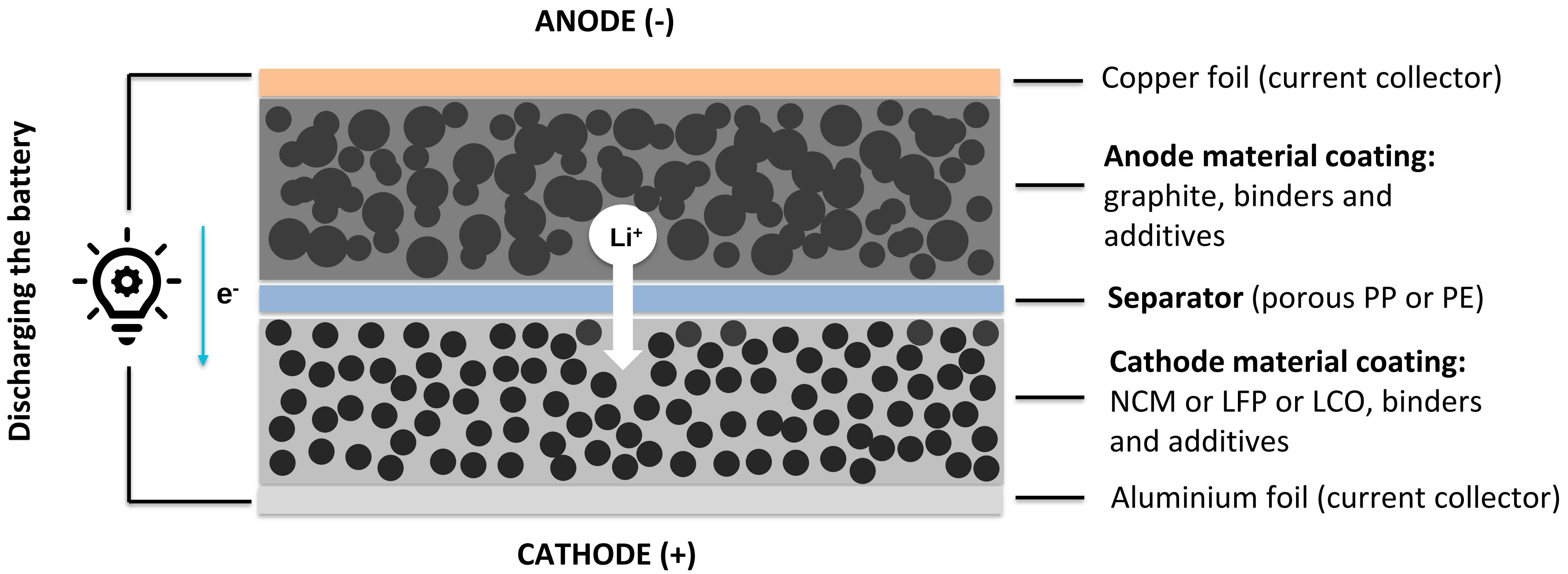
2023 Projection



Source: *McKinsey 2023 - Battery 2030: Resilient, sustainable, and circular*

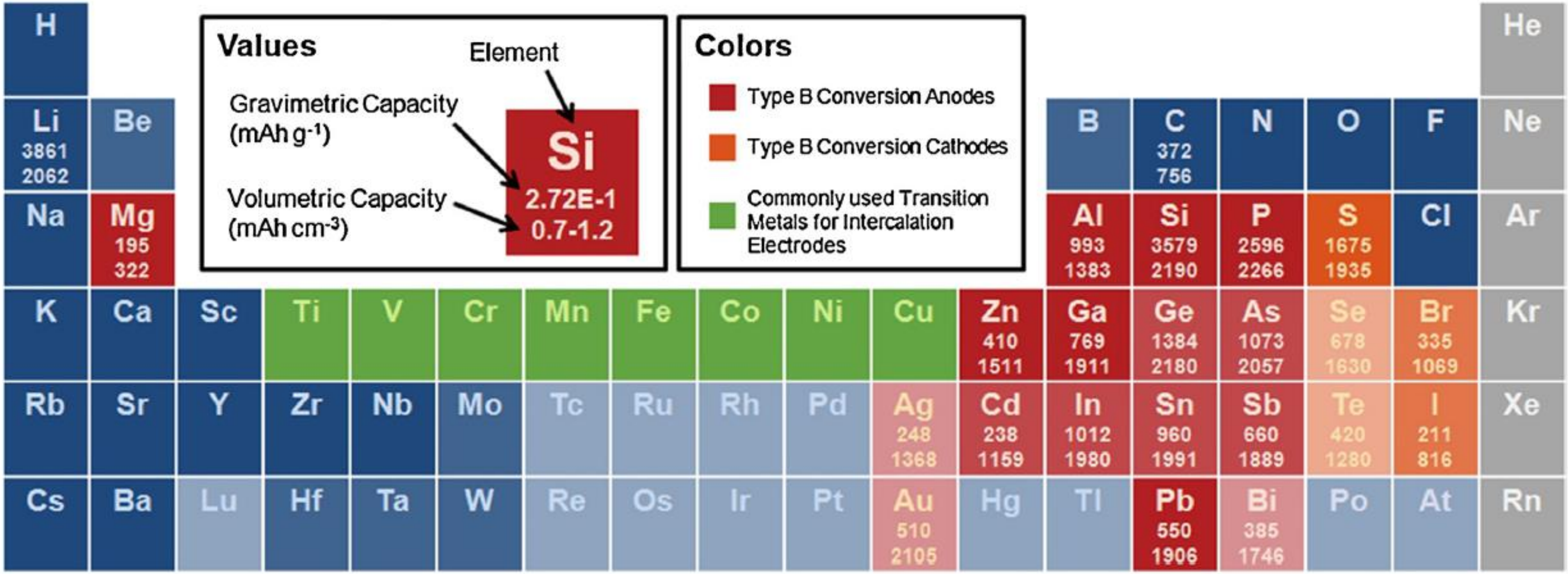
Anatomy of a lithium-ion battery

The most basic electrochemical unit



Battery chemistry – A spectrum of options

Most elements can be used for a form of energy storage

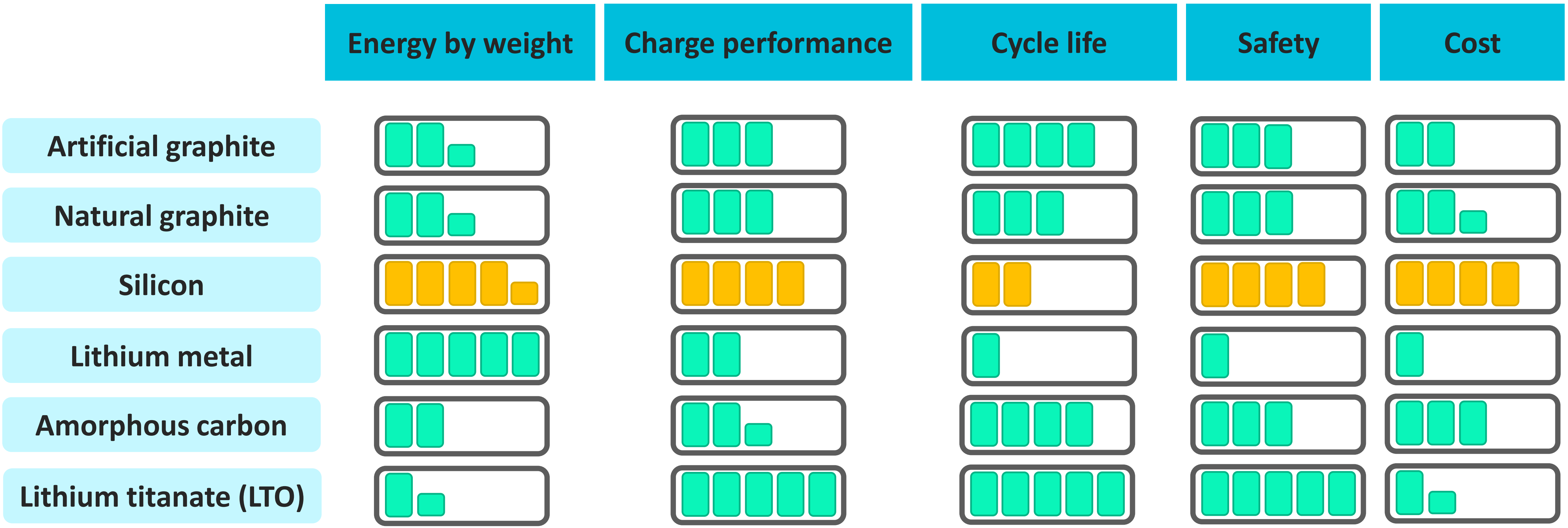


***Source**: Nitta et al., Materials Today Volume 18, Number 5 June 2015*

The anode (-)

Different anode materials can have very different characteristics across several metrics

Silicon and lithium metal's cycle life can be enhanced by use of appropriate enabling technologies

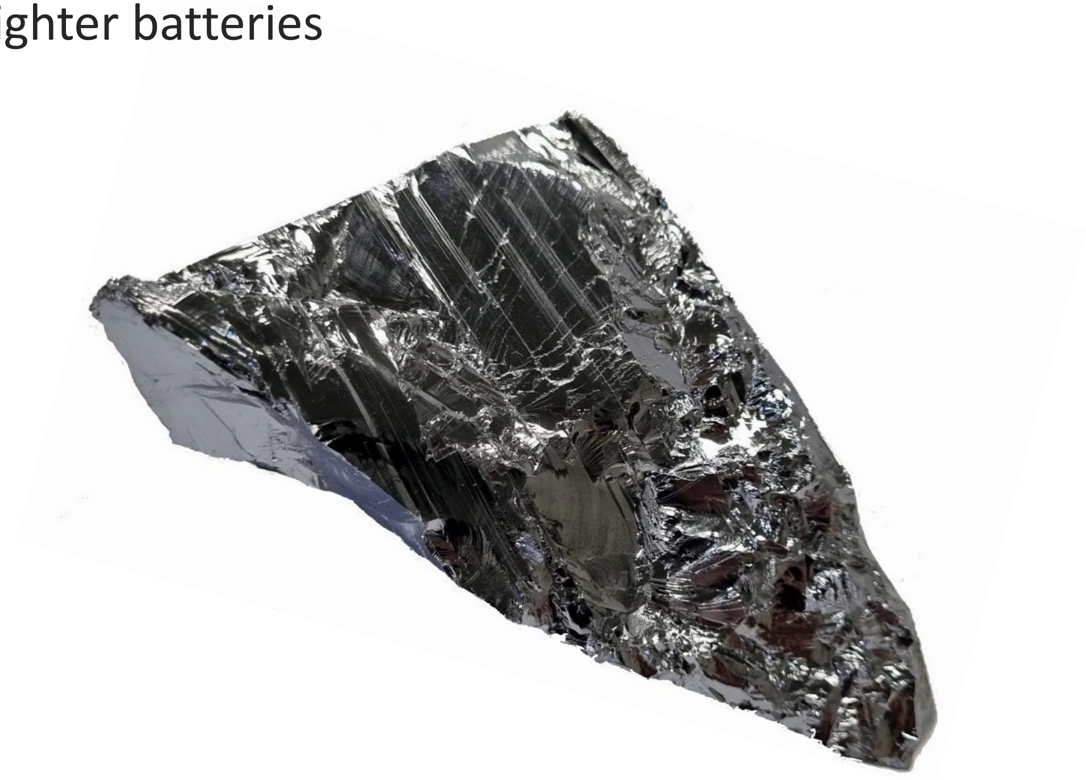


Why silicon?

Silicon stores close to 10x more Li^+ by weight and 3x more Li^+ by volume

Near term opportunity to develop cheaper, smaller and lighter batteries

VS



^{4}**C** - Graphite

371 mAh/g

^{14}**Si** - Silicon

3,579 mAh/g

AnteoTech

CLEAN ENERGY TECHNOLGY DIVISION

SILICON

‘Enabling technology for smaller, lighter and cheaper batteries’

AnteoTech – Pure silicon anode

Combining know how and complementary technologies to provide a step change in battery performance

500+ charge / discharge cycles
demonstrated whilst retaining 90% of the initial capacity in pure silicon anode

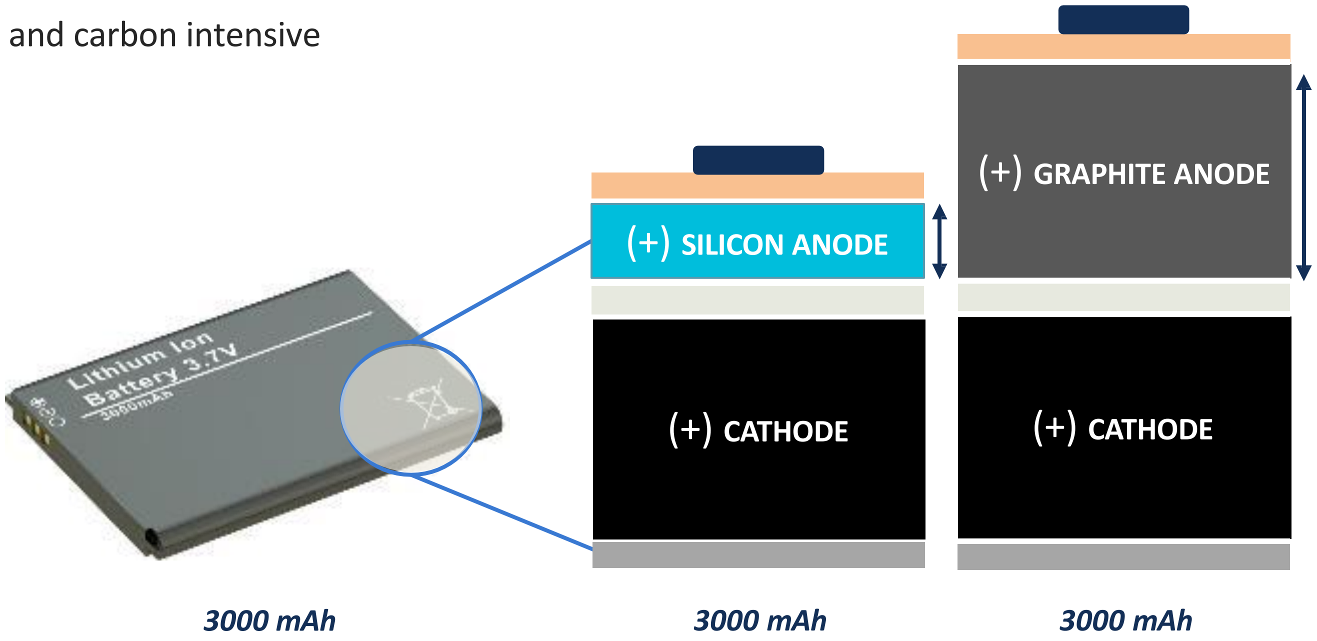
Low grade, unrefined silicon
competitors use super refined silicon - expensive, limited and carbon intensive

8.5x cheaper
active material on a $/kWh basis

35% improvement
in energy capacity

3x thinner
and also lighter

Silicon anodes can make batteries smaller, lighter and cheaper



The cathode (+)

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- Complex metal oxides
  - **1979:** R&D on lithium-ion batteries commences using LCO
  - **1991:** First LIB is commercialized by Sony (Coke/LCO)
  - **1996:** Lithium manganese oxide (LMO) is commercialized
  - **1996:** Lithium iron phosphate (LFP) is discovered
  - **1999:** Lithium nickel cobalt aluminium oxide (NCA) is discovered
  - **2000:** Nickel manganese cobalt chemistries (NMC) appear
- Further development of chemistry categories
  - **Higher Nickel** content in NMC to drive up capacity
  - **Higher Manganese** content in NMC to drive higher voltages
  - **LMFP:** Manganese introduction into LFP to drive to higher voltages
- Possible future cathode chemistries
  - **Sulfur** and possibly Air (**O_2**)

STANDARD

ADVANCED

NEW

CATHODE CHEMISTRIES

The NCM family of materials

Early NCM variants (past)

NCM 111 - Discharge capacity: ~ 150 mAh/g
NCM 523 - Discharge capacity: ~ 165 mAh/g

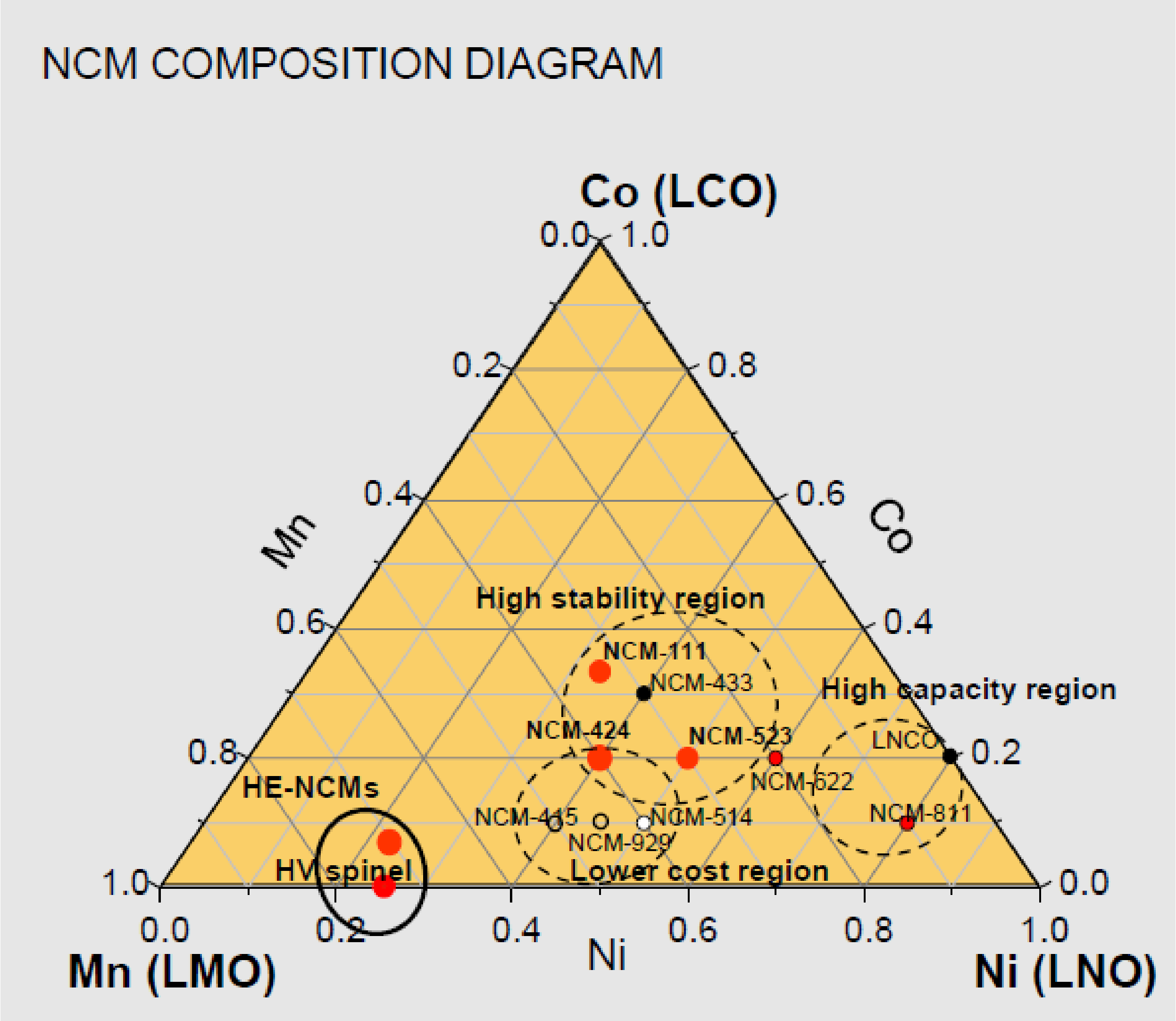
Nickel rich variants (now)

NCM 622 - Discharge capacity: ~ 175 mAh/g
NCM 811 - Discharge capacity: ~ 200 mAh/g

Manganese rich variants (future)

HE-NCM - Discharge capacity: > 250 mAh/g
HV-Spinel - Discharge capacity: ~ 140 mAh/g

Wh = **Ah***V vs. Ah***V**



Source: *BASF, 2014*

Beyond lithium-ion

Solid-state batteries

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- Conventional lithium-ion battery electrolytes consist of a mixture of flammable and toxic solvents
  - Electrolyte fills pores in anode, cathode and separator
  - Transports lithium ions between the two electrodes

- Solid-state electrolyte systems

Polymers PEO + additives	Oxides Perovskite, NASICON, Garnet	Sulphides Sulphide glasses & ceramics, Agryodite
+ Easy to scale & cost-effective processing + Good interfacial compatibility + Highly flexible	+ Good ionic conductivity + High strength but brittle + Good safety (thermal stability)	+ Highest ionic conductivity + Good interfacial compatibility + Reasonably scalable
- High operating temperatures required - Lowest ionic conductivity - Limited energy density improvement	- Poor interfacial compatibility (resistance) - Difficult to scale for mass manufacturing - High sintering temperatures required	- High reactivity with water and air - High cell pressure required for performance - Can generate toxic byproducts (H_2S)

Solid-state electrolytes and batteries

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	Claim	Practical consideration
Safety	• No flammable electrolyte leads to better safety and thermal stability	• Higher energy density paired with pure lithium metal as the anode does not necessarily mean better safety
Energy density	• Solid state electrolytes enable higher energy densities	• Without changing to a different anode and cathode chemistry gravimetric energy density would be reduced
Power capability (Charge)	• Fast charging is advertised by some companies as a feature of solid-state batteries	• Most solid-state chemistries struggle to deliver fast charge performance based on interface issues and lower ionic conductivities at room temperature
Manufacturing at scale	• Fewer manufacturing steps lead to a reduction in cost	• Processing steps are generally more complex and may require additional high temperature sintering steps and inert gas conditions paired with high capital investment
Battery cost	• Simplified battery pack cooling (heating as opposed to cooling) and protection packaging	• Battery pack heating requires re-engineering of end application while solid-state batteries generally require higher pressure to work well

Lithium - Metal oxide cathode

^{3}**Li** - Lithium

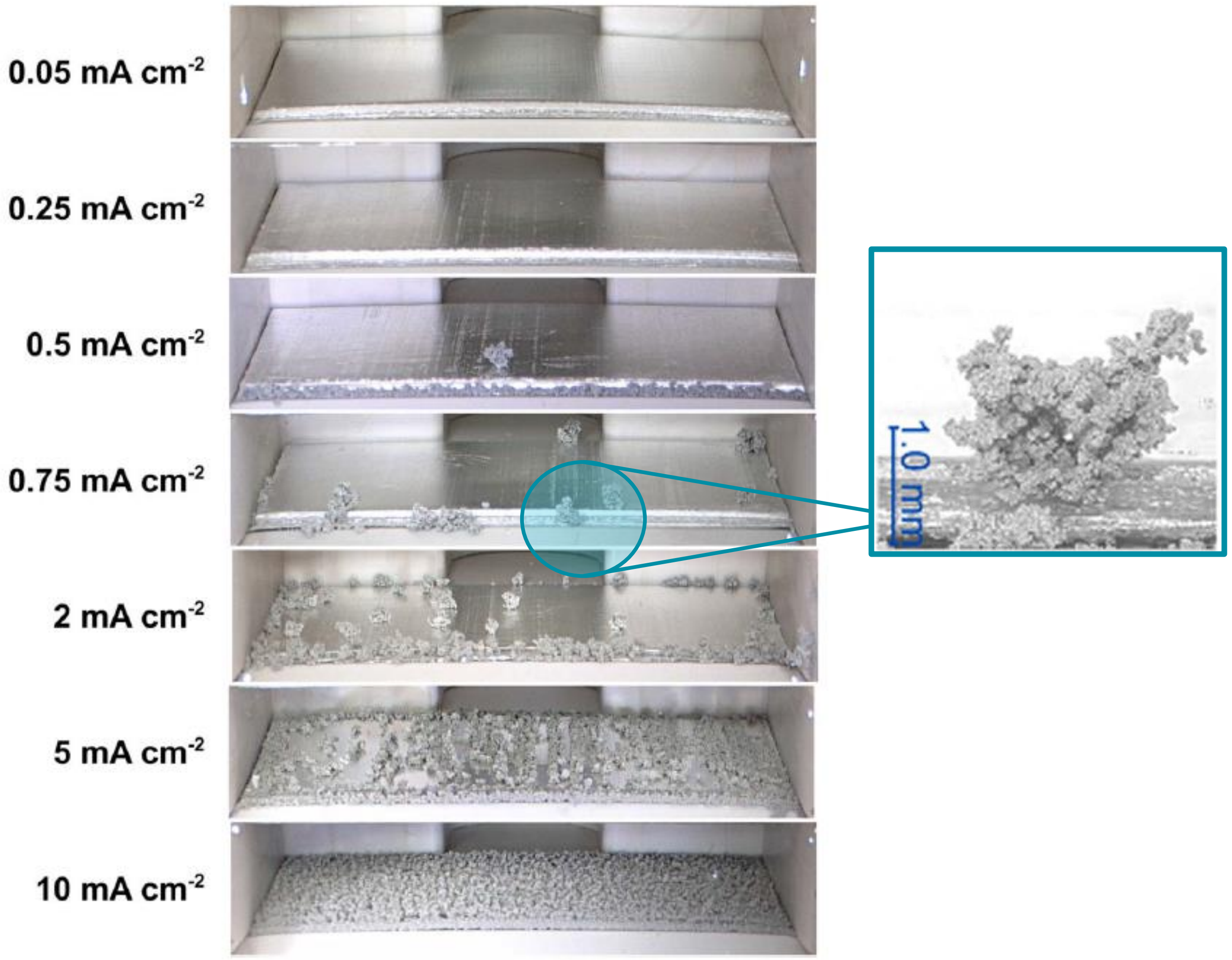
3,860 mAh/g

Metal oxides (NCM)

200+ mAh/g

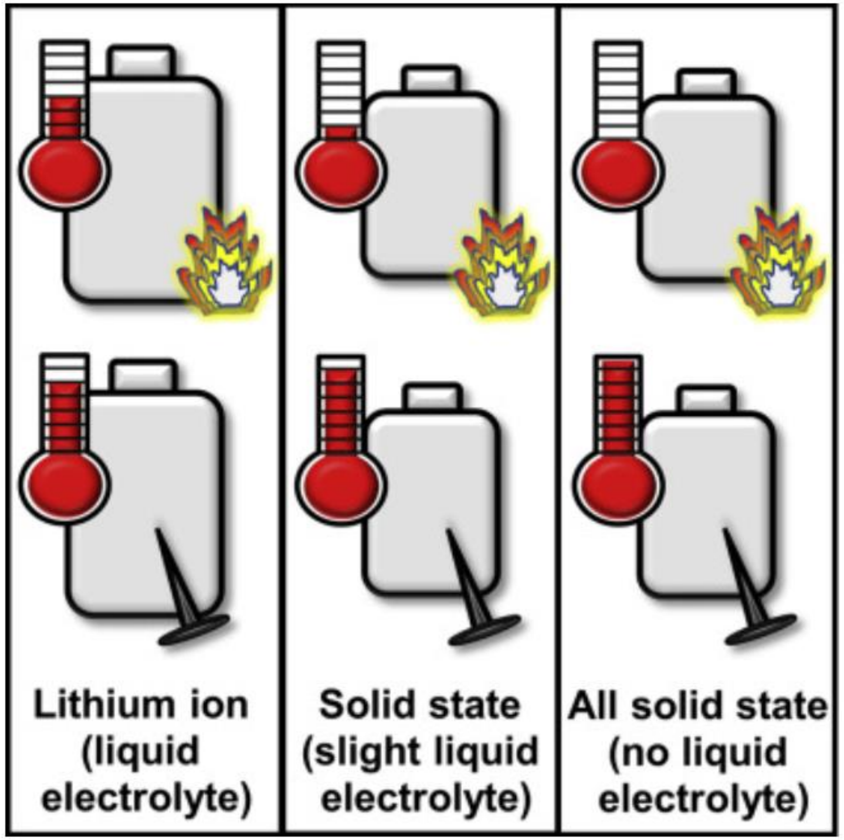
Lithium - Metal oxide cathode

Dendrite formation and controlled lithium deposition are key challenges



Source: *Kuehnle et al., Journal of the ECS, Vol 169, 2022*

External heating failure vs. Internal short-circuit vs. Nail penetration test



Source: *Bates et al., Joule, Vol 6, 2022*

Lithium - Sulfur

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^{3}**Li** - Lithium

3,860 mAh/g

^{16}**S** - Sulfur

1,675 mAh/g

Lithium - Sulfur

Targeted benefits

- High specific capacity: 1675 mAh/g (theoretic)
- Very light weight cells (promises cells with >400 Wh/kg)
- No heavy metals in cathode

Challenges

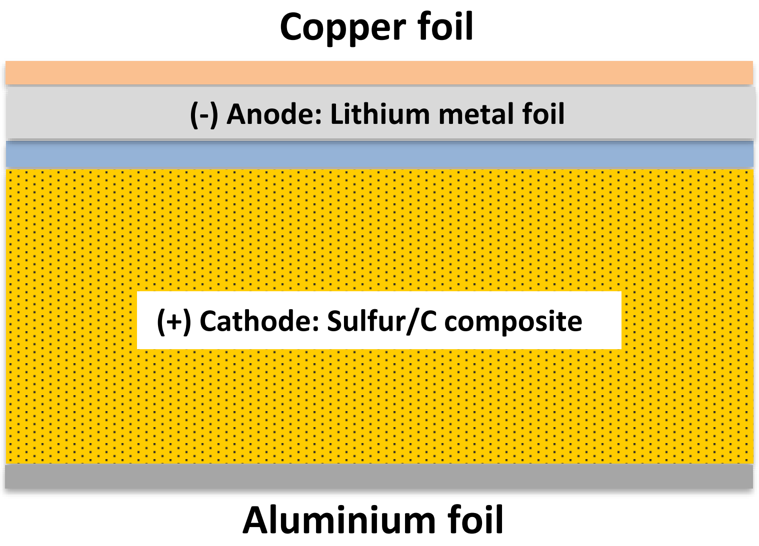
- Complex working mechanism (polysulfide formation)
- Sulfur is an electrical insulator (requires carbon)
- Sulfur has low density (impacts Wh/L)
- Average cell voltage is 2.1V (1.7V lower compared to LIB)
- Low published energy density values (50% lower than LIB)
- Poor cycle life at full depth of discharge or high rate

Lower predicted cost

- Sulfur costs < $150/t*
- Cobalt costs > $33,000/t*
- Nickel costs > $20,500/t*

Source: *12 July 2023 -* *Tradingeconomics.com*

Source: *12 July 2023 - Statista.com*



Anode: Lithium metal foil
Cathode: Sulfur/carbon composite

Electrolyte: New formulations required
Separator: Can be standard materials

Lithium - Sulfur

OXIS ENERGY
Next Generation Battery Technology

Sion Power

Energy cell (2016)
400 Wh/kg
310 Wh/L

Energy cell (2013)
350 Wh/kg
320 Wh/L

Next generation
Lithium-ion

Energy cell
244 Wh/kg*
650Wh/L*

Advanced cells
> 300 Wh/kg
> 750Wh/L

- **Most promising applications**
  - Low weight is key
  - Space is available
  - Cycle life is secondary

UAVs and Space | **Defense and Niche** — Now

Regional and urban air transport

Large commercial air transport

Large commercial vehicles, electric bus and truck — Future ??

Source: 13 July 2023 - Batterydesign.net

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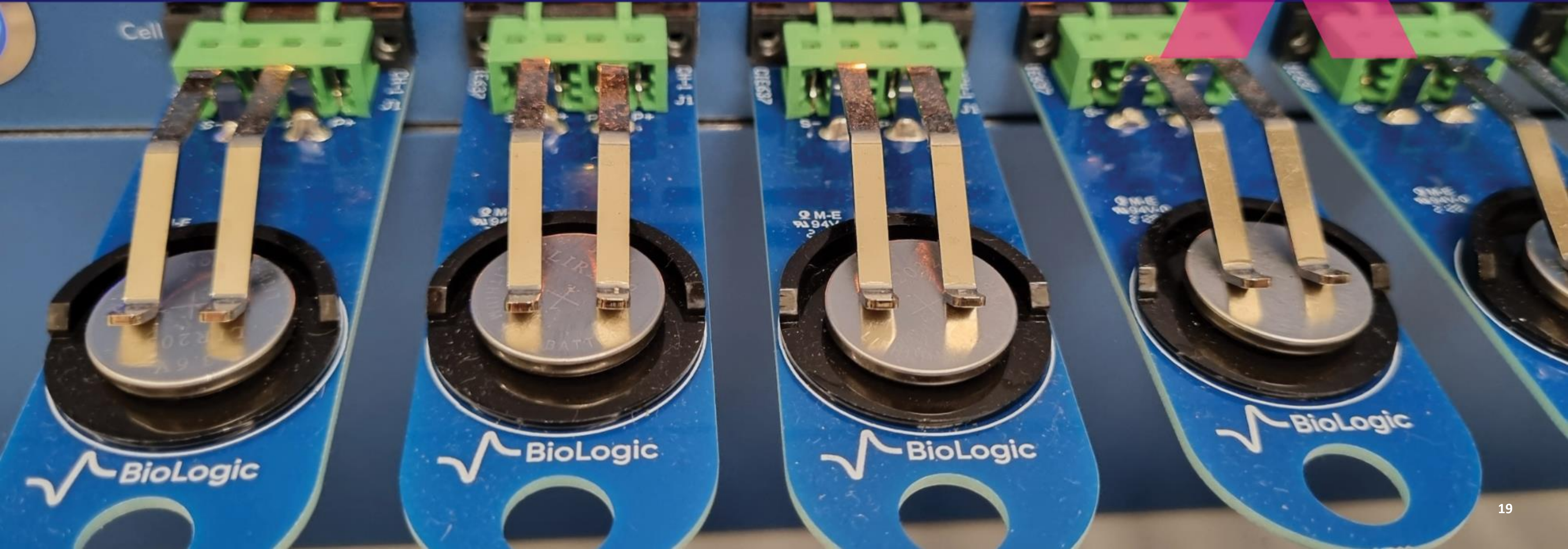
OUTLOOK



The future direction of lithium-ion batteries

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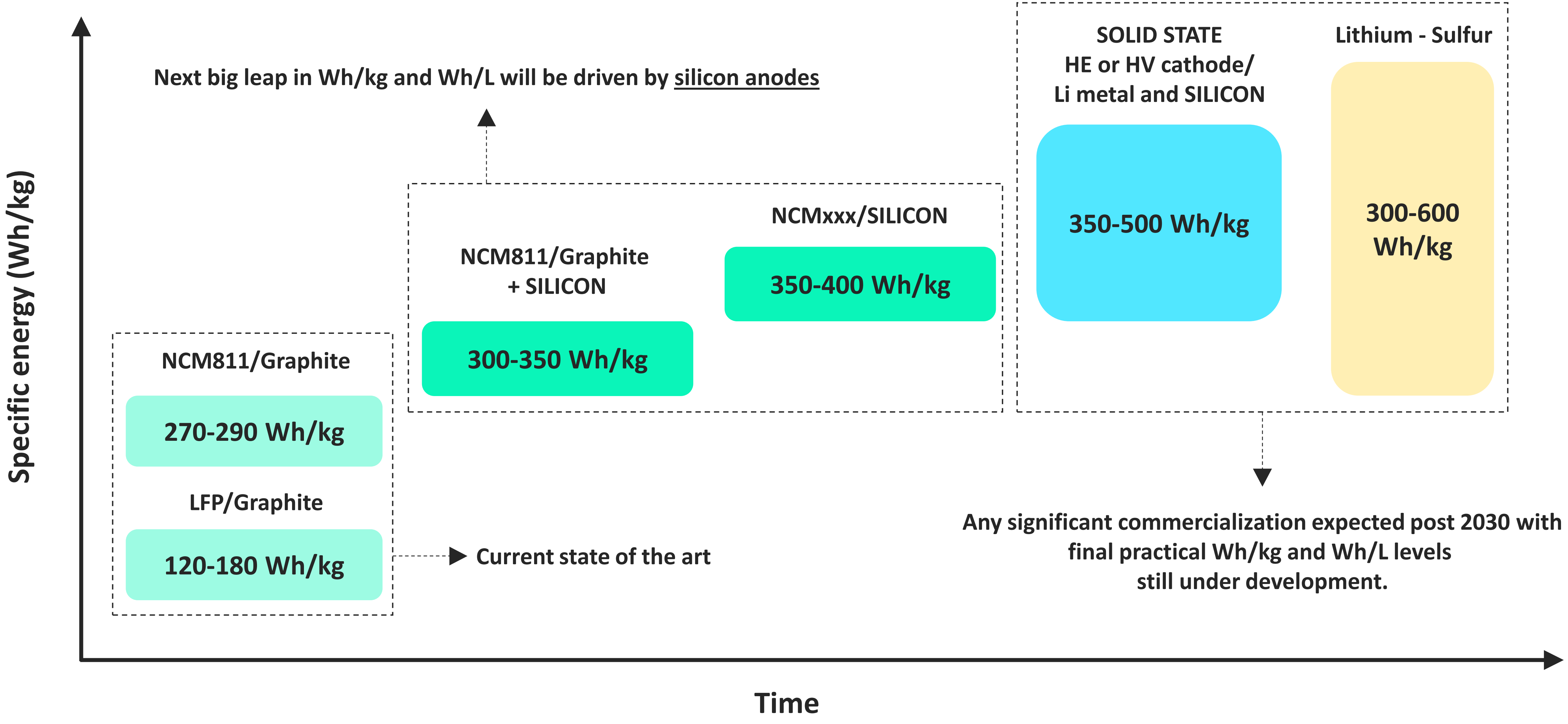

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