NAATBatt

SODIUM-ZINC BATTERY WORKSHOP

The Future of the Sodium Battery Market and Opportunities for North American Manufacturers

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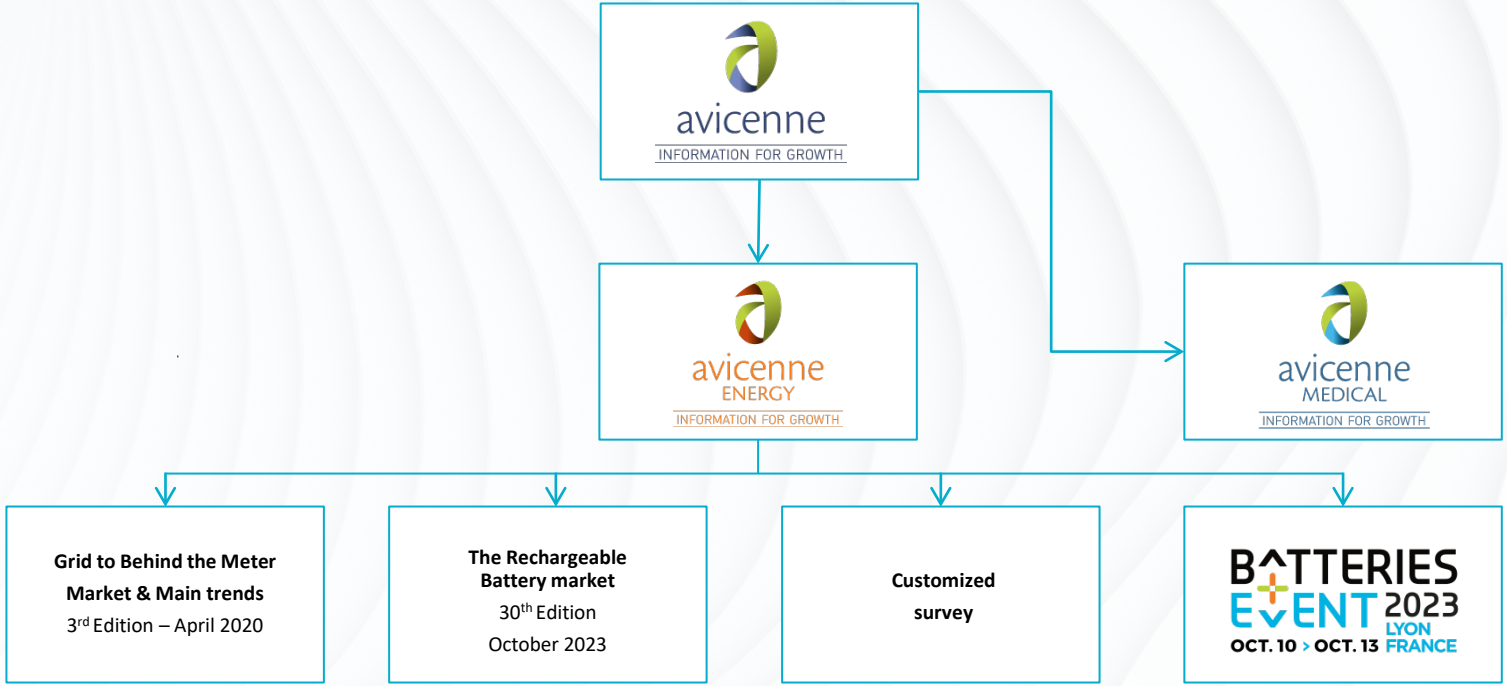
avicenne ENERGY

Presentation Outline

- Rechargeable Battery Market
- Sodium Ion Progress
- North American Opportunity

Avicenne profile

Information for Growth - Powering your company's market strategy with in-depth research



Source: Avicenne Energy 2023

Avicenne ENERGY TEAM

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Hengfeng Cui, Advisor

Source: Avicenne Energy 2023

Batteries Event 2024

- 3 days congress in France (Lyon)
- October 16–18, 2024
- 26th Edition (first edition in 1999)
- +1,000 attendees
- +100 Booths
  Battery makers, raw materials suppliers…
- IC & BMS suppliers, tests, machining, coating,
- +160 international speakers:
  Researchers, industrial process, marketing, financials,

BATTERIES EVENT 2024
LYON FRANCE
OCT. 16 > OCT. 18

Avicenne Energy: what else can we do for you?

Avicenne Energy Competencies

Avicenne Energy has provided deep market understanding, insights, strategic support and consulting in the rechargeable battery market for nearly 30 yrs.

We recognized the major challenges for many projects moving forward and to help drive growth in the battery industry: Availability of experienced people with battery and materials capabilities, along with resources to fill current organization gaps until the programs progress to have internal resources and to support governmental funding programs.

Avicenne Energy began to fill these gaps with our clients with very experienced resources both from our core team and subcontractors in 2018, this has continued to expand in the EU, US and AP to support clients.

Examples of projects underway and completed:

- M&A and Investment support – Target development, strategic fit, pre-diligence, and diligence
- DOE Submissions and Loan Validation Diligence
- Engineering Plans for Cell Plant – Pilot And Giga-scale
- RFI/RFP for materials and equipment
- Cell Plant Start-up Validation and Quality Audits
- Deep technology and process expertise in many areas of the battery value chain
- Detailed market opportunity and mapping analysis by segment, region and globally
- Our experts include a major engineering firm, ex-cell manufacturing and technology leaders, battery pack manufacturing and technology leaders, deep materials experts, etc. Our team continues to grow as our clients are driving more projects forward.
- **If you are interested in learning more, are facing experienced resource challenges or becoming part of our team, please let us know.**

Source: Avicenne Energy 2023

Pilot Line Demand Study

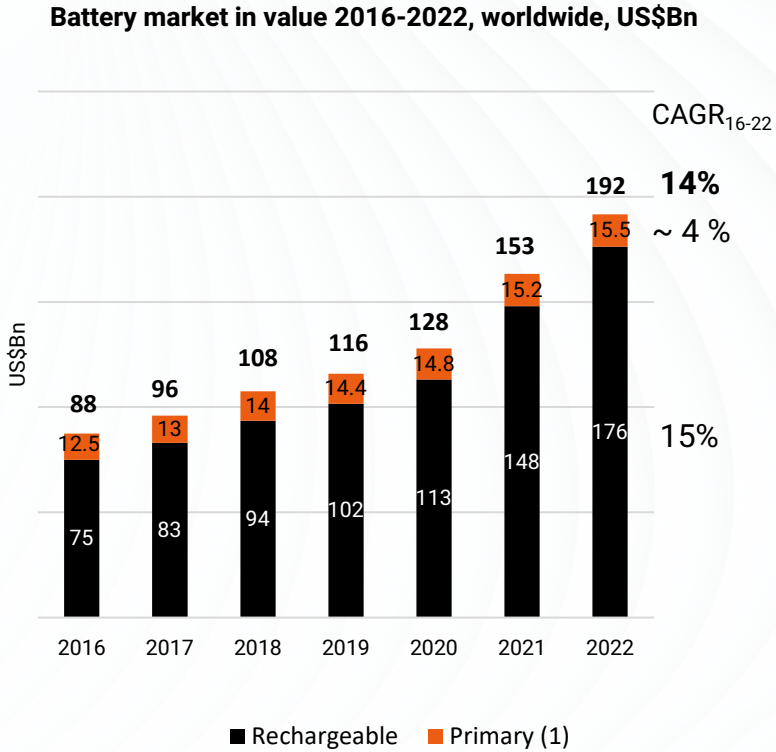
Li-Bridge has selected Avicenne Energy to (1) characterize the needs for shared pilot manufacturing resources and (2) understand how such a resource might improve US competitiveness - participation in our survey as a key component of the analysis. **There are two parts to the survey**: (1) **spreadsheet input** to semi-quantitatively describe your organization in an organized framework and (2) **open ended request for input on the needs/impact (questionnaire)** which allows elaboration. *This information will be held confidential and presented as an aggregate. We anticipate that completing the questionnaire and spreadsheet will take approximately a combined 60-75 minutes to complete.*

If your company would like to be added to the 130+ companies that we are getting input from, please let us know at d.sanders@avicenne.com

The worldwide rechargeable battery market in 2022

World battery market overview

Total Battery market Worldwide is almost US$200Bn



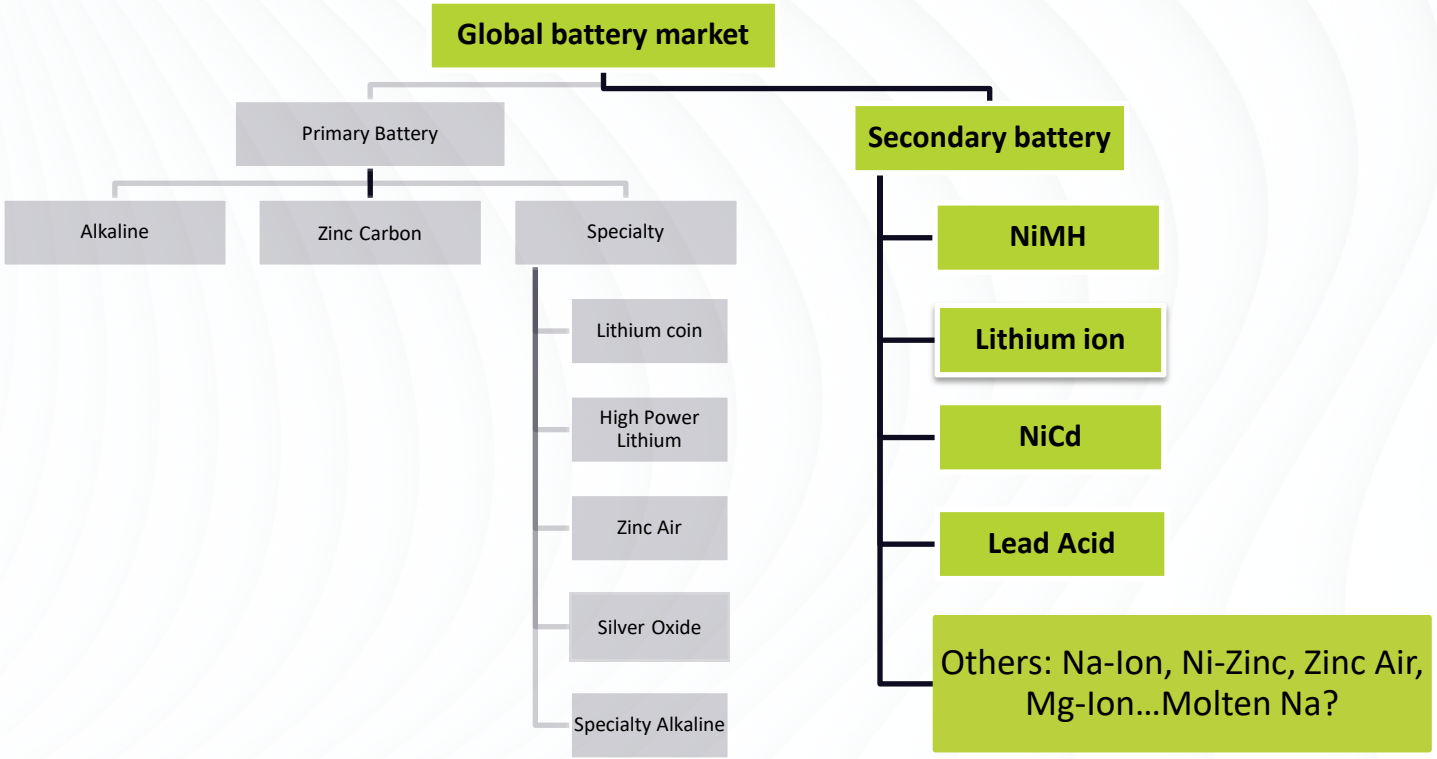
(1) Non rechargeable – Source: AT Kearney, Duracell, Avicenne
Based on selling price from manufacturer to retailer

Macro-trends driving the battery market

Battery is a key technology for new concepts of mobility and energy (e.g. electric mobility, stationary storage) supported by the following trends:

- Population increase and city growth challenging existing mobility and energy solutions
- Shift in energy production with an increasing focus on renewable energies as an alternative to fossil fuel and nuclear
- Global awareness regarding global warming pushing for adoption of green solutions (global objective of CO2 emissions reduction, government regulations and incentives, social pressure for environmental-friendly solutions)

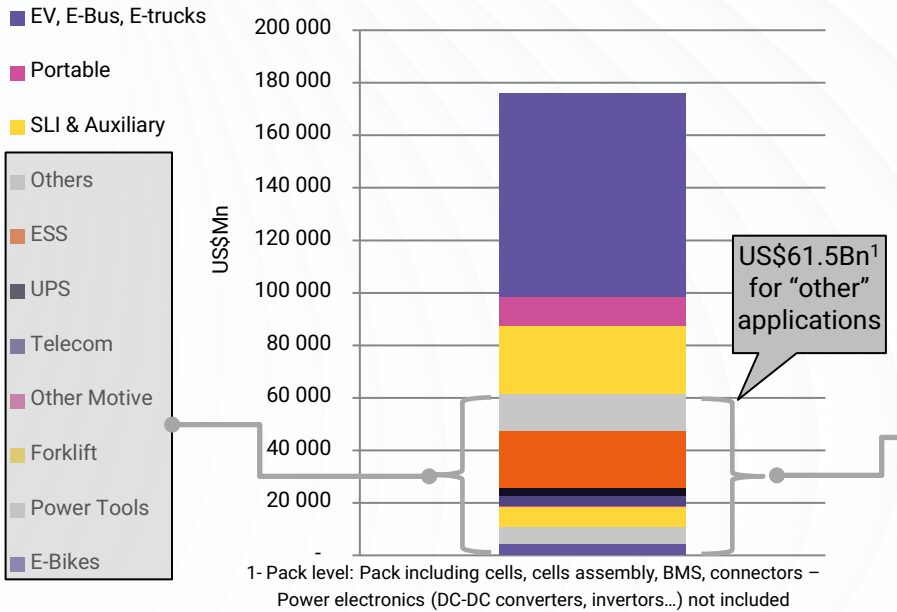
Battery segmentation by chemistry



The worldwide battery market in 2022

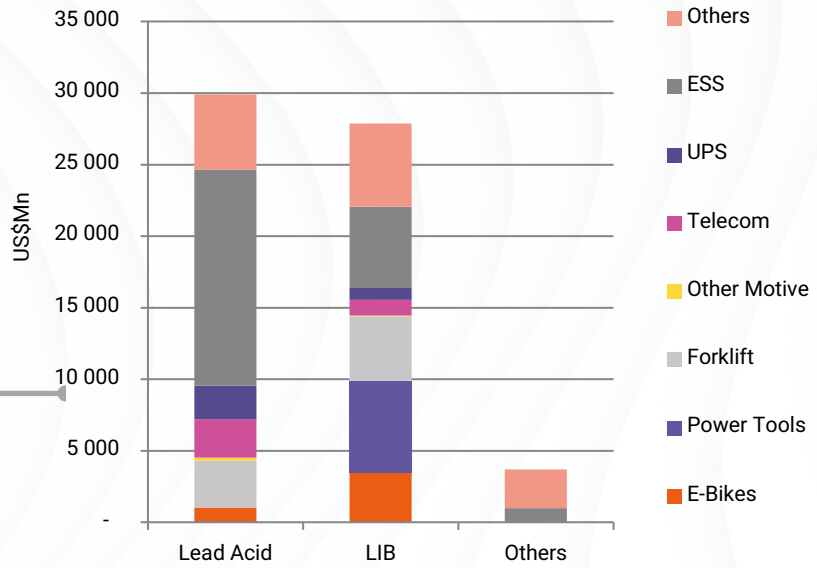
Beyond EV, Portable & SLI market, a lot of “other” applications are growing, representing an additional market of US$61.5Bn[1] in 2022

Worldwide battery Market split in applications, 2022, US$Mn



1- Pack level: Pack including cells, cells assembly, BMS, connectors – Power electronics (DC-DC converters, invertors…) not included

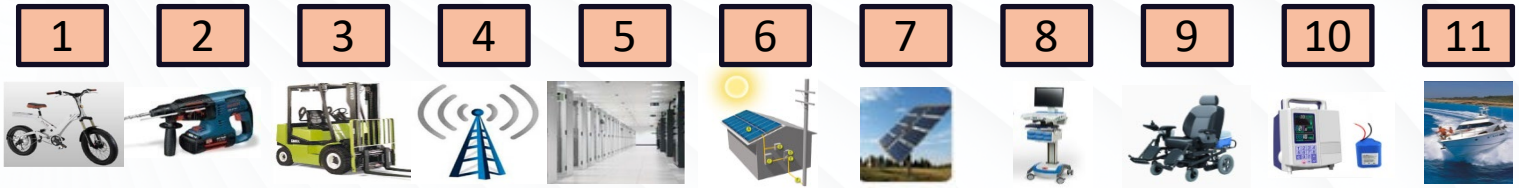
Worldwide « other » battery applications split in applications & chemistry, 2022, US$Mn



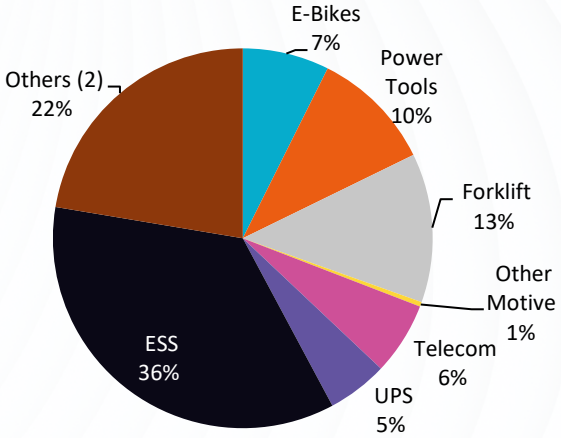
Source: Avicenne Energy 2023

Total potential market (US$Mn, Pack level[1])

Application details



US$ 61.5 Billions in 2022[1]

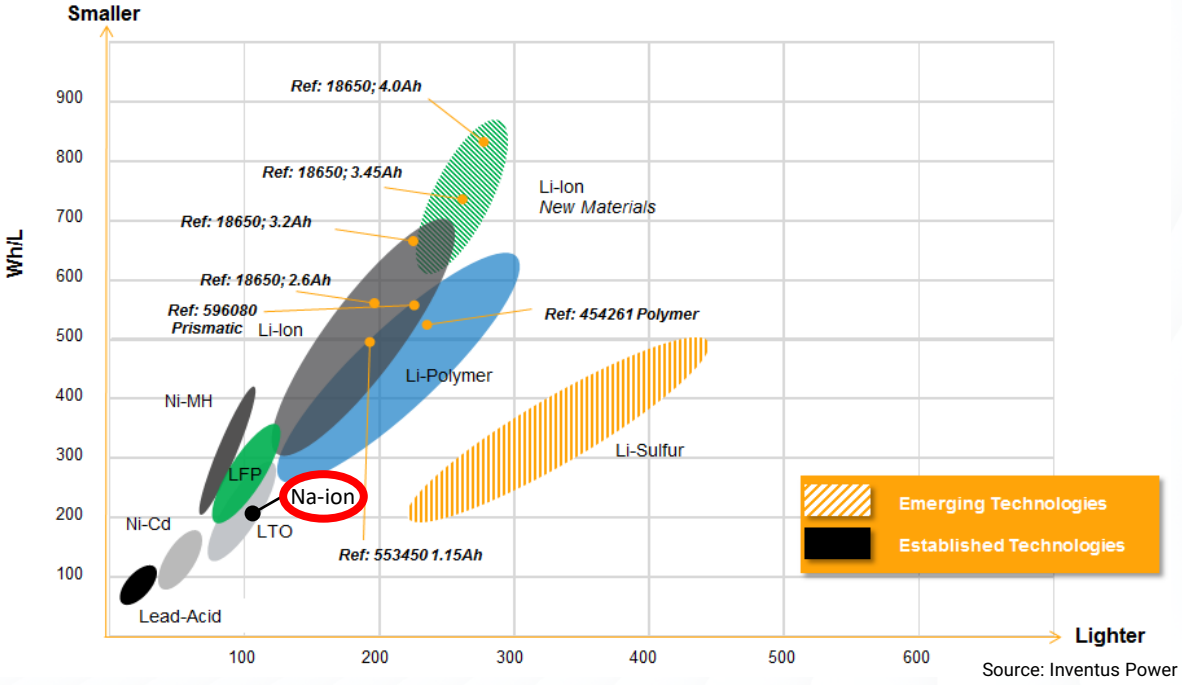


1- Pack level: Pack including cells, cells assembly, BMS, connectors – Power electronics (DC-DC converters, invertors…) not included
2- Other App: Military, aerospace, Oil & Gas, Railways, Aviation, Utility metering,…

Source: Avicenne Energy 2023

NiCd, NiMH & Li-ion product performances

Li-ion achieves an energy density of >800 Wh/L versus 50-90 Wh/L for Lead Acid batteries allowing a10+ times higher energy release



Source: Inventus Power

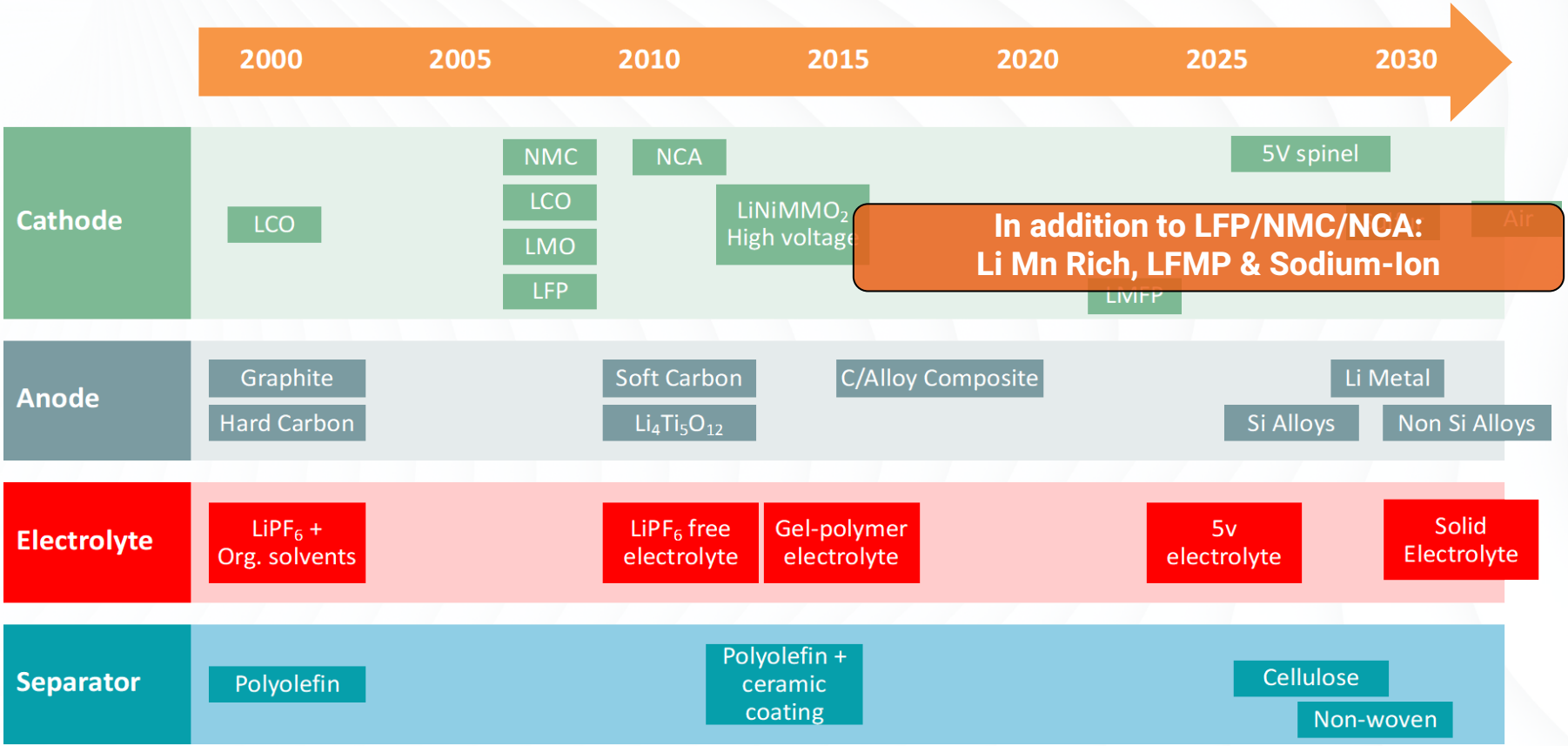
Source: Avicenne Energy 2023

Sodium Ion Drivers

Market moving toward more commercial availability

- Energy density of Sodium Ion is viewed as attractive with low-cost materials as long as Lithium pricing is high, if in low-mid range many question the value for this technology
- Primary competition for Sodium Ion is both Lead Acid for improved energy density and LFP Lithium-Ion Batteries for reduced cost
- Cycle life, lifetime and aging have to be improved
- Safety of cell and systems needs validation
- Transportation of Sodium Ion Batteries with 0 volt could become a clear advantage for transportation & storage if UN creates a new specific class for transportation in the existing class 9

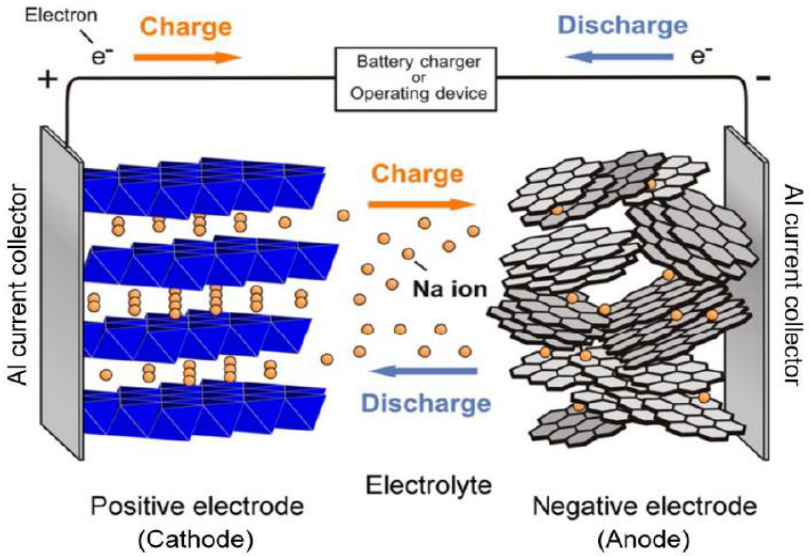
Technology roadmap



Source: Avicenne Energy 2023

Renault Technology and Changes for Sodium Ion

Cell level change Li-ion → Na-ion – from supply chain signals and media coverage



Source : Renault CIFRE PhD Q. Wang (collab; Collège de France, JM Tarascon, industrial supervisor M. Chakir)

Materials

- Negative active material : Graphite → Hard Carbon
- Positive AM :
  - NMC or LFP → Polyanionic (NVPF) ; layered oxides (ex : NFM) ; Prussian Blue Analog
- Electrolyte : basically Na adaptation of Li counterparts

Source: Renault – Batteries 2023 Lyon

NIB on Pack, Module, and System Level

Challenges vs. advantages

Larger Cells
- Trend goes towards large prismatic and pouch cells (>300 Ah)
- To achieve the same capacity, NIB cells will be even larger
- Reduces need for packs and modules

High Flexibility
- LIBs and NIBs can be combined at module and system level
- Combine the strengths of different cell chemistries
- Intelligent BMS needed

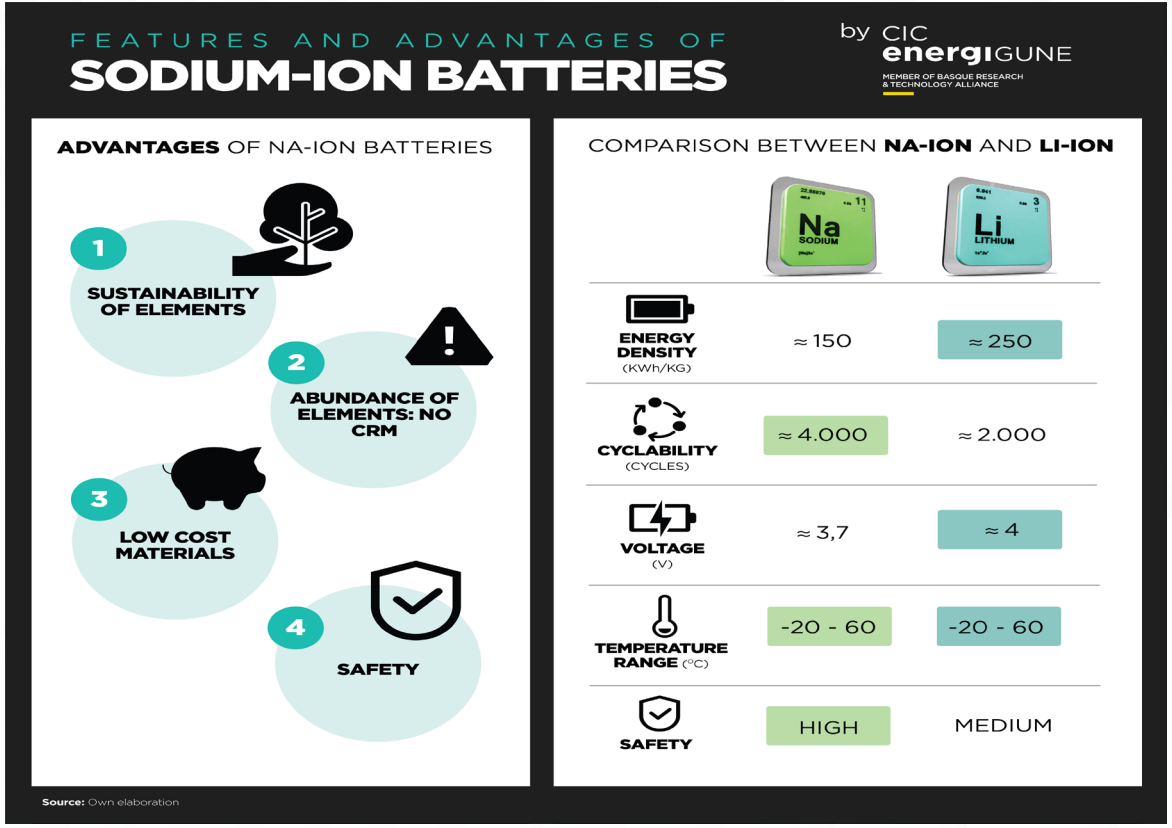
High Safety
- NIBs show less tendency for thermal runaway events
- Reduced thermal management

Lower Cost
- Less inactive components on module and system level
- Less cost-intense cell components

High Energy Density
- Less inactive components on module and system level due to reduced risk for thermal runaway
- High cell-to-pack efficiency

Source: Accenture 2023

Features and Advantages of Sodium-Ion Batteries



Sodium Ion Batteries

What must be true to be successful?

- Lithium pricing and supply to return to concern levels?
- Cost/Performance close to LFP
- Safety
- Value chain capabilities – all levels
- End Users and Applications motivated for developments and commercialization

North America Capabilities

- ❑ Lithium pricing and supply to return to concern levels?
- ✓ Cost/Performance close to LFP – limited demonstration
- ❑ Safety
- ❑ Value chain capabilities – all levels
- ❑ End Users and Applications motivated for developments and commercialization

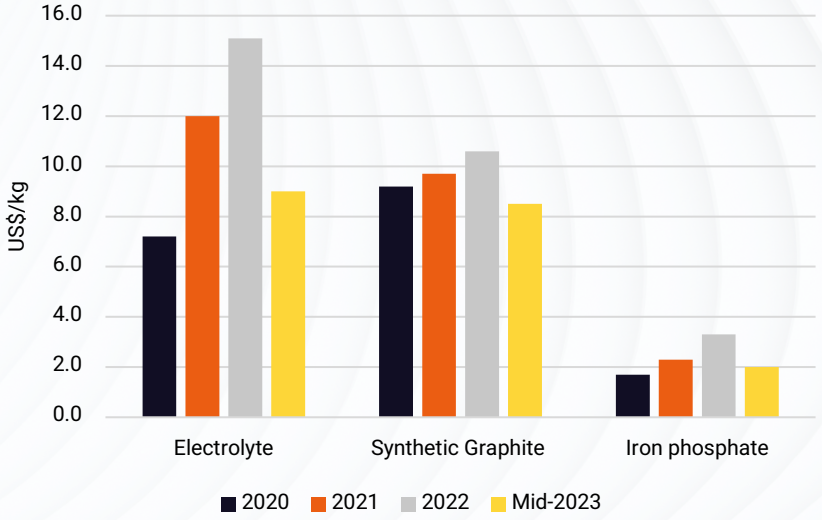
China Capabilities

- ❑ Lithium pricing and supply to return to concern levels?
- ✓ Cost/Performance close to LFP
- ✓ Safety
- ✓ Value chain capabilities – all levels
- ✓ End Users and Applications motivated for developments and commercialization

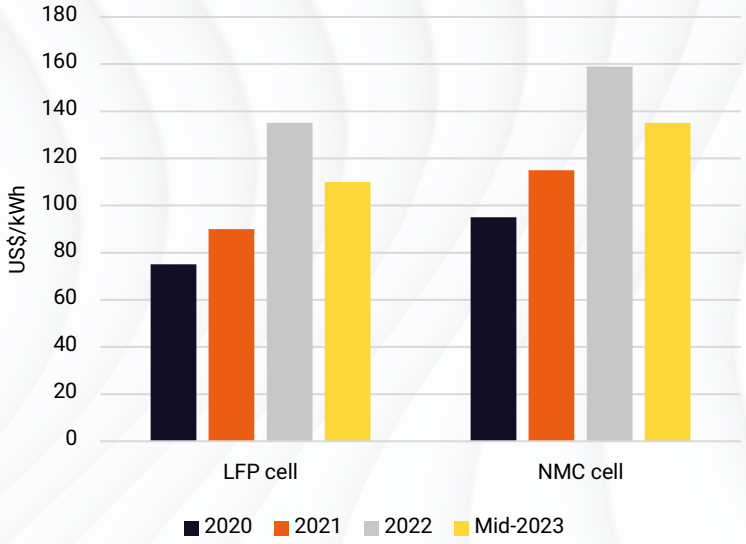
Lithium-ion Batterie price decrease in 2023 versus 2022 peak

In 2023, raw material price decrease allowed, prices of LFP cells to decrease from US$135 in 2022 to US$110/kWh in 2023, while NMC cells decreased from US$160 to US$135/kWh

Electrolyte, Synthetic graphite & Iron phosphate price in US$/kg , 2020-Mid 2023



Cells price in US$/kWh, 2020-Mid 2023

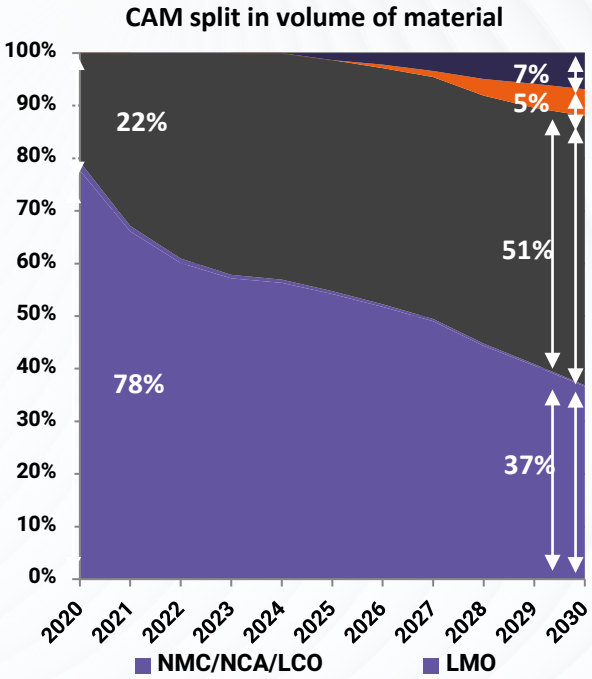


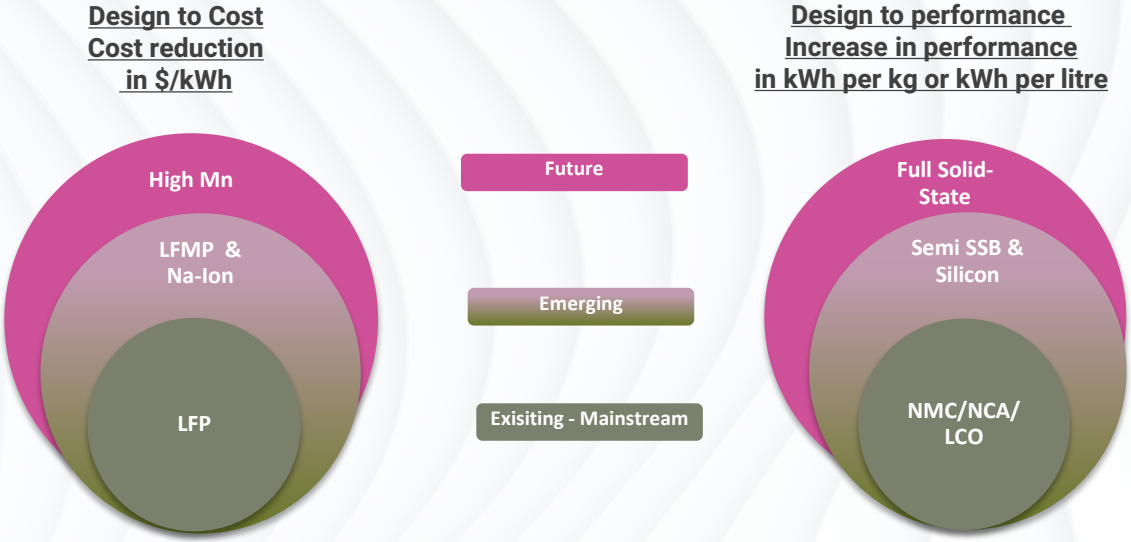
Source: Avicenne Energy 2023

Design to cost : competition Phosphate-based / Sodium-based / High Manganese

Key points :

- Technologies aimed at improving performance, in particular the switch to solid-state and the gradual integration of silicone in the anode, have no direct impact on CAM
- Technologies aimed at reducing the cost in $/kWh are essentially in direct competition with LFP, all other things being equal. LFMP will also become an option to improve energy density, sodium-ion is essentially aimed at ESS and certain light vehicles, high Mn is being promoted by the major ternary CAM manufacturers but remains very uncertain in terms of cost





Sodium Ion battery SIB 2023

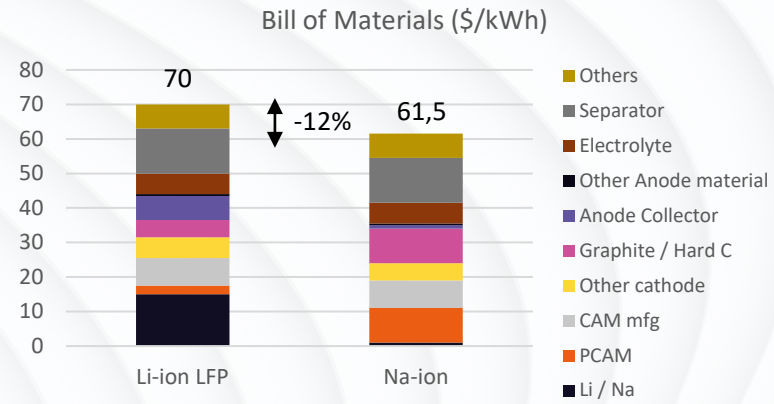
Avicenne's overall approach for Na-Ion cost is based on :

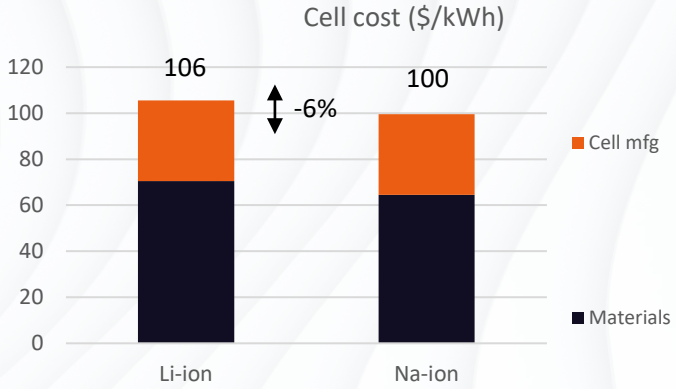
- Na is cheaper than Li (+)
- Al collector cheaper than Cu (+)
- Na-ion could probably use similar cathode process than Li-ion batteries (=)
- For Na Layered Oxide, PCAM higher than FePO4 (-)
- Hard carbon is more expensive than Graphite (-)

Na-ion cell could be ≈ 6% cheaper than typical (non-Chinese) LFP cell

If

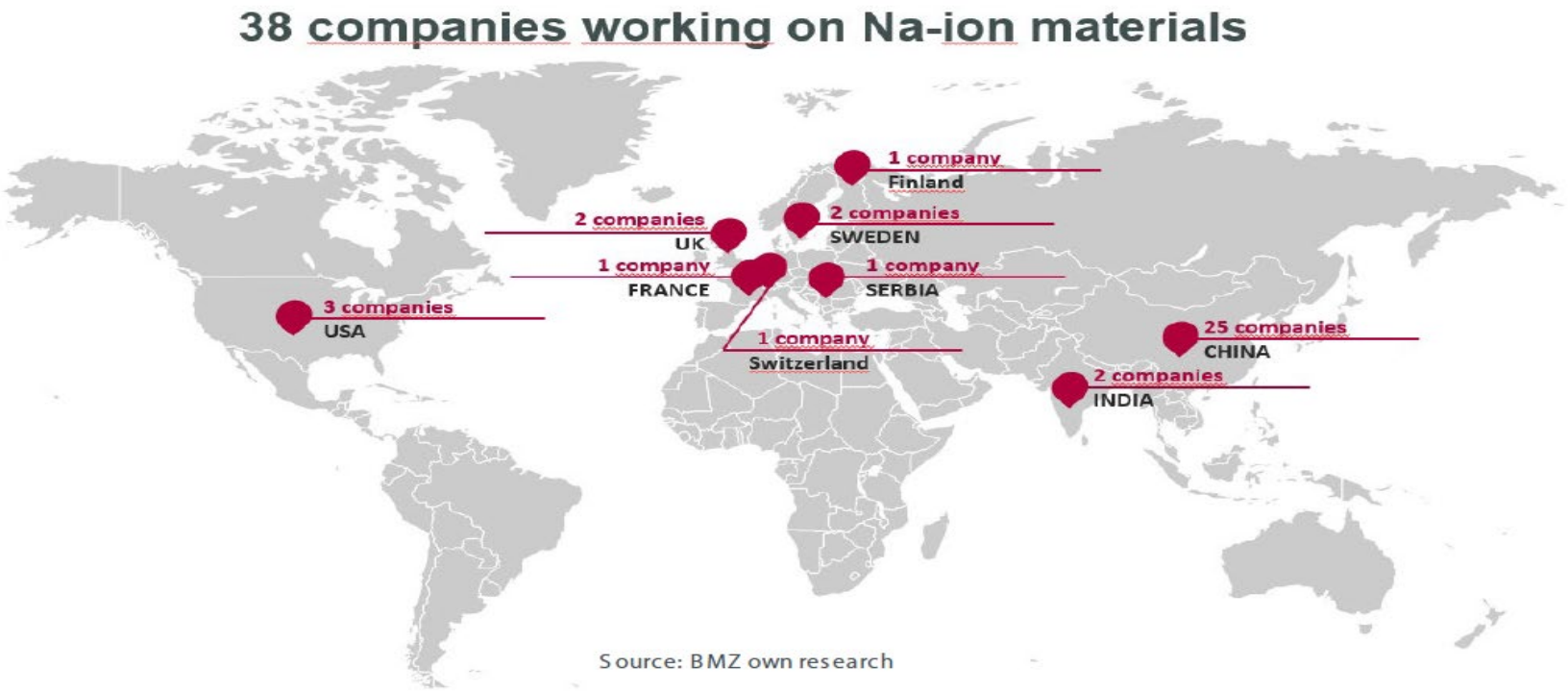
We consider that the two chemistry LIBs and SIBs have the same capacity in terms of kWh per kg



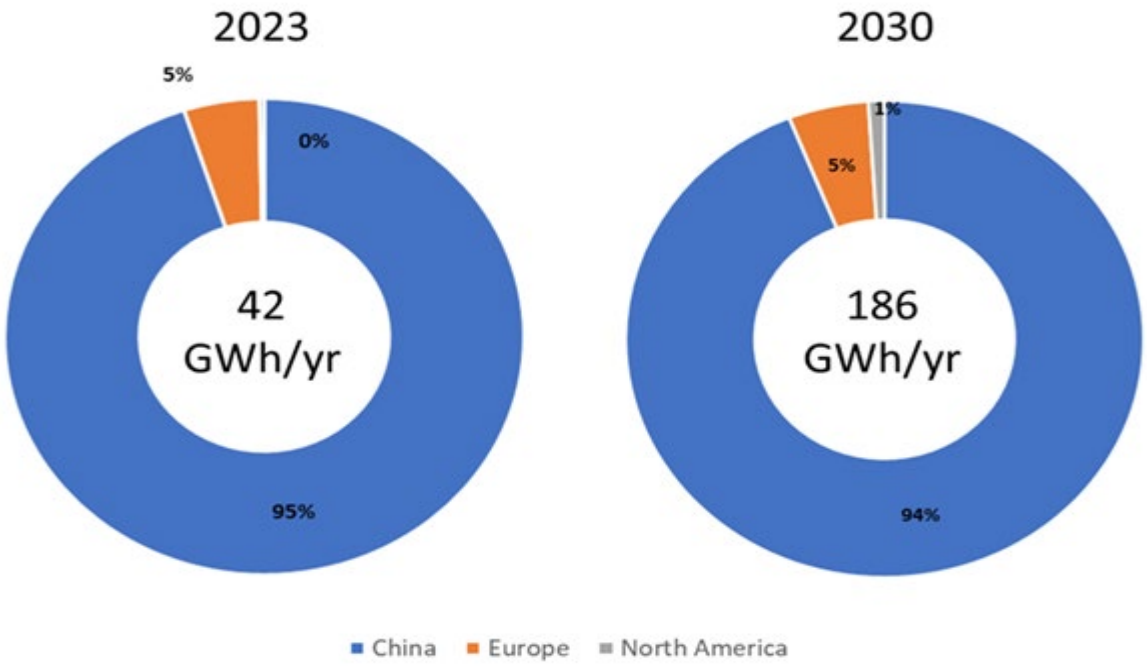


Source : Avicenne Energy 2023 with Lithium Carbonate at 30$/kg

BMZ Region Analysis



Sodium Ion Capacity



Source: IRENA 2023

Sodium Ion Battery – Cell Producers

The main cell producers/challengers in the sodium market today are:

- Existing China LIB Leaders and Producers: CATL, BYD – Hauhai (30GWh), EVE, Gotion, Svolt, Farasis and others
- Sodium Ion Specialists: Faradion, Natron, HiNa, LiFun, Tiamet and others

- **Faradion** (UK, founded in 2012) : partnership with Haldor Topsoe, AGM batteries, Sharp… , chemistry based on NaNiMnMgTiO2 for high energy application, acquired by Reliance
- **Tiamat** (FR, founded in 2017) : spin-off of CNRS and CEA, chemistry based on Na-V-P-F for high-power applications, partners with Plastic Omnium and Startec for module/pack development, ABB did systems testing and some safety testing.
- **HiNa Battery Technology Co** (CN, founded in 2017) : spin-off from the Institute of Physics, Chinese Academy of Sciences, chemistry based on Na-Cu-Fe-Mn-O for Low speed EV and ESS applications. First 100 kWh installed in 2019.
- **Natron Energy** (US, founded in 2012) : spin-out of Stanford University, chemistry based on PABs (Prussian Bue analogs) materials for data center UPS and motive applications. Manufacturing partnership using Clarios LIB facility for production – capacity up to 600MWhr.

Source: Avicenne Energy 2023

Sodium Ion Battery – Materials Producers

The main materials producers/challengers are much less developed than the cell production for the sodium market today are:

- Existing China LIB Leaders and Producers: Easpring, Ronbay, Zenhua E-Chem and GEM
- Sodium Ion Specialists:
  - **Arxada** – German based paints and coatings additive supplier, Prussian Blue contract with **Natron Energy**
  - **Malion and Hifi Group**– China based JV between Hifichem and Malion with $40M investment, acquired Huihong pigment (Prussian White) for $20M in 2023
  - **Altris** – (Cooperation with Sandvik Materials) Sweden based new entrant Prussian White 2kT/yr
  - **Aotelec** – China based Prussian White
  - **Bedrock** –Start-up focused on US based production of Prussian cathodes
  - **Talos Tech** – SBIR level start-up developing separators specifically focused on Sodium Ion batteries using freeze casting technology.
- Significant activity at academic level and national labs

Source: Avicenne Energy 2023

Sodium Ion Battery – System Developers and Producers

The system developers and producers are barely starting in most regions including Chinamain materials producers/challengers are much less developed than the cell production for the sodium market today are:

- Sodium Ion Specialists:
  - **Natron –** Focused on data centers, telecom, industrial mobility and EV fast charging. Integration partner ABB
  - **Peak Energy** – Start-up focused on ESS system development and growth, then moving to cell production. Core team has strong battery, systems and industrialization experience, very early stage.

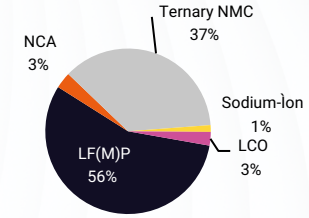
Source: Avicenne Energy 2023

Significant Lithium-ion production chemistry variations by region

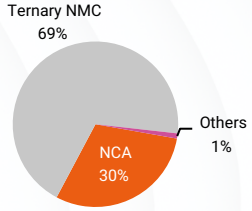
Ternary NMC will be the main chemistry worldwide, especially in Europe

2025

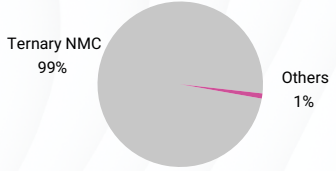
China: 960 GWh



North America: 195 GWh

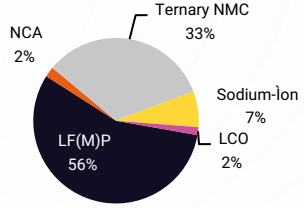


Europe: 220 GWh

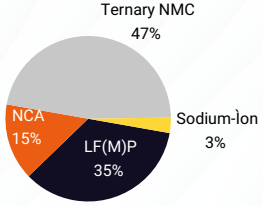


2030

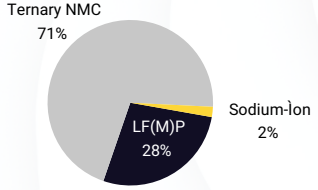
China: 1,980 GWh



North America: 650 GWh



Europe: 760 GWh

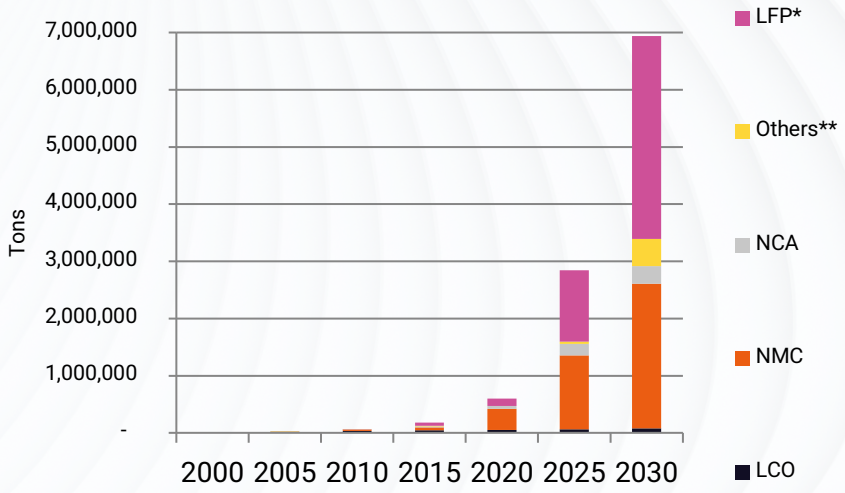


Source: Avicenne Energy 2023

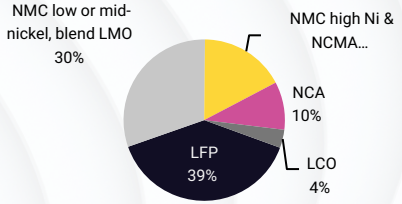
Cathode Active Material demand 2030 forecast

In 2030, the main chemistries used will be NMC based & LFP/LFMP representing together ~88% of the market

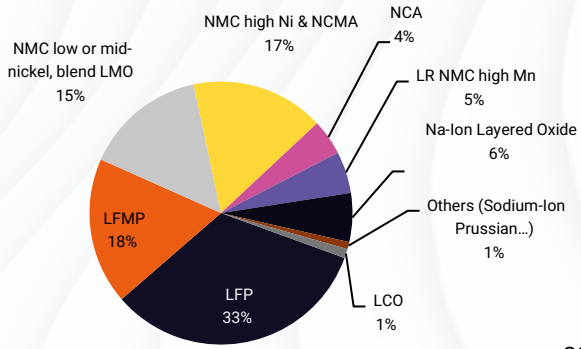
Cathode active materials by chemistry in Tons, 2000-2030



Cathode Active Materials in 2022: 1,500+ kTons



Cathode Active Materials in 2030: 6,900+ kTons



*: LFP: LFP+LFMP, NMC: Low-mid and High NMC, Lithium Rich High Mn

**: Others: Na-ion, Zinc…

October 2023

Source: Avicenne Energy 2023

Sodium Ion battery technology available

Prussian analog can address some ESS applications.The most promising volume for Sodium-ion for mobility will be layered oxide, based on an NMC mid nickel with Na in substitution of Li

	CATL gen1 Northvolt/Altris	CATL gen2 Faradion, HiNa, BYD	Tiamat	Natron
	Prussian White	Layered oxide	Polyanion	Prussian Blue
Power	+++	+	++	+++
Energy	++ (150 to 160 kWh/kg)	++ (150 to 200 kWh/kg)	+ (100 to 150 kWh/kg)	- (0 to 50 kWh/kg)
Cycle life	-	-	++	+++
Cost of raw materials	+	+	- (Vanadium)	+
Typical competition	Energy Li-Ion	Energy Li-Ion	LTO	Supercap

CATL, Tiamat… are also developping the layered oxide structure

Each company has its own receipt, for reference:

- **Tiamat: Na-V-P-F**
- **Faradion: Na-Ni-Mn-Mg-Ti**
- **HiNa: Na-Cu-Fe-Mn-O**

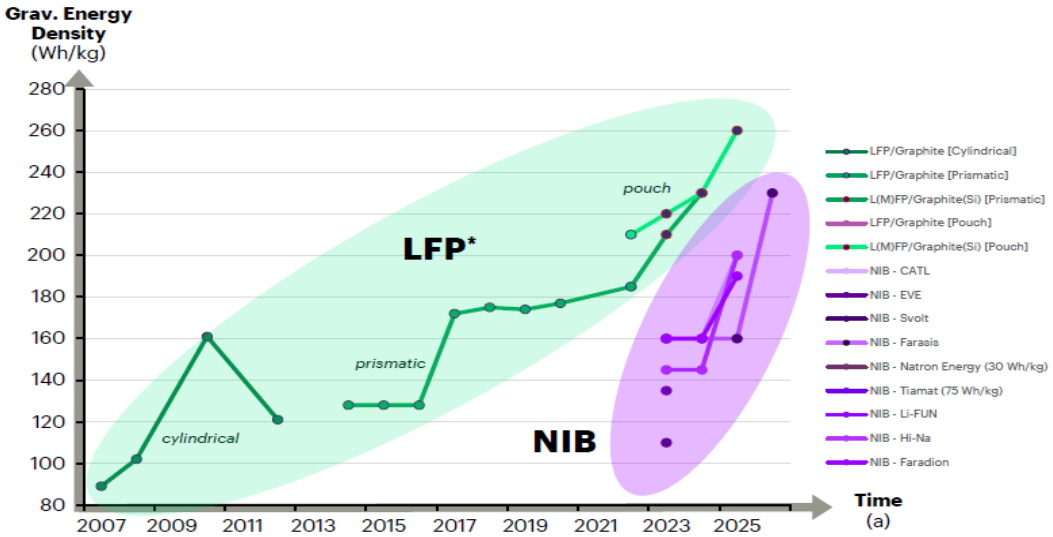
Source: Avicenne Energy 2023

Sodium Ion Progress

Learnings from LIB has accelerated developments

Roadmap – LFP vs. NIB

Will NIB development learn from the LIB journey?



LFP history

- 1996 Discovered by J.B. Goodenough at UT Austin, 1999 patented
- 2001 Poor electronic conductivity issue solved – patent (expired in 04/22)
- 2006 Improvement of Nanostructure by A123; commercialization by Valence Technology
- 2010 NMC started to take over the market due to increased energy densities @ similar cycle life; LFP remained for the Chinese domestic market (Busses)
- **2017 Increased energy density** due to improved cell-to-pack design, cost benefit compared to NMC
- 2019 Broadening of the market – many cell manufacturers deliver LFP cells with high energy density
- **2022 Advanced cell chemistry** (addition of LMFP for cathode & Si added to the anode) introduced

NIB potential

- Cell-to-pack designs can be utilized & simplified
- Known strategies for hierarchical cathode morphologies
- Established and enhanced cell manufacturing process

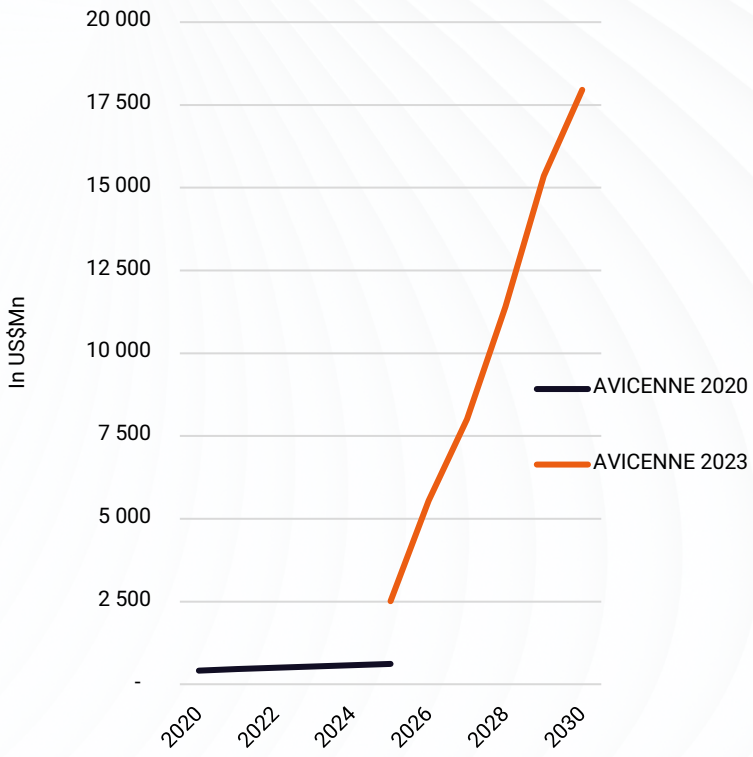
Source: Fraunhofer ICI 2023

The Sodium-Ion battery market

Unexpected take-off three years ago

Major applications and participants

- Market scope: Mostly LSEV and Budget Auto, ESS applications – Telecom, UPS and Renewables
- Market will remain smaller than for lead-acid and lithium-ion
- Mostly being developed by large CN Battery and mid-stage start-ups
- The sodium-ion battery market is mostly consolidated and limited to mid-stage start-ups making it challenging to forecast
- The key players in the market include CATL, BYD, Faradion, AGM, NGK, TIAMAT, HiNa, Altris, and Natron



Source: Avicenne Energy 2023

Molten Sodium Batteries

Interesting Technology – Limited Commmercialization

- Many reports of widely varying energy densities and operating temperatures
- Multiple market efforts with larger company support with very limited results
- Panel later today will give an updated current status

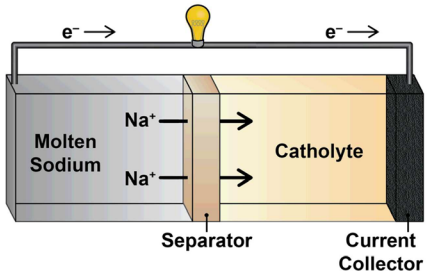


Figure 1. Schematic depiction of a molten sodium battery comprising a molten sodium anode, a solid-state sodium ion separator, a molten (or partially molten) catholyte, and a cathode current collector. (Sodium serves as anode current collector)

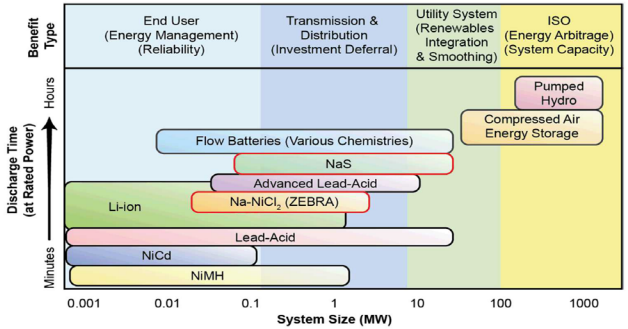


Figure 2. Generalized comparison of discharge time and power rating for different electrical energy storage technologies. Data obtained from Ref. [4] and Ref. [6].

Source: Sandia National Lab 2020

The Future of the Sodium Battery Market and Opportunities for North American Manufacturers

Conclusions

Sodium Ion

- Market is in the very early stages globally and much more nascent in North America.
- If this is to be successful in a competitive and competent value chain needs to be established and ready to grow with the opportunity.
- If Sodium Ion battery has a clear advantage (-20% in $/kWh) compared to LFP some target customers could switch; some contacts are skeptical on the announced BOM of Na-ion – needs validation
- Most work has been done in pouch which will require new format: prismatic (ESS, E-Buses) & broader cylindrical (e-bikes, Small ESS, Forklift, Telecom, UPS)
- China leaders are targeting low cost and small budget cars for China and other developing markets
- Many of the start-ups are targeting first the applications which are using lead acid and those which have not yet switch to LFP (UPS, Telecom, ESS both Grid & Residential seems to be the most promising applications)
- Documentation of fire and safety benefits needs to be completed.

Molten Sodium

- Market and applications for molten sodium need to accept value proposition and operating at elevated temperatures for this to become a substantial opportunity.

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