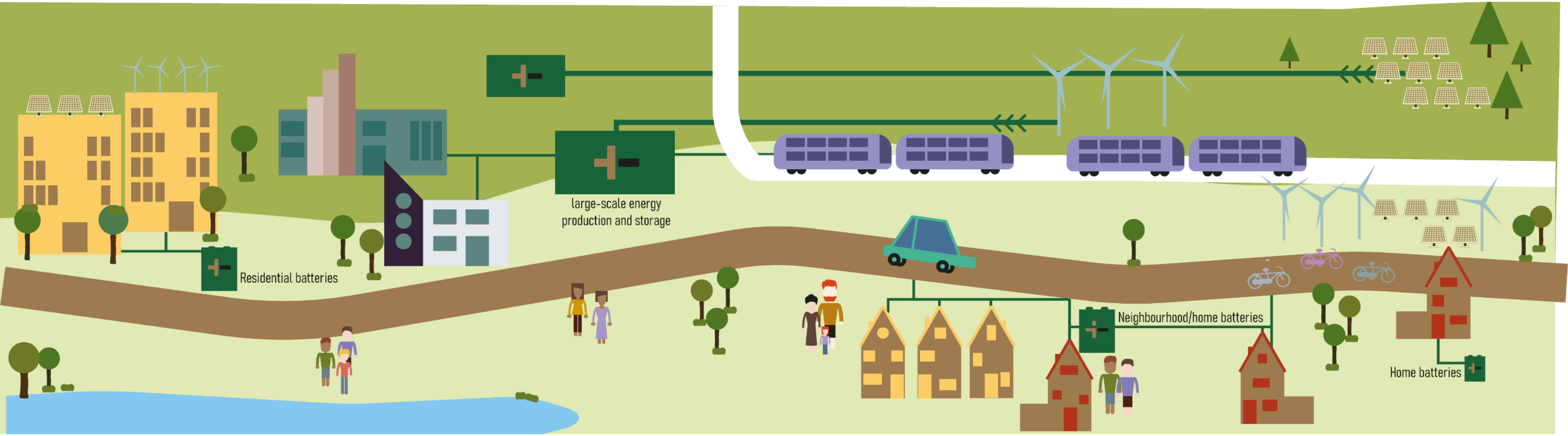
FINAL EVENT
– SIMBA COORDINATION TEAM

Sodium Ion and sodium Metal BAtteries for efficient and sustainable next-generation energy storage – The SIMBA Project



CONTENT

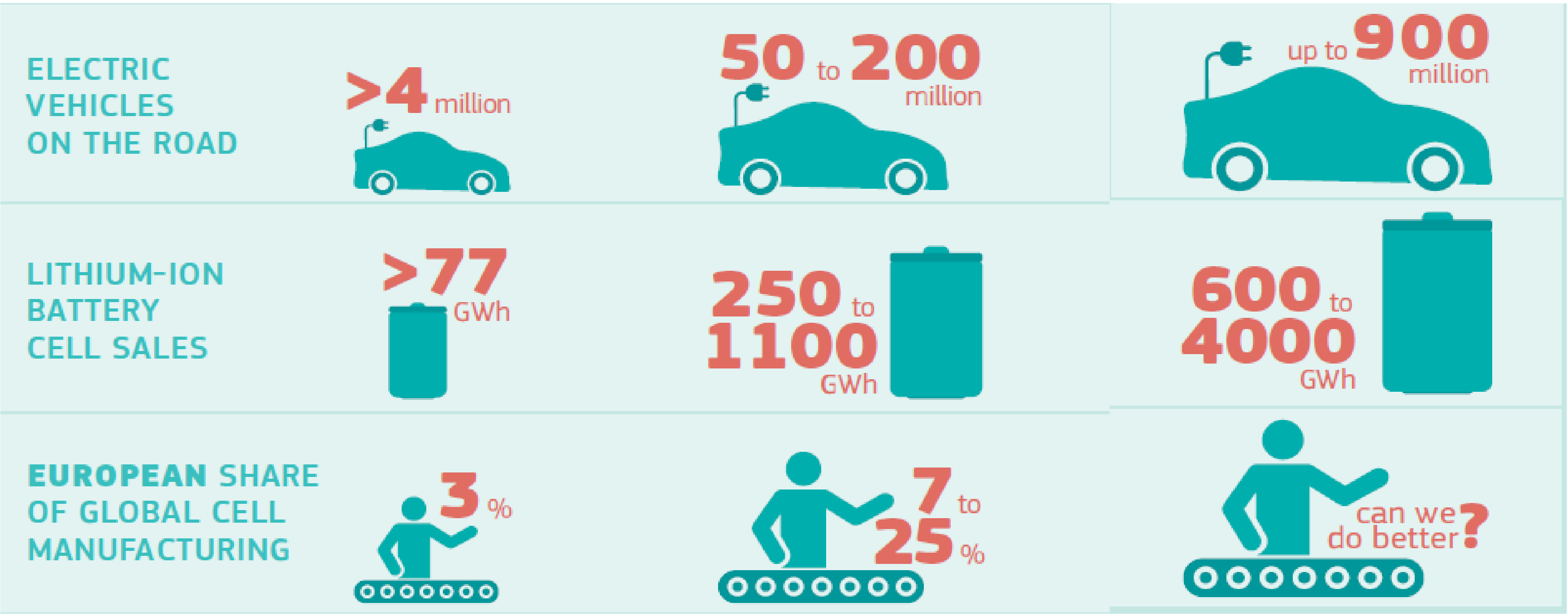
Li-ION BATTERIES

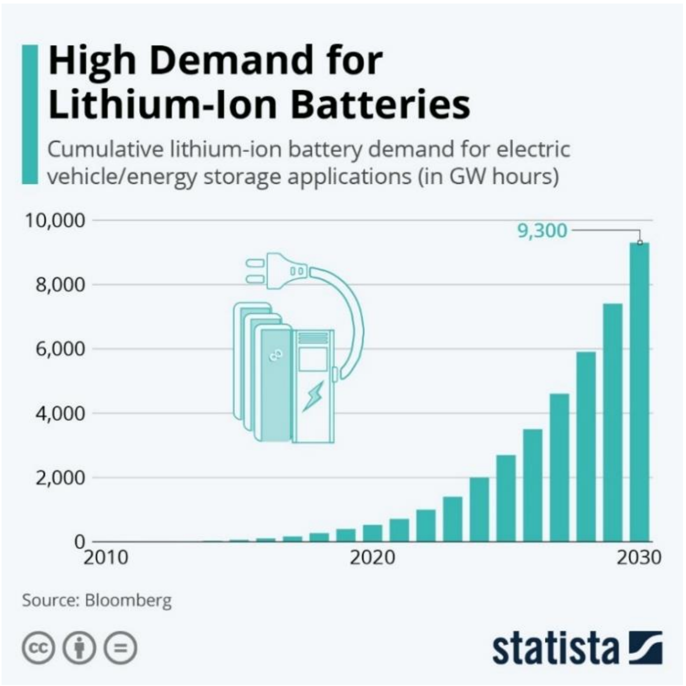
SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

Global supply and demand of lithium-ion batteries today and in the future

2018 | 2028 | 2040





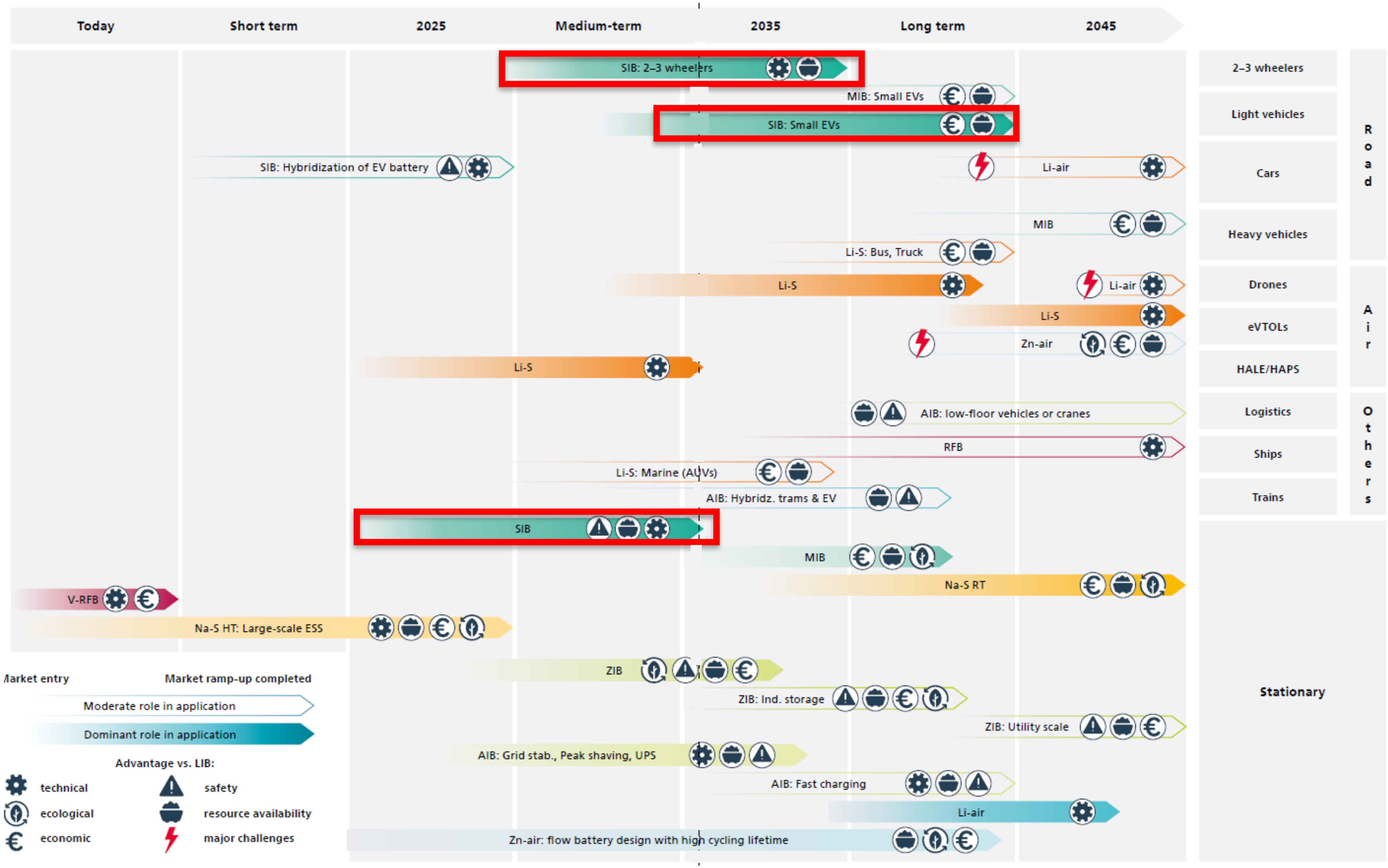
…but Lithium-ion batteries show environmental and societal challenges associated with their mass production

https://ec.europa.eu/jrc/sites/default/files/jrc114616_li-ion_batteries_two-pager_final.pdf
https://www.statista.com/chart/23808/lithium-ion-battery-demand/

ALTERNATIVE BATTERY TECHNOLOGY ROADMAP - APPLICATIONS

SIMBA
SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT



Fraunhofer ISI. Alternative Battery Technologies Roadmap 2030+.

WHY SODIUM TECHNOLOGY?

SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

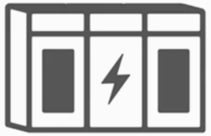
LIBs: dependency on critical materials

- Geopolitical supply risks
- Substitutability supply restrictions
- Environmental implications

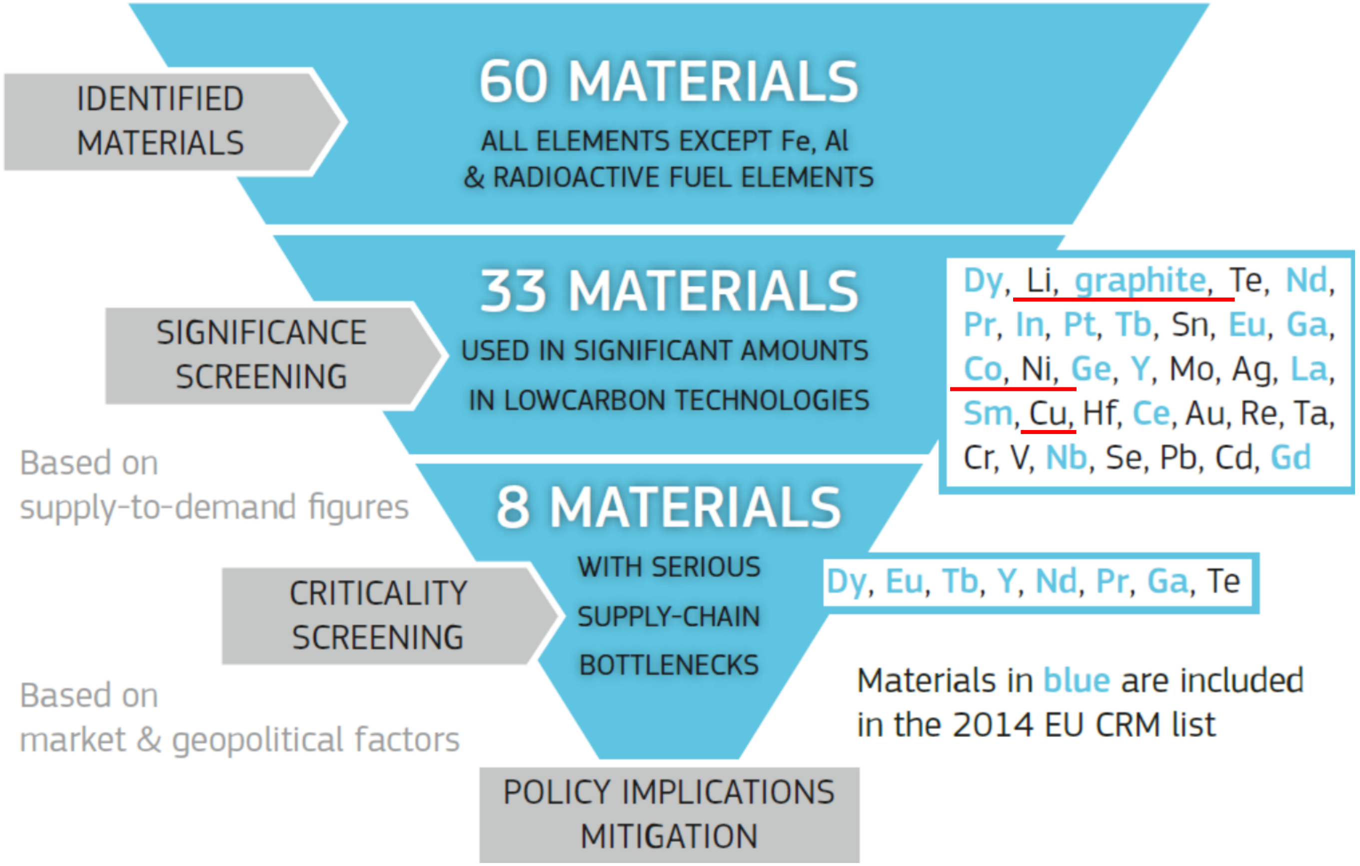
Alternative low-cost, sustainable and more environmentally friendly ESS

Sodium-ion batteries

Manganese
Iron
Hard Carbon
Sodium
Aluminum



Identification of critical materials for the EU



https://setis.ec.europa.eu/setis-reports/setis-magazine/materials-energy/critical-materials-energy-technologies-evangelos
I. Hasa et al. J. Power Sources (2021) 482, 228872

WHY SODIUM TECHNOLOGY?

+SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

	Lead-acid Battery	LFP LIB	NCM LIB	SIBs
Energy Density (Wh/kg)	30-50	120-180	200-300	120-160
Cycle Life (cycle)	300-500	> 3000	ca. 1000	> 2000
Average Voltage	2 V	3.2 V	3.7 V	3.2-3.6 V
Safety	♦♦♦	♦♦	♦	♦♦
Fast Charging	♦	♦♦	♦♦	♦♦♦
Environmental Friendliness	♦	♦♦♦	♦♦	♦♦♦
High T Performance	♦	♦♦♦	♦	♦♦♦
Low T Performance	♦	♦	♦♦	♦♦♦

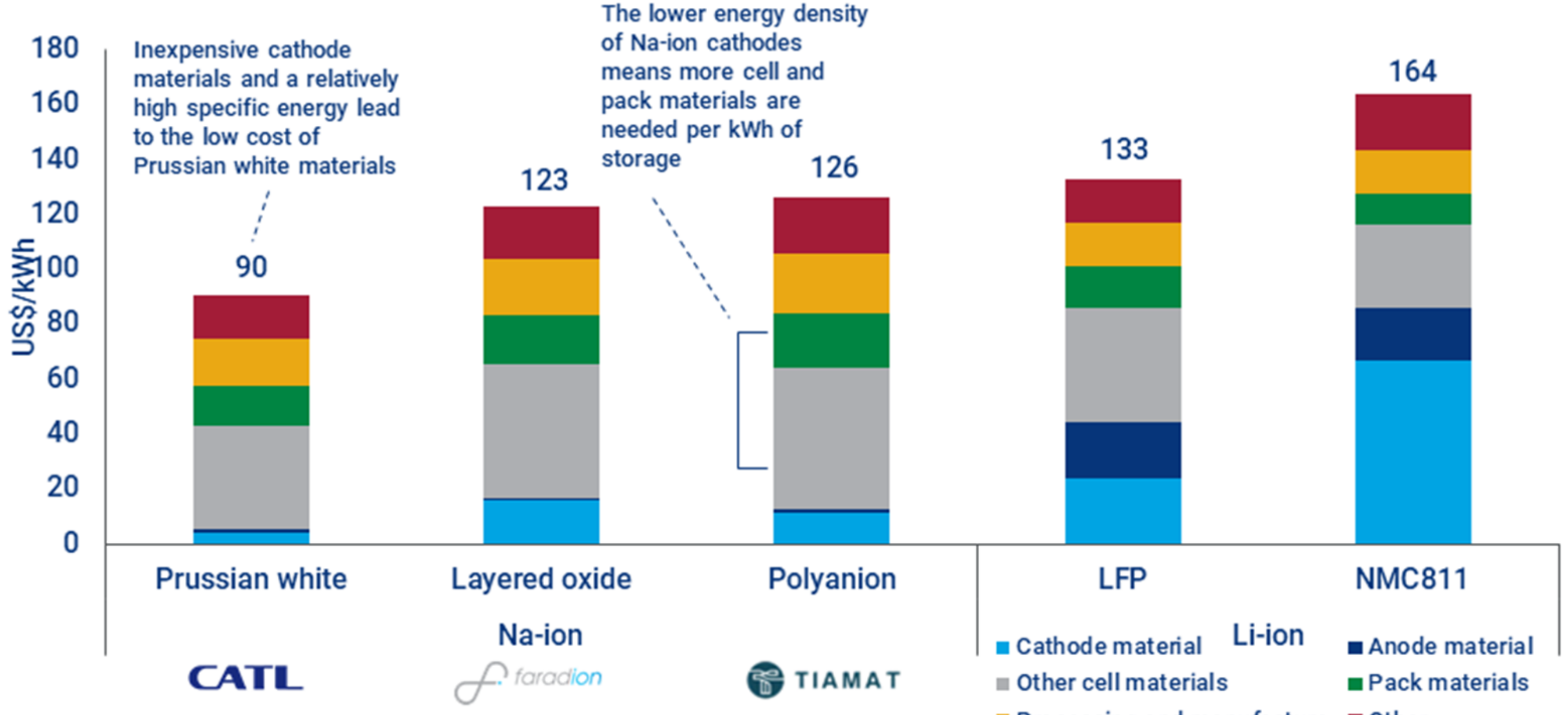
COMPARING Li AND Na-ION CELLS
Material Cost Analysis

SIMBA
SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

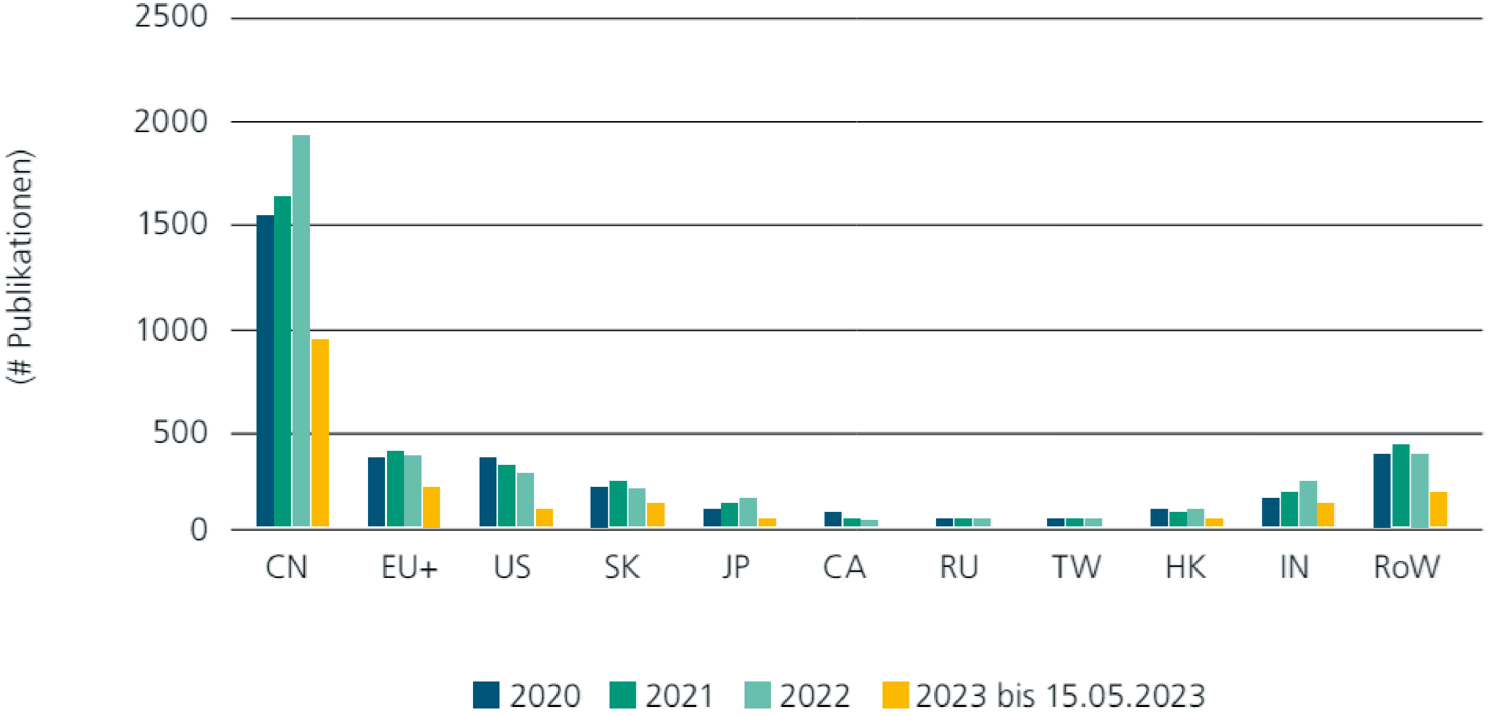
Sodium-ion (Na-ion) batteries present a lower cost option than lithium-based counterparts

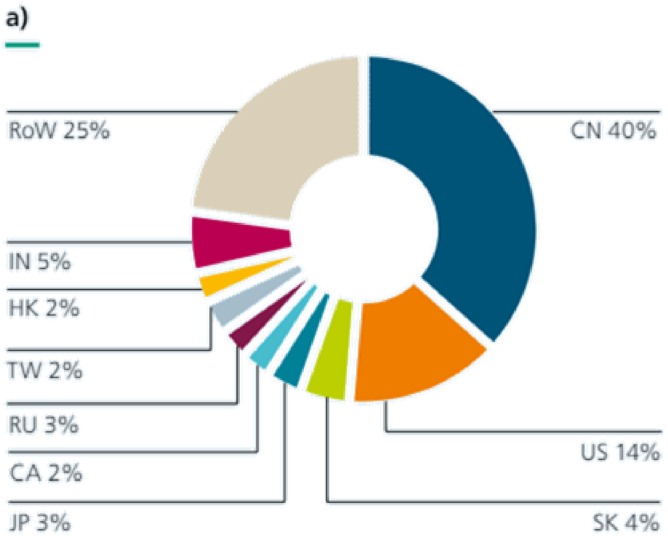
2022 battery pack costs by chemistry

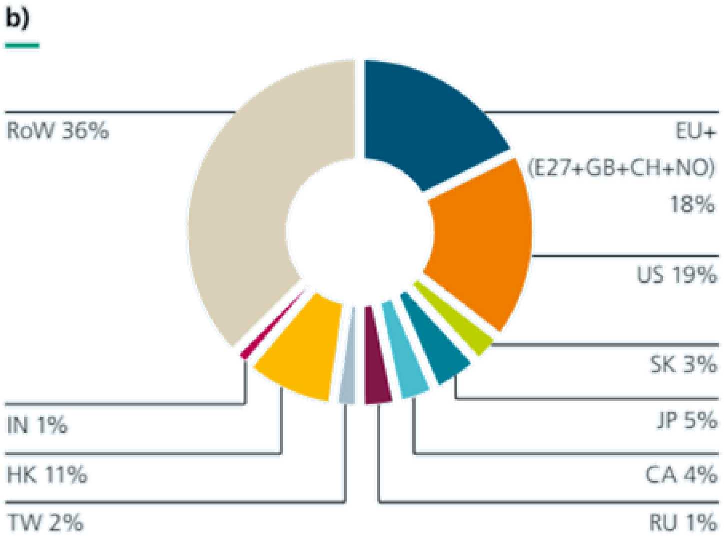


Source: Wood Mackenzie

SCIENCE INDICATORS IN COMPARISON
Publications







- >2500 SIB publications in 2022
- Stagnating situation outside CN and IN
- International European publications (>60%) with a high proportion of Chinese co-authors

MARKET ESTIMATION FOR SIBs
Application match and market growth

SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

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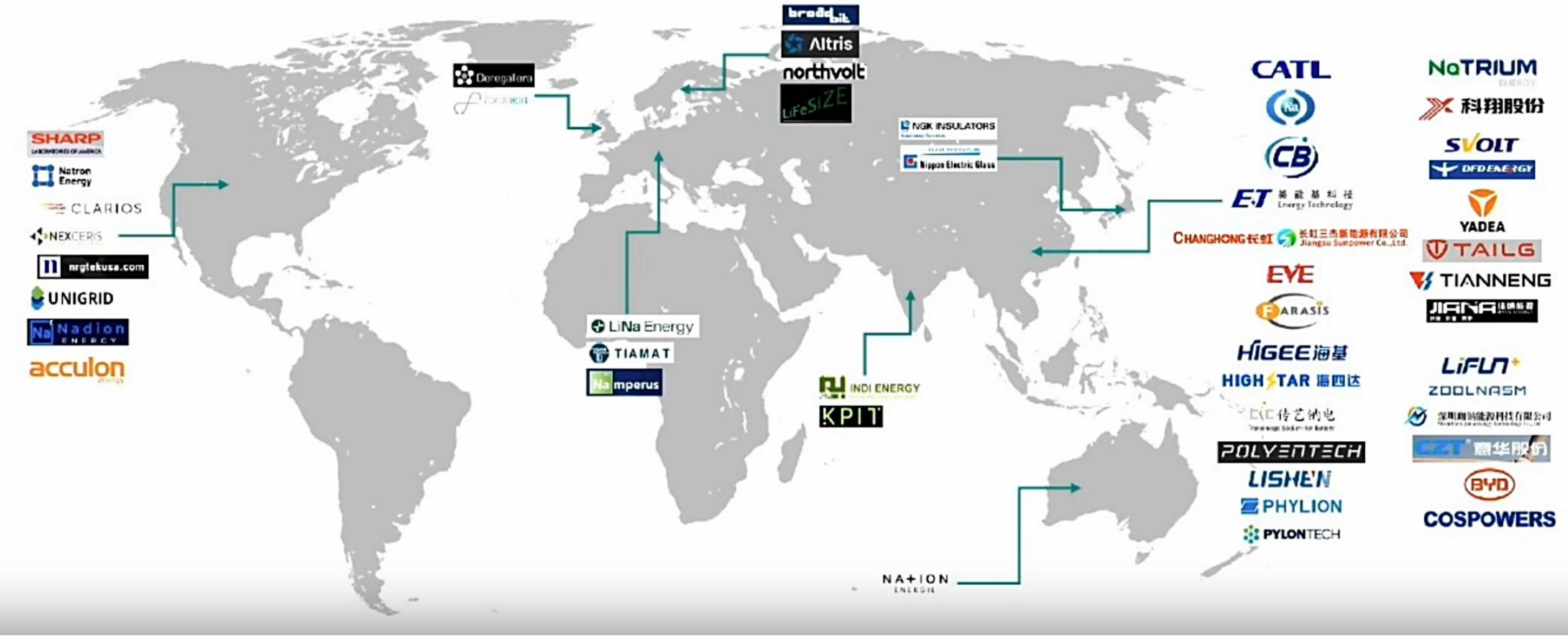
- **ESS:** Capacity based FTM and BTM. Low cycle requirements / long life in UPS, Telecom
- **2W/3W:** Low range eMotorcycles / eScooter
- **Small EV:** Low range and low cost
- **PHEV:** Potential use case but expiring technology
- **Hybridization:** Unclear cost effects

*FTM: Front-of-the-Meter
*BTM: Behind-the-Meter

INDUSTRY LANDSCAPE
SIB Cell Production



SODIUM-ION BATTERY PROTOTYPES

+SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

2013

SUMITOMO CHEMICAL

Anode: **Hard carbon**
Cathode: **Layered oxide**

中科海钠 HiNa BATTERY

Anode: Soft carbon

CATL 宁德时代

Anode: **Hard carbon**
Cathode: **Prussian White**

2015

SHARP

Anode: **Hard carbon**
Cathode: **Prussian W**

- Cathode material: **Prussian White** or **Layered oxides**
- Anode material: **Hard carbon**
- Electrolyte: **Carbonate-based liquid electrolyte**

faradion

Reliance Industries Limited

Anode: **Hard carbon**
Cathode: **Layered oxide**

Anode: **Hard carbon**
Cathode: **Phosphate**

Anode: **Prussian Blue**
Cathode: **Prussian White**

S. Kuze, et al. *R&D Report "SUMITOMO KAGAKU"* (2013) / A. Bauer et al. Adv. Energy Mater. (2018) 8, 1702869 / K. Smith et al. ECS Trans. (2017) 75, 13.
S. Kakimoto, et al. J. Am. Chem. Soc. (2015) 137, 2548 / https://news.cnrs.fr/articles/a-battery-revolution-in-motion / Y. Li et al. Energy Storage Mater. (2016) 5, 191.

RECENT NEWS FLOW IN RELATION TO SIBs
Investment And Commercialization

SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

Dec-21 – Reliance Industries Limited: *"acquires battery tech firm Faradion for GBP100m"*

Nov-22 – MERCURIA: *"Invests in Natron Energy's Sodium-Ion Battery Technology"*

Dec-22 – BYD: *"BYD to launch electric hatchbacks with new Sodium-ion batteries"*

Jan-23 – NGK: *"begins operation of NAS batteries for self-wheeling of renewable energy"*

Jul-21 – CATL: *"Unveils Its Latest Breakthrough Technology by Releasing Its First Generation of Sodium-ion Batteries"*

Oct-22 – CATL: *"Will Mass Produce Sodium-Ion Batteries in 2023"*

Dec-22 – UNITED AIRLINES: *"United Airlines is investing in sodium-ion battery development"*

Feb-23 – 大众安徽 VOLKSWAGEN ANHUI: *"Hina Battery becomes 1st battery maker to put sodium-ion batteries in EVs in China"*

First BYD model to use SIBs, launched in ***April 2023***

First mass-produced SIB vehicle, launched by HiNa and JAC Yiwei in ***Q4 2023***

https://www.sparctechnologies.com.au
https://www.catl.com/en/news/6013.html

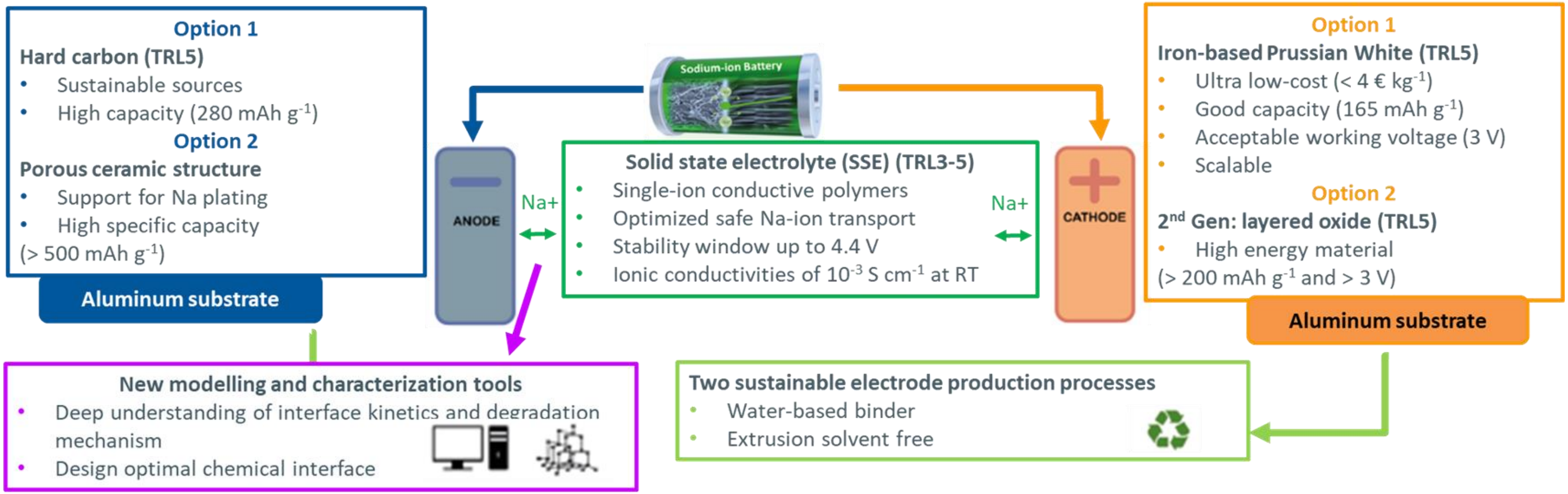
THE SIMBA PROJECT

SIMBA CONSORTIUM

- Acronym: SIMBA
- Call: H2020-LC-BAT08-2020
- Coordination: TU Darmstadt
- Duration: 42 months
- Start date: 1 January 2021
- Budget/funding: 7.91 M

SIMBA GOALS

Development of a highly cost-effective, safe, all-solid-state-battery with sodium as mobile ionic charge carrier for stationary energy storage applications



VALUE CHAIN AND THE ROLE OF THE SIMBA CONSORTIUM

Material Development	Characterization and Modelling	Material Production Up-Scaling	Electrode and Cell Production	Module and BMS Development	Testing and Validation	Recycling	End User
TUDa_RR	TUDa_RR	Elkem	WMG	Yunasko	UU	UBham	Yunasko
SAS	TUDa_GB	Altris	CEA	FHG	SAFT	TES-Recupyl	SAFT
IFE	TUDa_KA	KIT	UBham				
KIT	CEA	JM	JM				
UU							

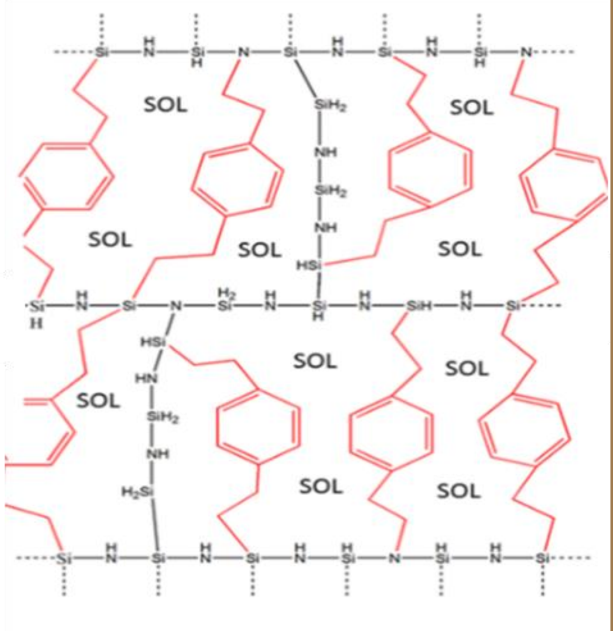
The SIMBA consortium exists out of 16 partners, from 8 different EU countries

Advisory Board Members

- *EnBW*
- *Leclanche*
- *Varta*
- *GAZ*
- *ENEA*
- *Rolls Royce*

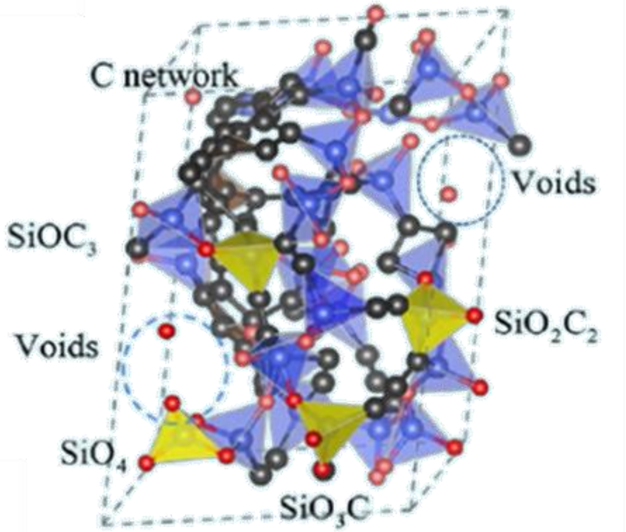
SIMBA ANODE MATERIALS

SiCN



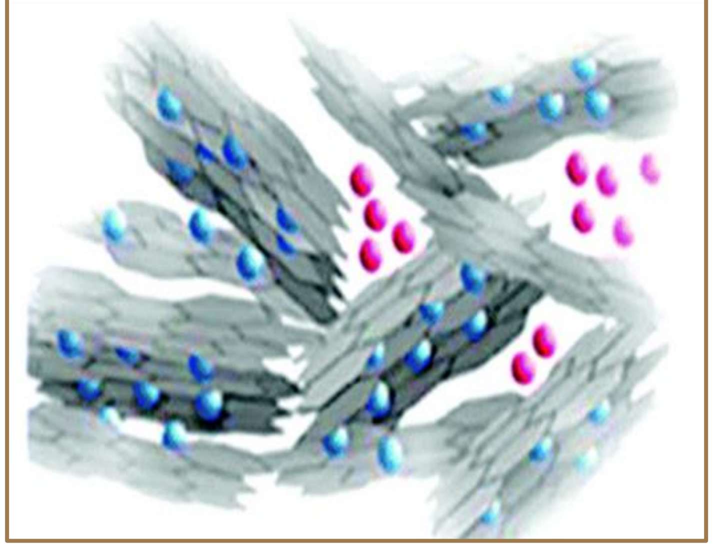
- Highly porous ceramic materials
- As Na plating matrix
- Sodium-metal batteries

SiOC



- Highly porous ceramic materials
- As Na plating matrix
- Sodium-metal batteries

Hard Carbon

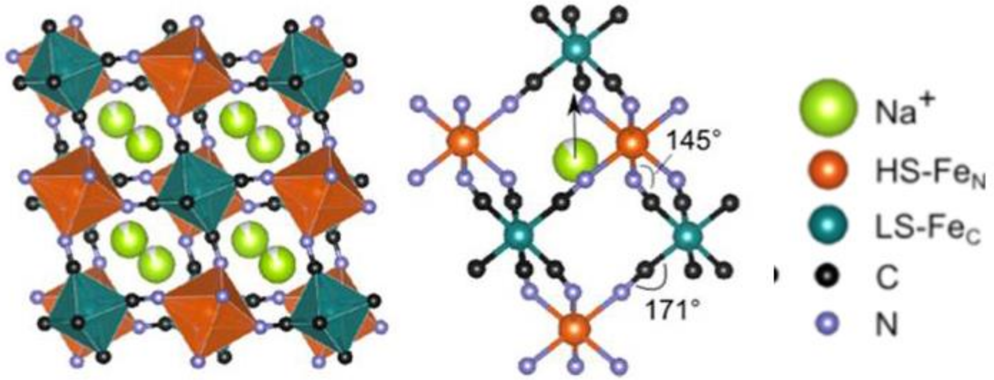


- Biomass-derived hard carbon
- Lignin-based precursors
- Sodium-ion batteries

Q. Wen, et al. J. Advanced Ceramics (2022) 11, 197-246
D. A. Stevens et al. J. Electrochem. Soc. (2000) 147, 1271–1273

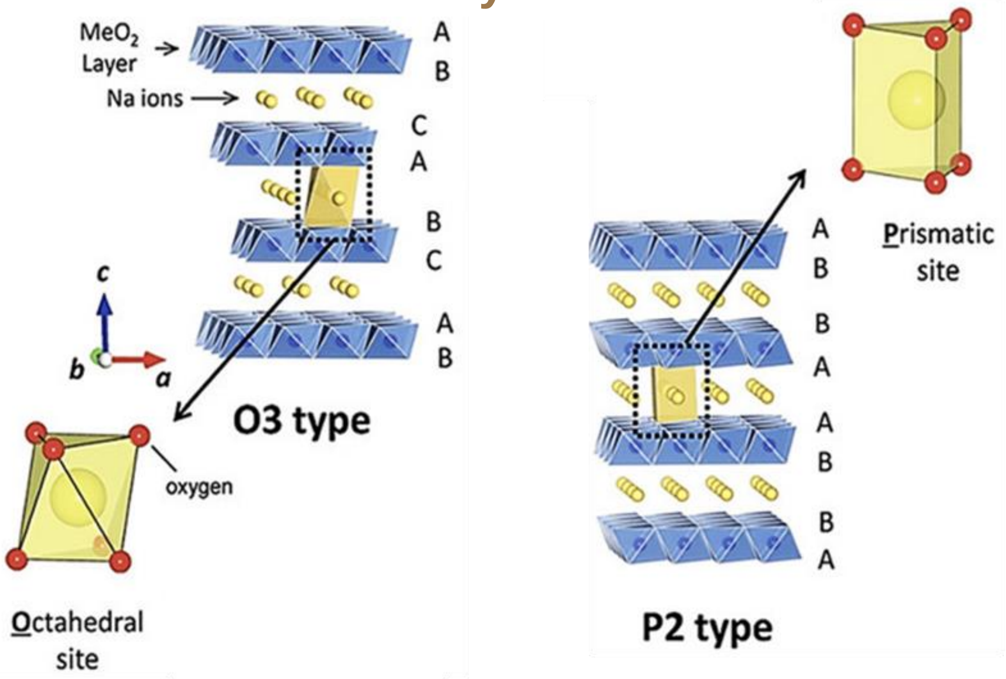
SIMBA CATHODE MATERIALS

Prussian White



+ Low-cost synthesis process
+ Good capacity and acceptable average voltage

P2/O3 layered oxides



+ Higher specific capacity

W. R. Brant, et al. Chem Mater (2019) 31, 7203-7211
K. Kubota, et al. MRS Bulletin (2014) 39, 416–422

SIMBA SOLID-STATE ELECTROLYTE

SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

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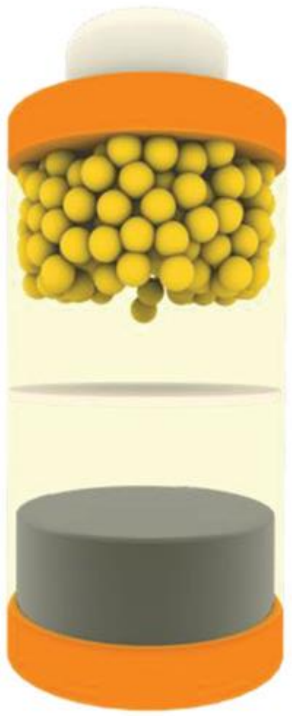
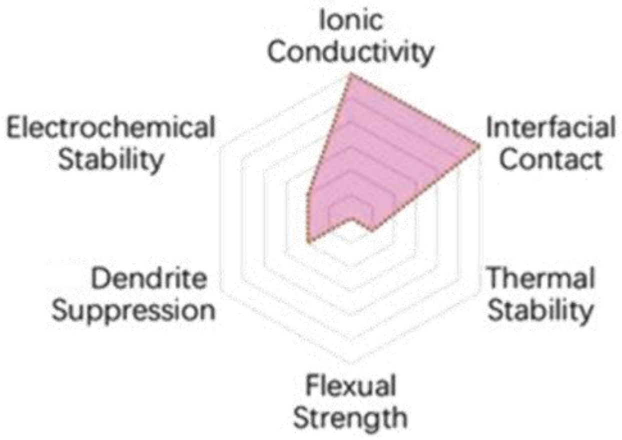
Liquid electrolytes

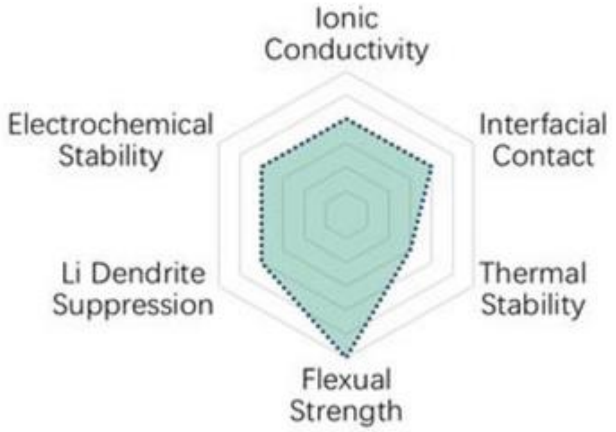




HIU HELMHOLTZ INSTITUTE ULM Electrochemical Energy Storage

KIT Karlsruher Institut für Technologie

Solid polymer electrolytes



S. Li, et al. *Adv. Sci. 2020, 7, 1903088* / Y. Wang, et al. Nano Mater. Sci. 2019, 1 91-100

CHARACTERIZATIONS AND MODELLING

SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

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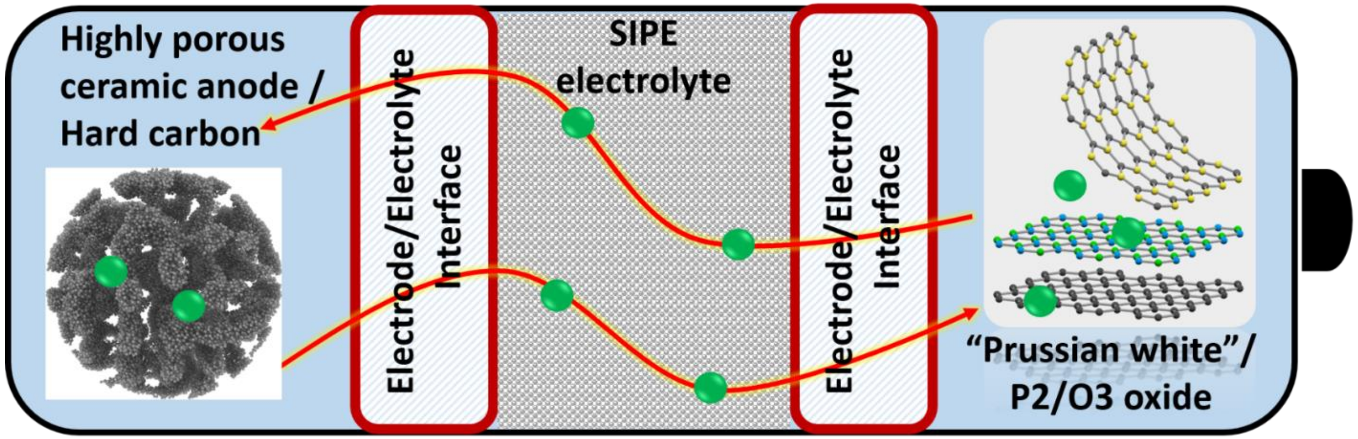
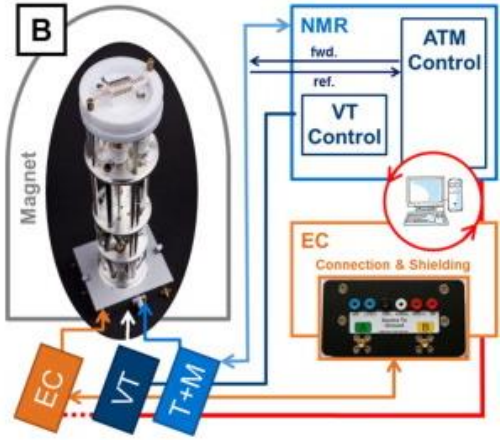
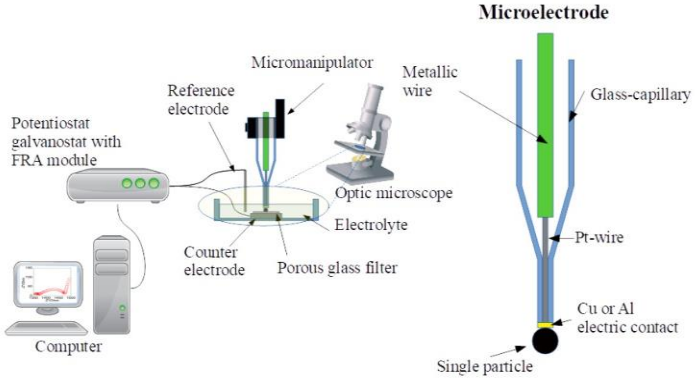
TECHNISCHE UNIVERSITÄT DARMSTADT

WMG THE UNIVERSITY OF WARWICK

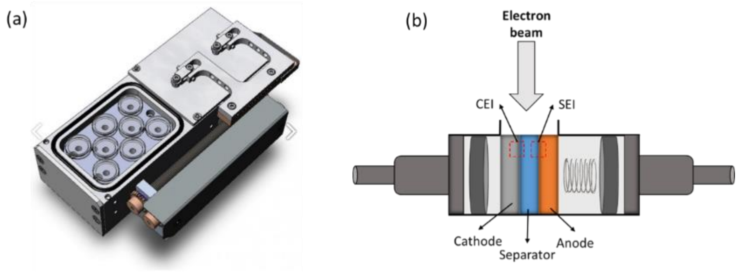




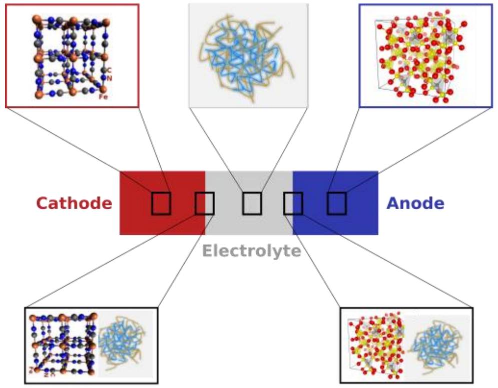
In-situ NMR



Single Particle Measurement



Operando SEM

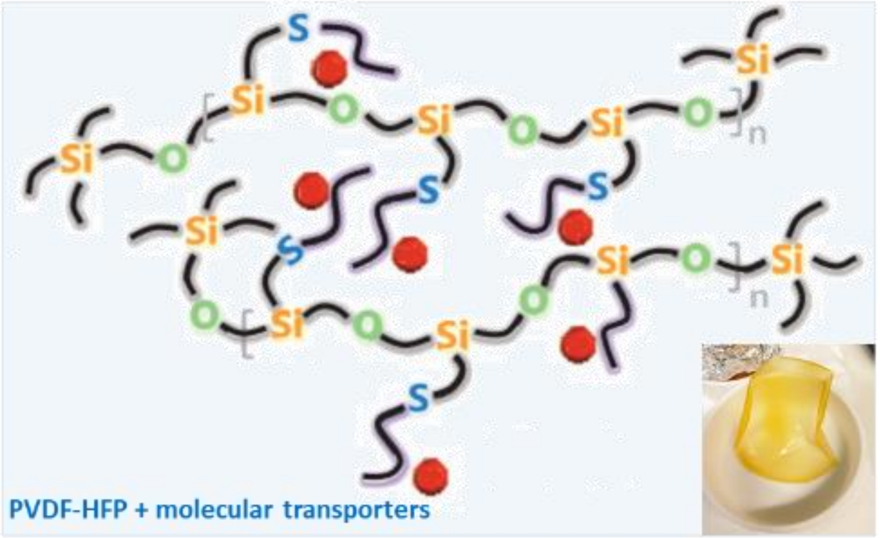


Modeling

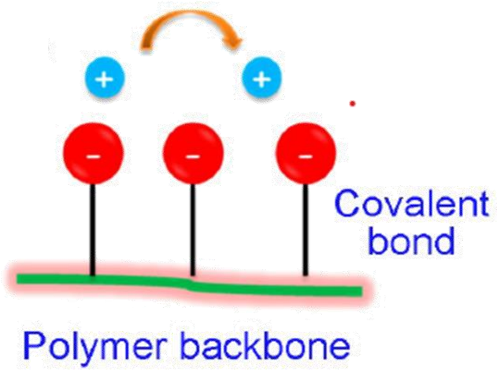
SIMBA HIGHLIGHTS: MATERIALS

Development of a stable single-ion conductor polymer electrolyte

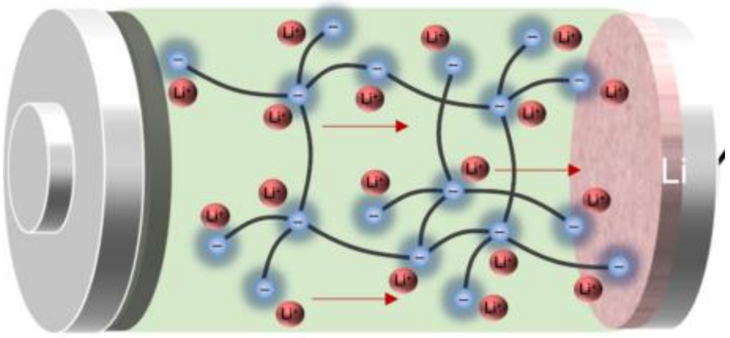
Single-ion polymer electrolytes (SIPEs)



*Modified from: H. Liang et al. Adv. Energy Mater. 2022, 12, 2200013



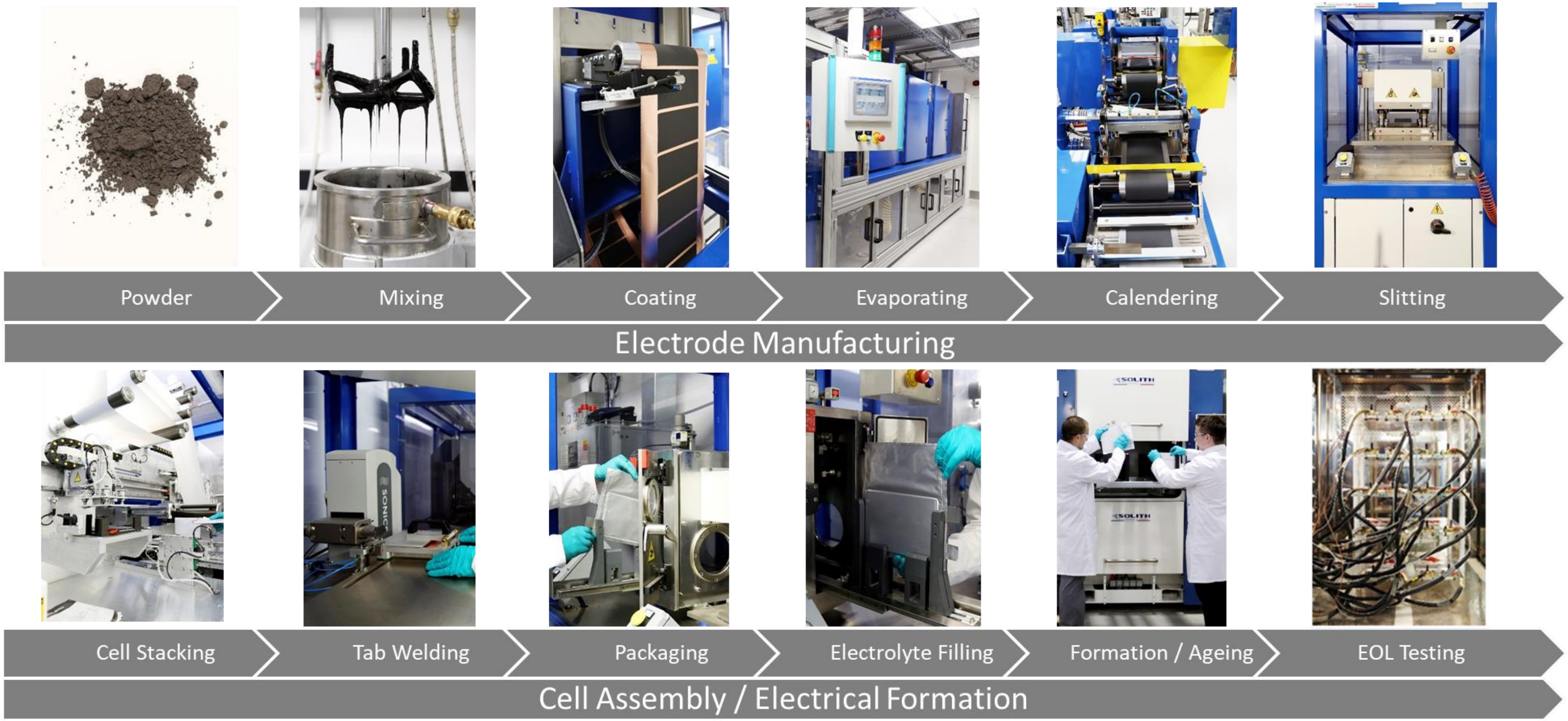
- Production upscaled
- Electrochemical stability
- Good mechanical properties
- Successful use in full cells
- Successfully tested in extrusion



- Mobile species: cation
- No concentration gradient
- Enhanced Na dendrite suppression
- Na^+ transference number: high (close to 1.0)

SIMBA HIGHLIGHT: CELL MANUFACTURING

SIBs are a drop in technology! Current manufacturing facilities can be employed!



SIMBA HIGHLIGHTS: PROCESSES

Development of the extrusion process: Prussian White + Polymer + SIPE

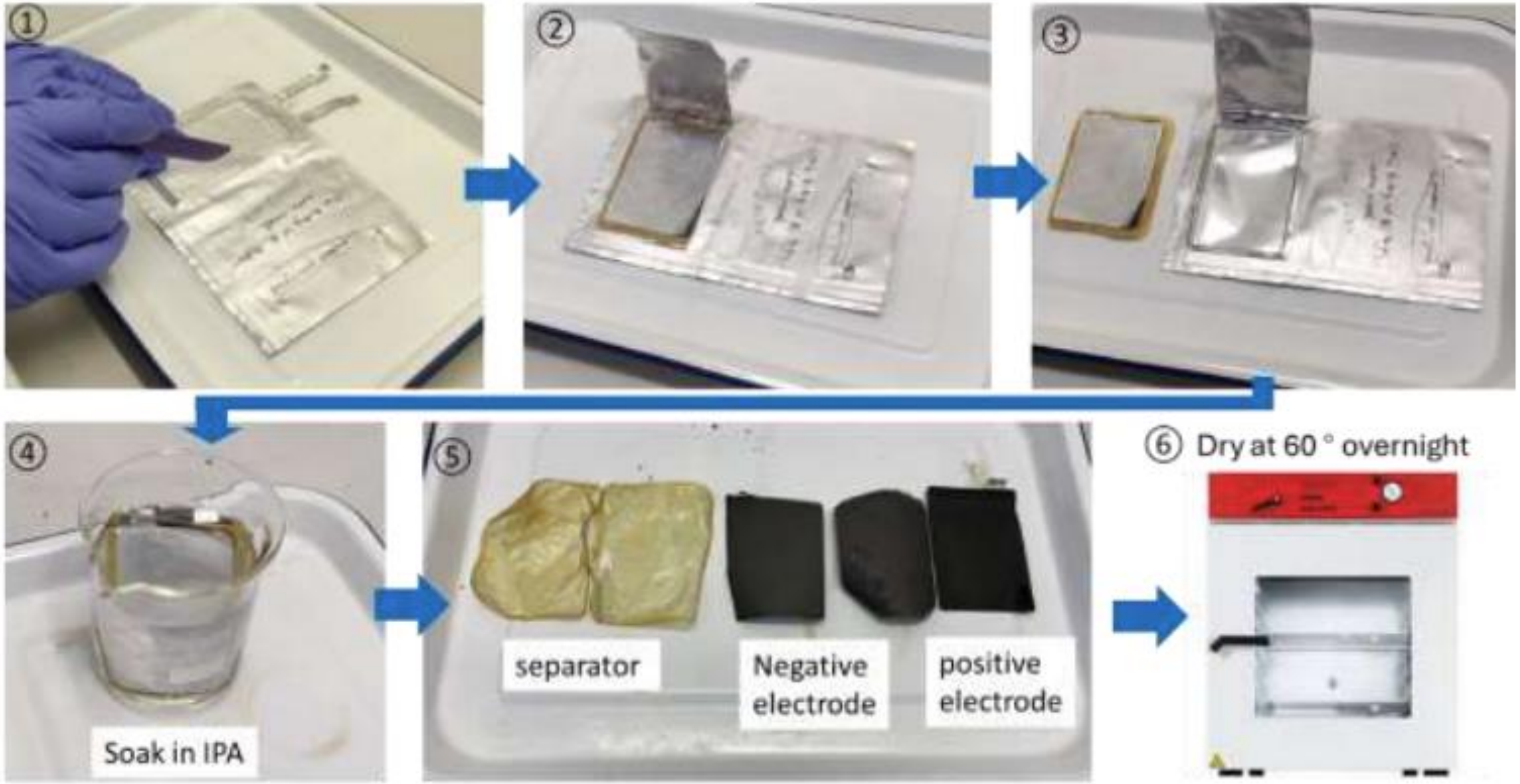
- Extrudate presents a smooth appearance and a good texture

- Equipment: Pharma11 (ThermoScientific), 11 mm diameter, L/D=40

- Adhesion on aluminium collector is quite good after lamination

SIMBA HIGHLIGHTS: PROCESSES

Design for Disassembly, Separation And Recycling



Opening process of end-of-life SSB, separation of the components

SIMBA HIGHLIGHTS: METHODS

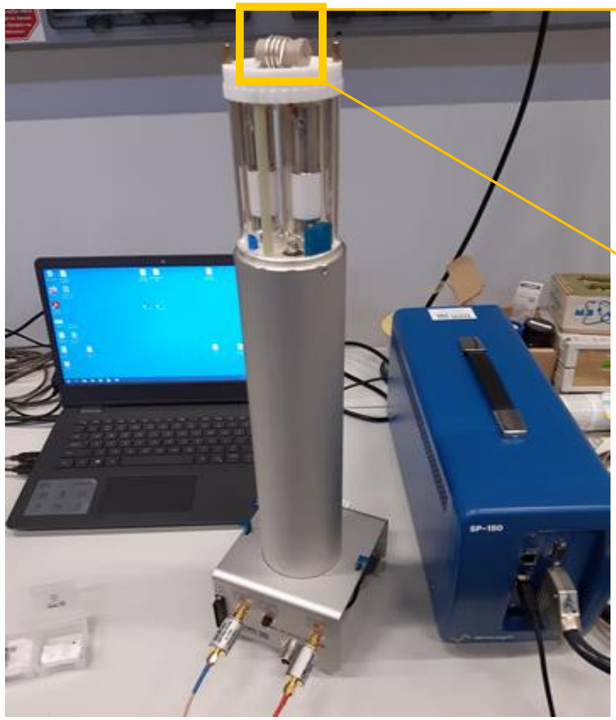
SODIUM-ION AND SODIUM METAL BATTERIES

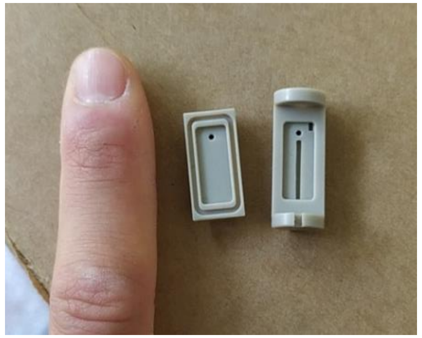
TECHNISCHE UNIVERSITÄT DARMSTADT

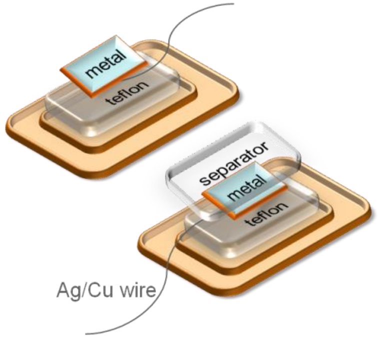
RG Buntkowsky

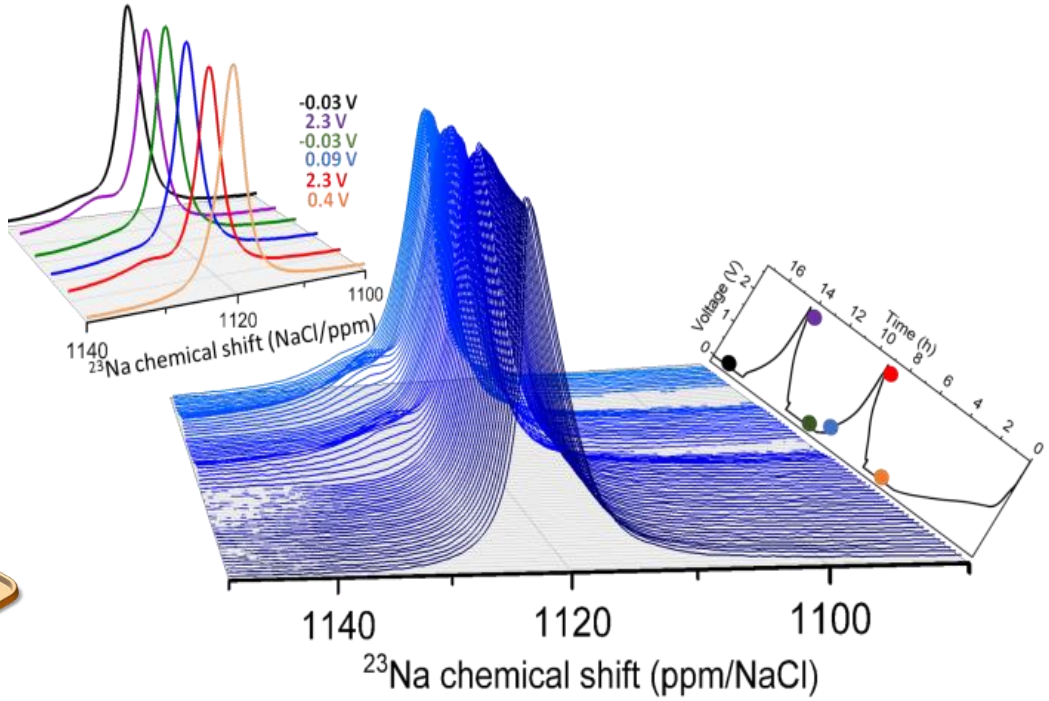
In-situ solid state NMR setup

One channel solid-state probe head and electrochemical cycler







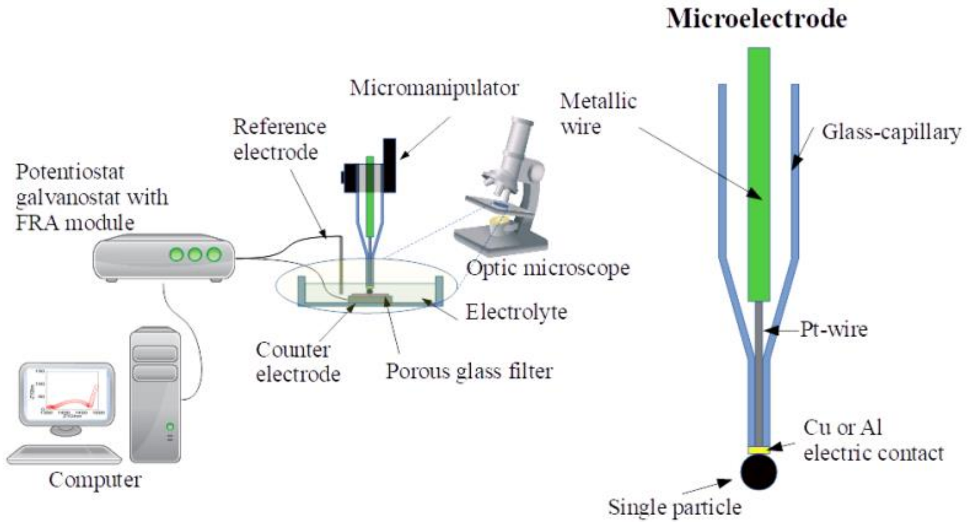


- Enables recording NMR spectra under electrochemical charge/discharge conditions
- Successful measurements for SIMBA anodes and electrolytes performed

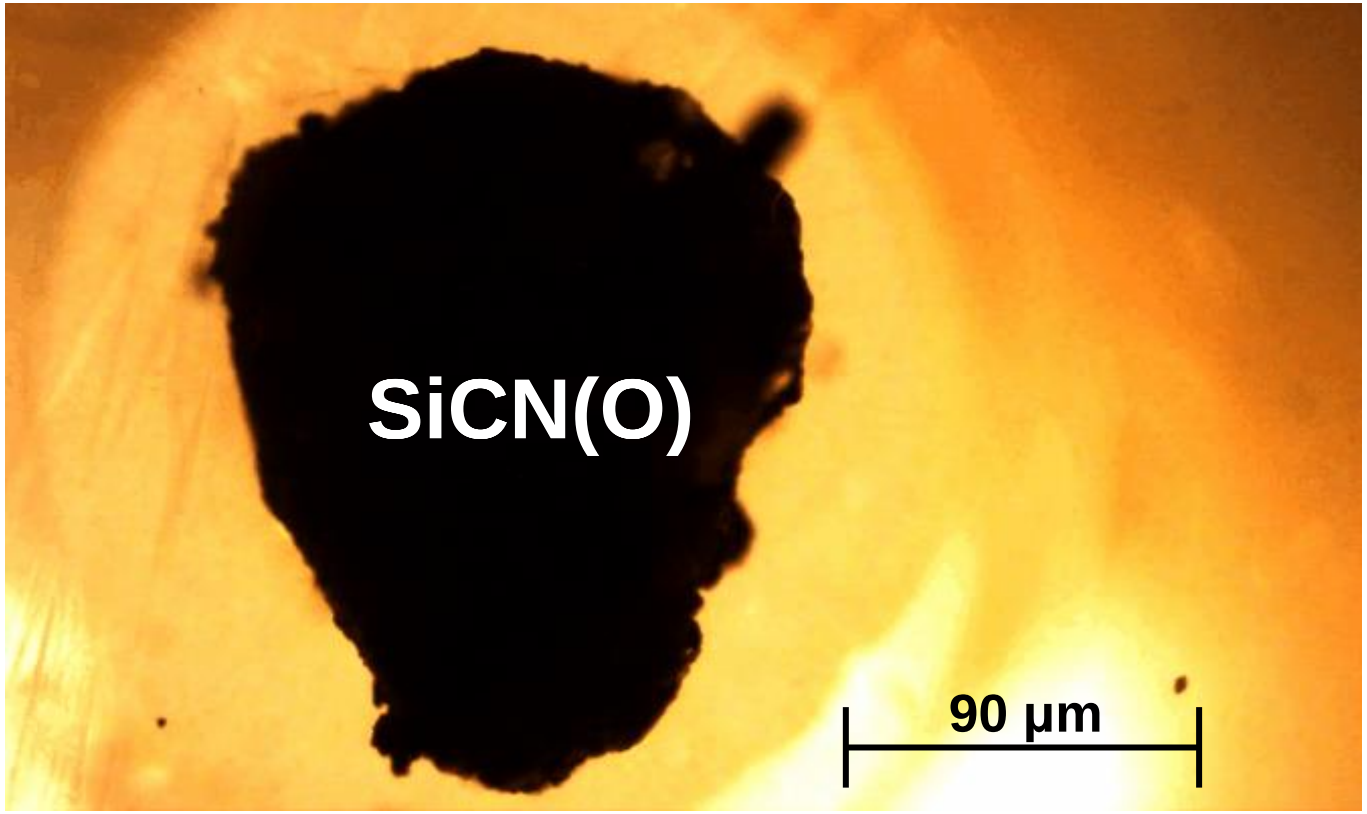
SIMBA HIGHLIGHTS: METHODS

Single particle measurement setup

Schematic of the SPM setup

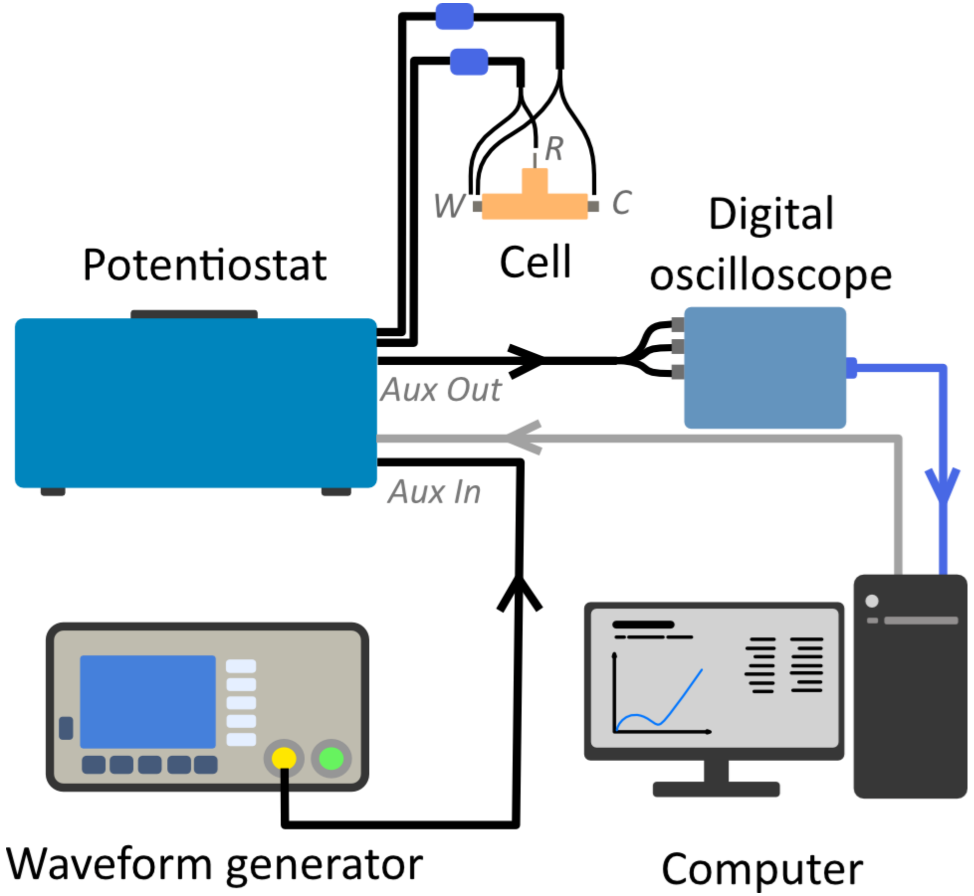


Dendrites growth on SiCN(O) particle

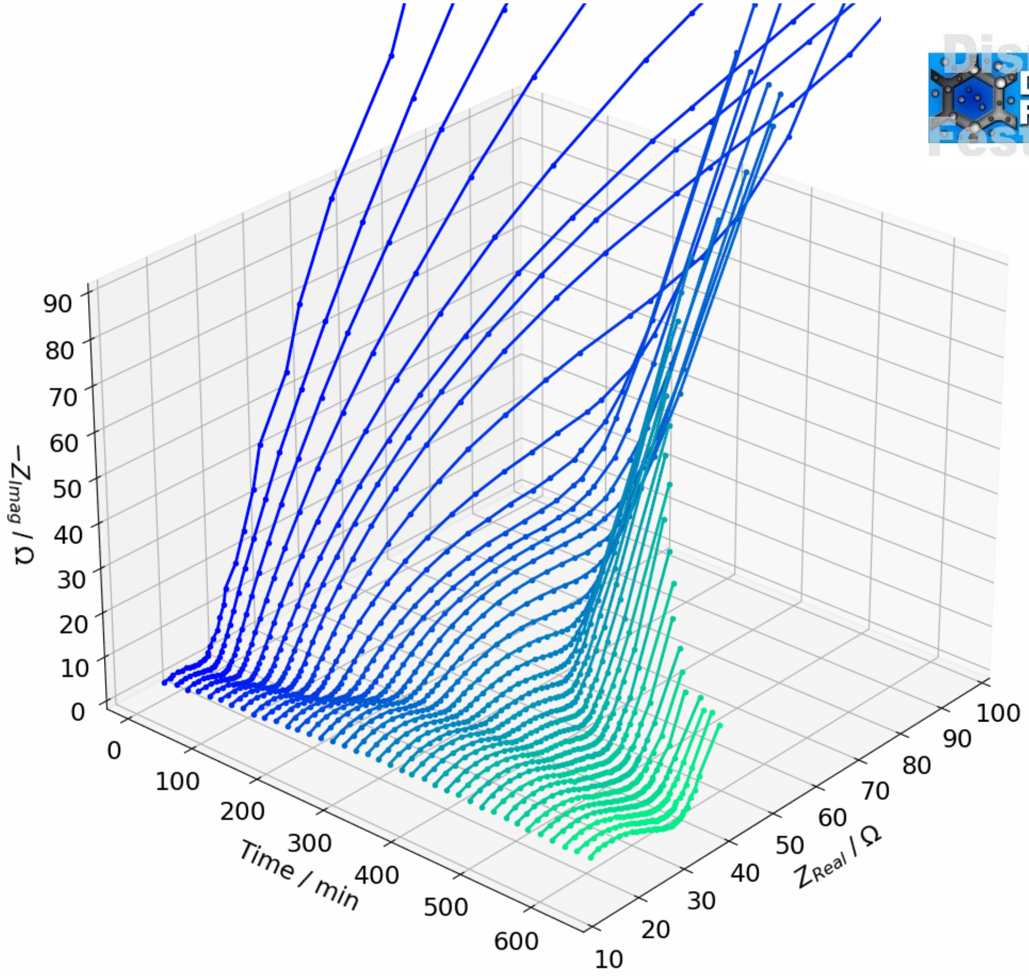


SIMBA HIGHLIGHTS: METHODS

Dynamic Electrochemical Impedance Spectroscopy (DEIS)



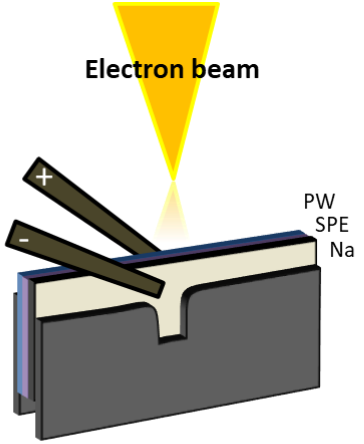
Pianta, Scarpioni et al. Evaluation of kinetic parameters of non-faradic processes in carbon-based electrodes using multisine dynamic electrochemical impedance spectroscopy, Electrochim. Acta 2023, 141462

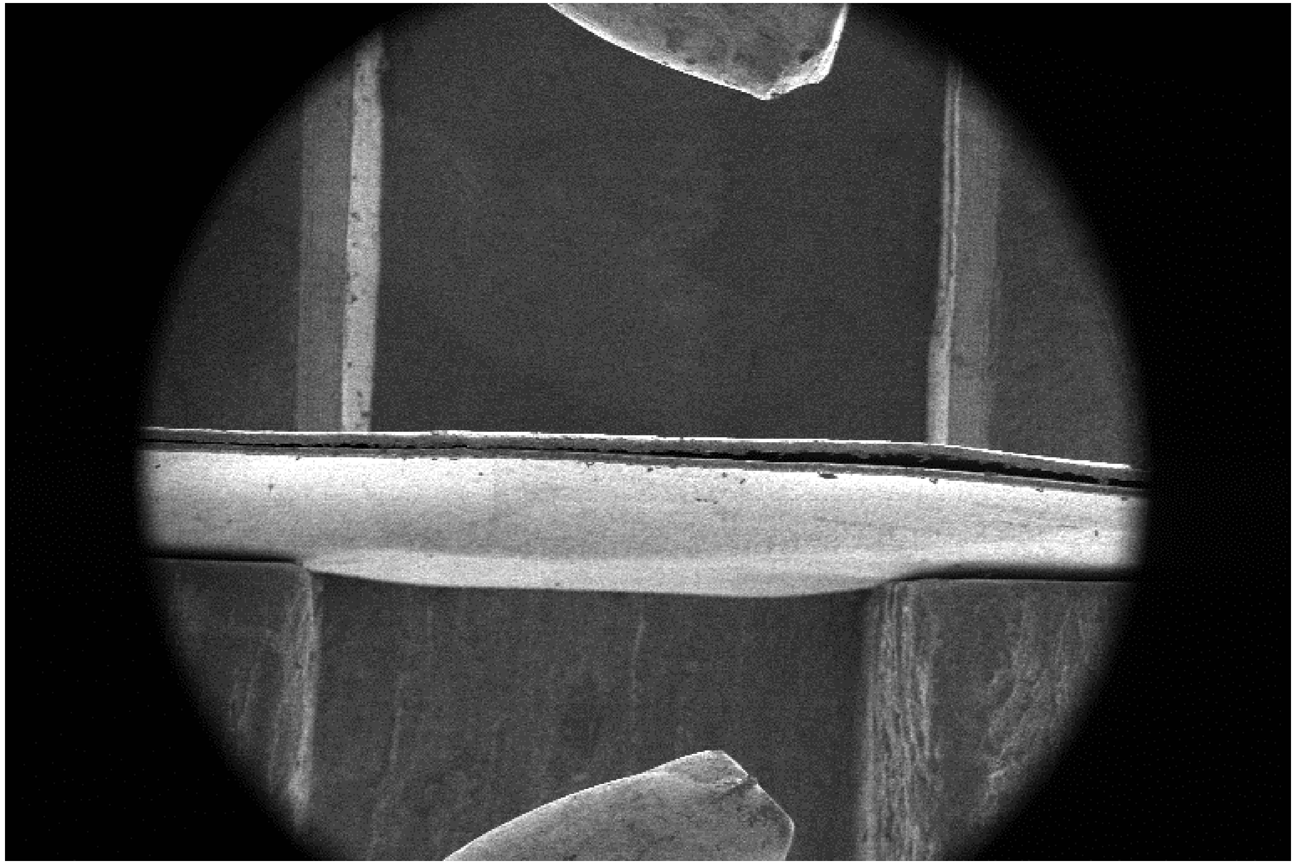


Marco Melzi d´Eril, TUDa unpublished

SIMBA HIGHLIGHTS: METHODS

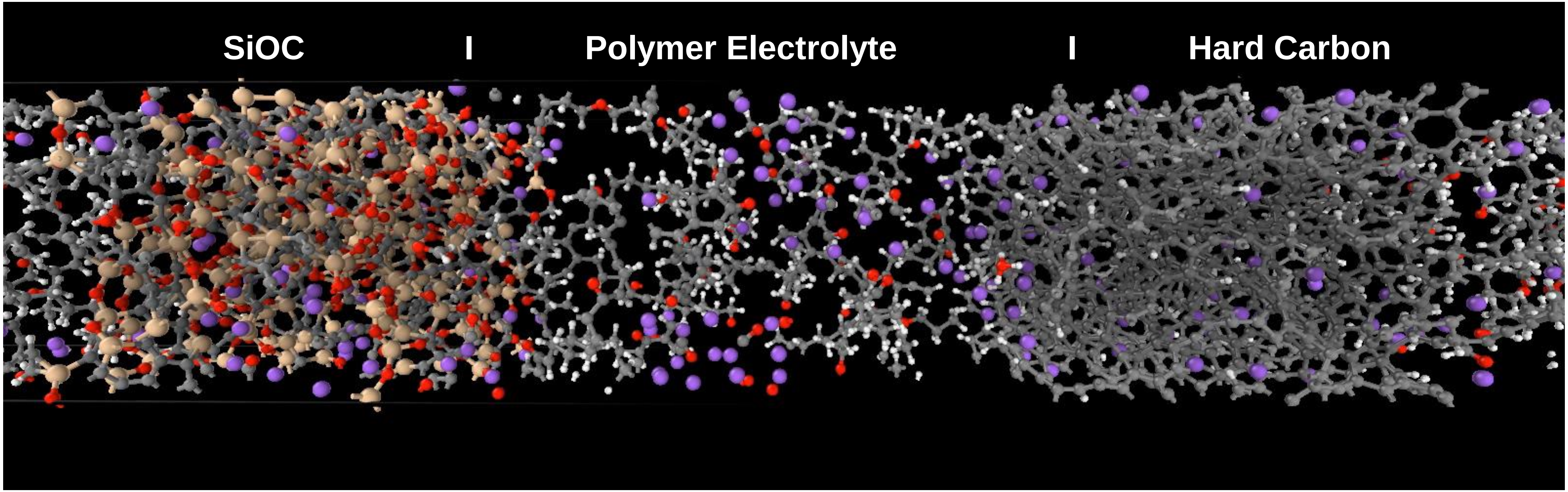
In-situ SEM analysis of the interface in the cell





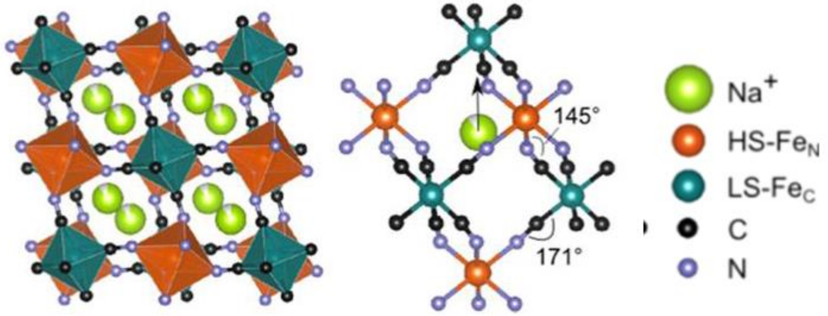
SIMBA HIGHLIGHTS: MODELLING

Model of the sodium transfer across interfaces of the cell with a polymer electrolyte

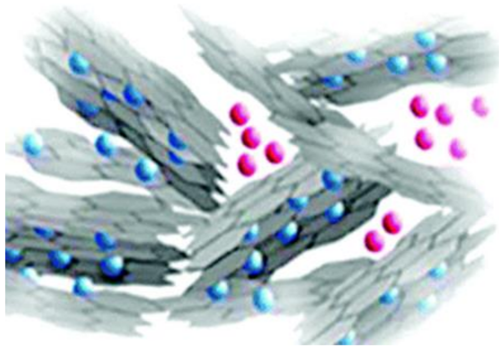


SUMMARY

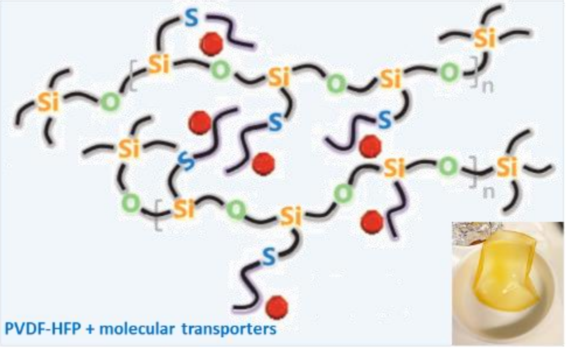
Prussian White



Hard Carbon



SIPE



Pouch SIMBA Cell incl. Temperature Sensor (Thermistor)

ACKNOWLEDGEMENTS (TU DARMSTADT)

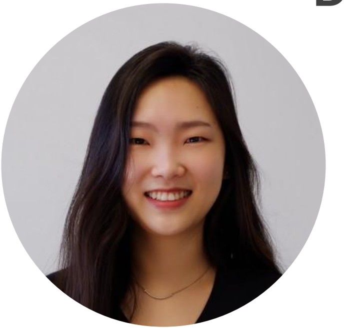
SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

Dr. Magdalena Graczyk-Zajac

Dr. Dario De Carolis

Dr. Ying Zhan



Marco Melzi d'Eril

Horizon 2020
European Union Funding
for Research & Innovation

ACKNOWLEDGEMENTS (UNIRESEARCH)

Dr. Arjo Roersch van der Hoogte

Dr. Piter Miedema

Horizon 2020
European Union Funding
for Research & Innovation

THANK YOU FOR YOUR ATTENTION!

Horizon 2020
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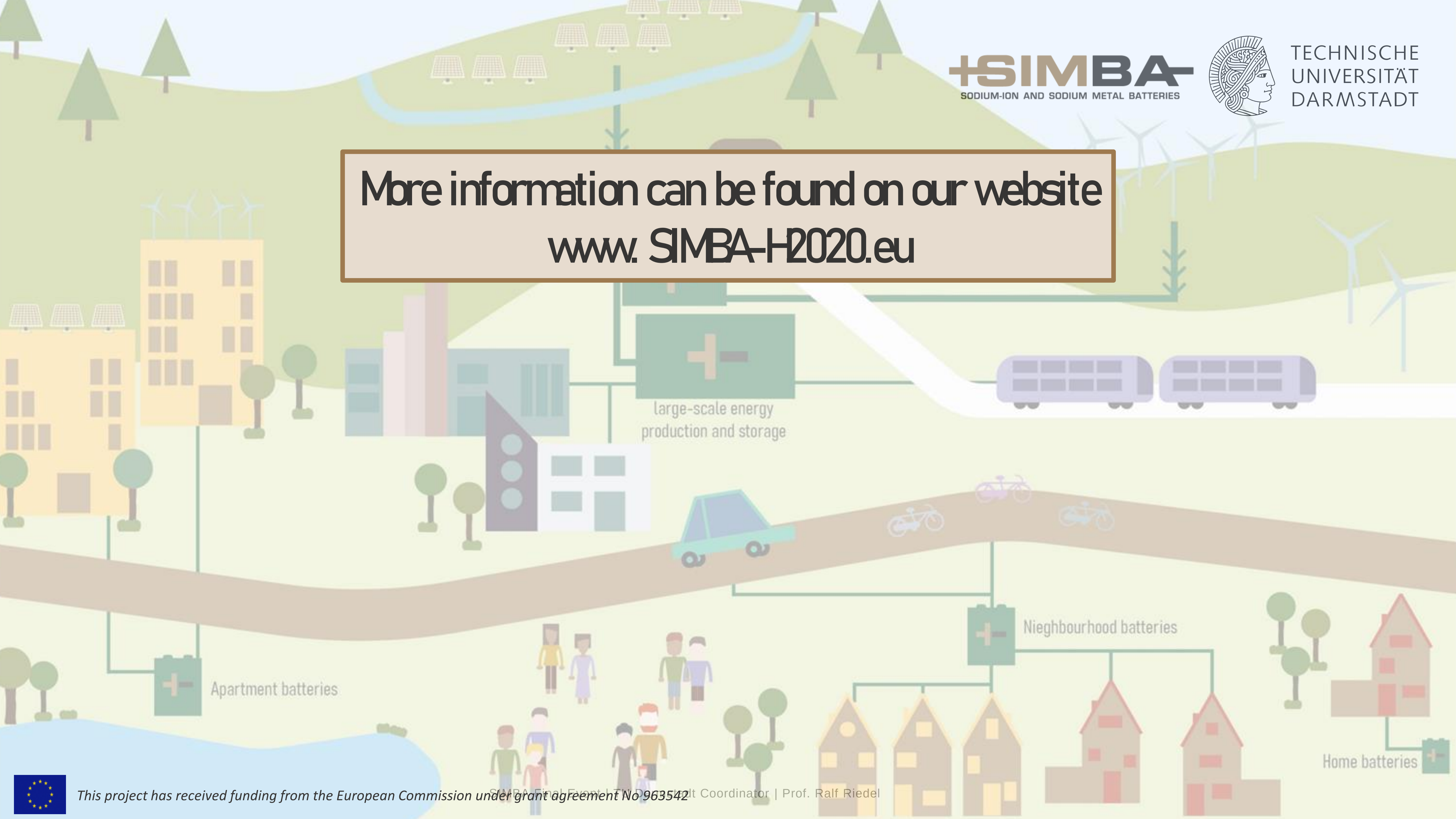

SIMBA SODIUM-ION AND SODIUM METAL BATTERIES

TECHNISCHE UNIVERSITÄT DARMSTADT

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