Empa
Materials Science and Technology

Energy Research Talks Disentis 2025

Towards rapid laser joining of ceramic-metal components for molten-salt battery manufacturing

<u>Heloisa Ramlow</u>[1], Hossein Ghasemi-Tabasi[2], Michael Harald Bayer[3], Andreas Burn[2], Johann Jakob Schwiedrzik[1], Gurdial Blugan[1]

[1]Laboratory for High Performance Ceramics, Empa, Swiss Federal Laboratories for Materials Science & Technology, CH-8600 Dübendorf, Switzerland

[2]Switzerland Innovation Park Biel/Bienne AG, Aarbergstrasse 46, 2503 Biel/Bienne, Switzerland

[3]Saleon AG, Zeughausstrasse 19d, 3860 Meiringen, Switzerland

Where are batteries used?

Electronic devices

Electromobility

Home storage

Large stationary storage systems

Special applications

Which technologies are used?

Lead-acid battery

Alkali-manganese

Nickel metal hydride

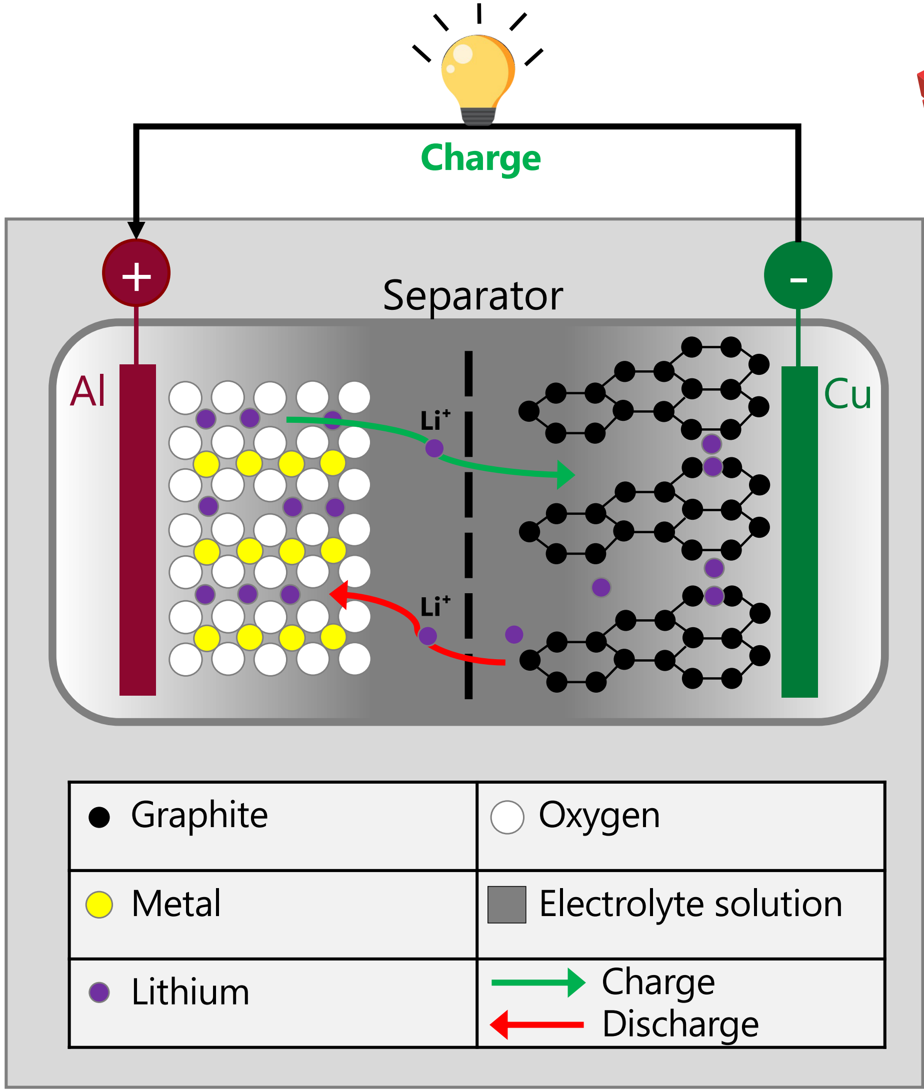
Zinc-carbon

Zinc-air

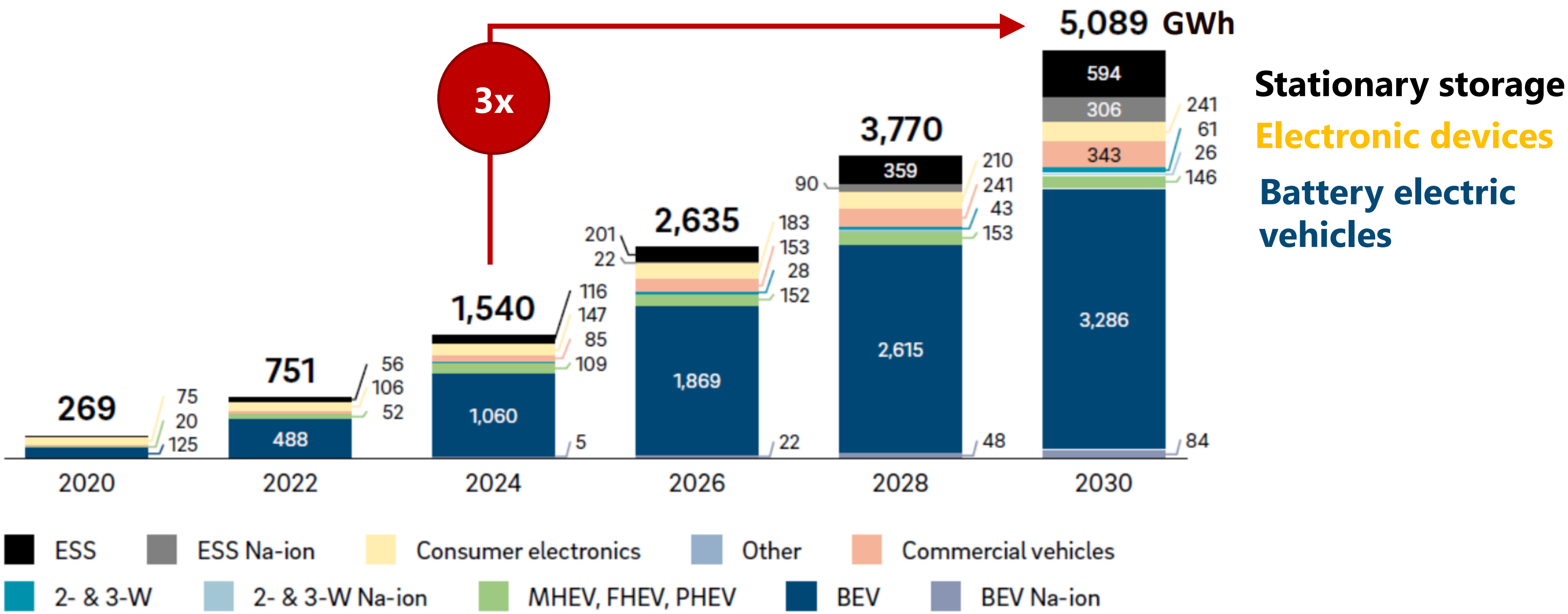
Lithium-ion batteries

Lithium-ion batteries

- Lithium-ion batteries are widely used in most applications today (> 90% of today's batteries)
- During charging, lithium ions (Li^+) move to the graphite anode (right), and during discharging, they migrate to the cathode (left)



Expected development of the battery markets

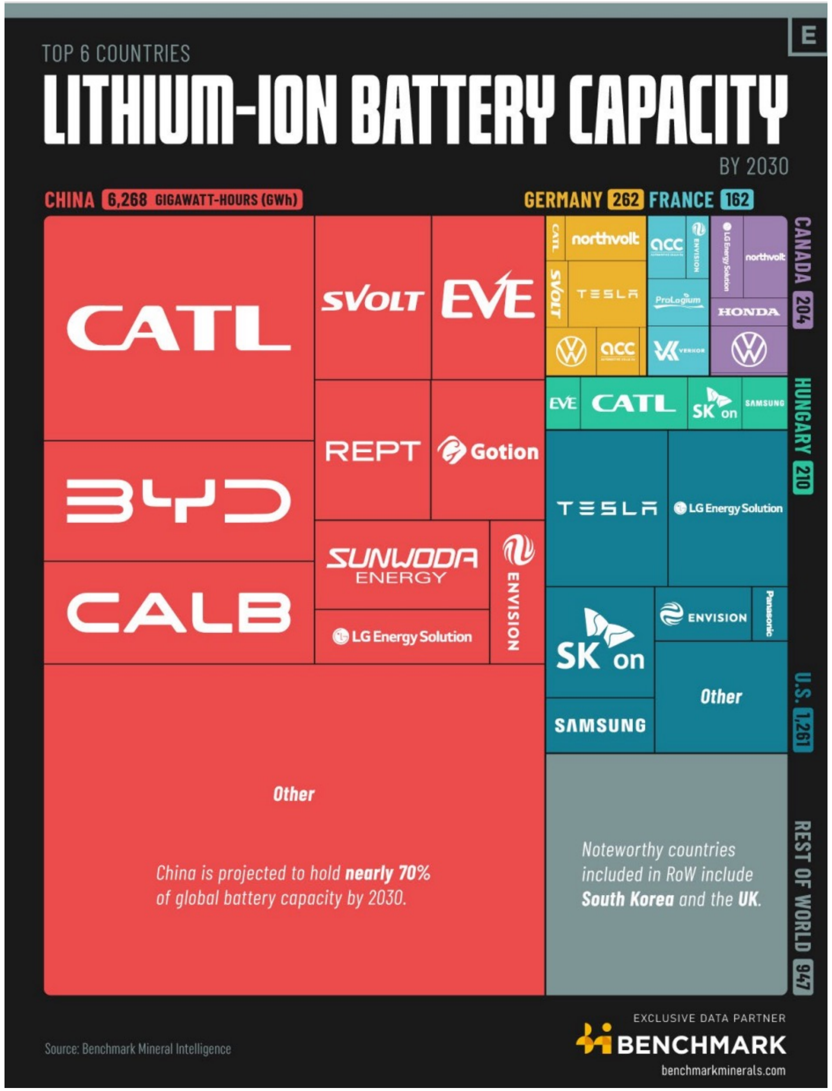


1) BEV, 2- & 3-W and ESS CAGR including Na-ion demand. Abbreviations: BEV: Battery Electric Vehicles; MHEV, FHEV, PHEV: Mild Hybrid, Full Hybrid and Plug-in Hybrid Electric Vehicle; Light vehicle: Passenger cars and light commercial vehicles up to 6 tons; LSEV: Low-Speed Electric Vehicle; 2- & 3-W: Electric Two-/Three-Wheelers

Source IHS, SMM, Roland Berger

Battery production in the world

- Most battery production currently occurs in Asia, particularly in China
- However, efforts are underway to enhance supply security and achieve technological independence, with an increasing number of batteries being produced in Europe
- This shift is driven by
  - 1) Asian manufacturers establishing factories in Europe, and
  - 2) the involvement of American and European companies, including startups
- While numerous plans and announcements have been made, many projects have recently been delayed due to the challenging market conditions



Battery production in Switzerland

renata batteries
A COMPANY OF THE SWATCH GROUP

Hearing aid batteries

WYON
SWISS BATTERIES

Li-ion micro batteries for implants

Leclanché
Energy Storage Solutions

Powerful Li-ion based on LTO

BATTERY CONSULT

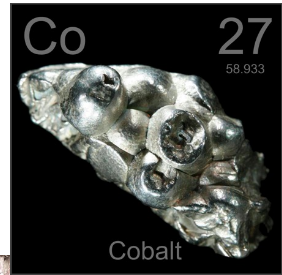
HORIEN
Salt Battery Solutions

Sodium metal chloride batteries for stationary storage

Lithium: key characteristics

- Li is the lightest metal (density = 0.543 kg/cm^3)
- Highest electrochemical potential (E^0 = -3.04 V)
- Reacts violently with O_2 in metallic form (burns!)
- Relatively common (more common than Cu in the earth's crust), approx. USD 20/kg
- Extracted from salt lakes and especially from mines (Australia)
- Non-toxic (used as a medicine)
- Only approx. 2% of the battery mass is lithium

And what about cobalt?



- Co lies between Fe and Ni in the periodic table (± 1 proton, Cu +2)
- Frequently used as an alloy component, e.g. in aircraft turbines
- Mined mostly as a by-product of Cu or Ni, approx. USD 50/kg
- Somewhat rarer in the earth's crust than Cu, Ni, Cr
- Component of vitamin B12 (cobalamin), very important for ruminants
- Approx. 75% comes from large mines (Congo), 13% from artisanal and small-scale mining
  - Small-scale mining* with demonstrably enormous social problems
- Proportion of cobalt in battery: ~ 8% for NMC 1:1:1, ~ 3% for NMC 8:1:1

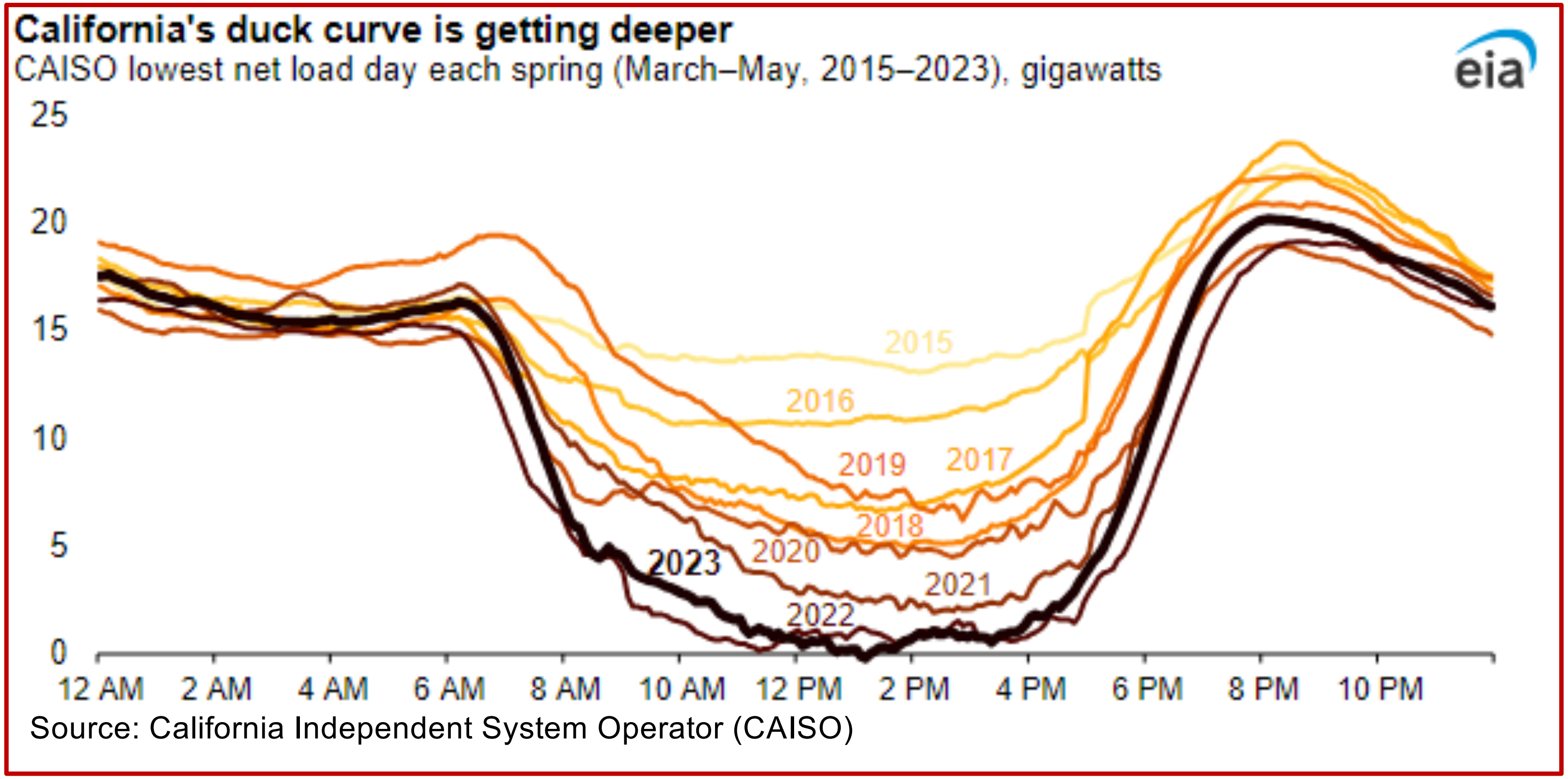
What developments can be expected?

- **There will be further progress in**
  - reusing and recycling
  - the avoidance of critical materials (e.g. Co, Li)
  - the further reduction of costs (which have already fallen massively in recent years)
  - in terms of energy density, e.g. with solid-state batteries
  - solid-state electrolytes (closo-borane, titanium nitride, Al, ...)
  - anode: graphite with silicon, Li-metal, Na-metal
  - cathode: little cobalt, NMC 8:1:1, $LiFePO_4$
  - alternative: sodium nickel chloride (ZEBRA) and redox flow batteries
  - 'air-metal' batteries e.g. Li-Air

...but certain limits will remain: extremely high energy densities, such as those required for long-haul air travel, for example, are not to be expected

Stationary battery storage – Example from California

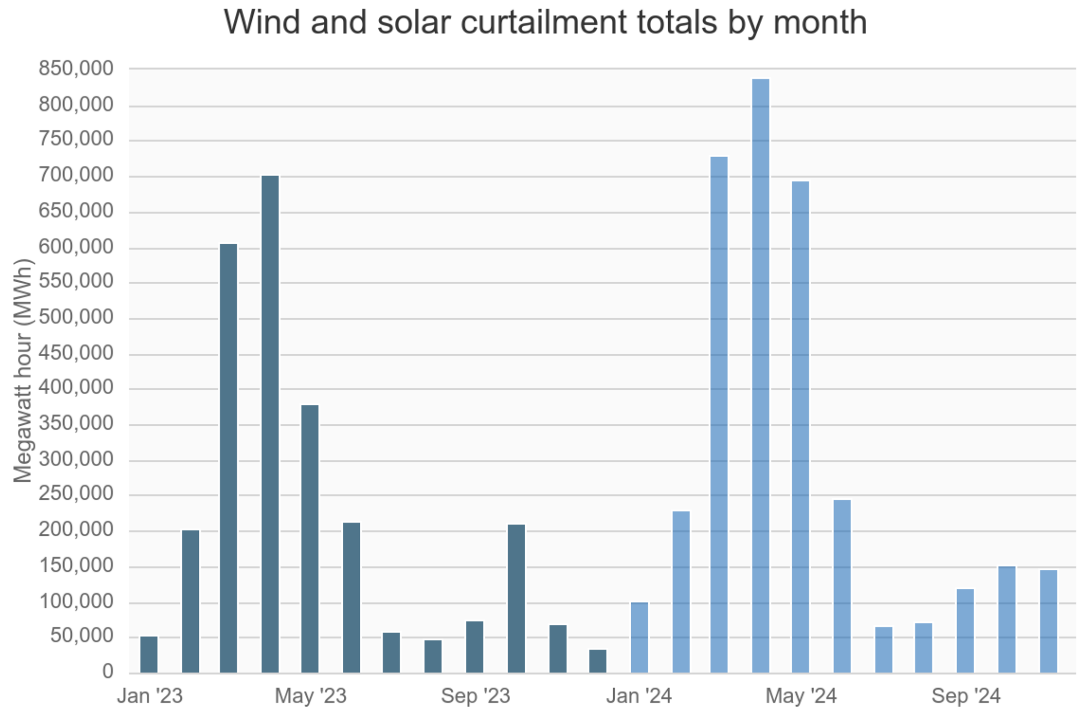
- ‘Duck curve’



- Conventional power plants are used less during the day and need to ramp up quickly in the evening when solar drops
- Curtailment and economic issues

Stationary battery storage – Example from California

- CAISO has already reduced 3.4 TWh of wind and solar energy until November/2024
- Equivalent to the energy requirements of around 680,000 Swiss households
- Batteries help to smooth the duck curve by storing excess renewable energy when generation exceeds demand
- Grid stability and efficiency with batteries



Updated as of 12/10/2024

Source: California Independent System Operator (CAISO)

Stationary battery storage – Lithium-ion batteries

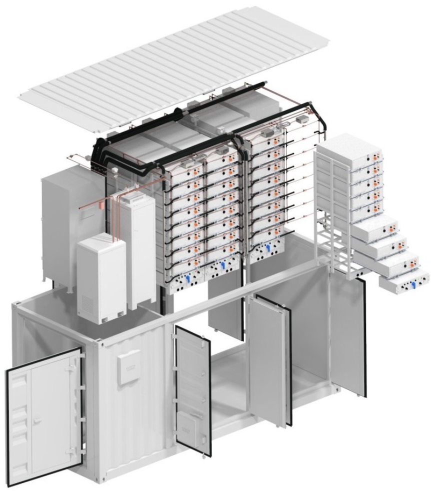
- Dominate the battery market
- High energy density, up to 8 MWh per container
- Edwards & Sanborn

solar-plus storage project in

California: 864 MWdc

of solar and 3,287 MWh

of energy storage



Source: https://cambridgerenewables.co.uk/megawatt-hour-container-bess/

California solar-plus-storage project with world's largest BESS fully online

By Cameron Murray

January 24, 2024

US & Canada, Americas · Grid Scale · Business

LinkedIn · Twitter · Reddit · Facebook · Email

The project in California. Image: Mortenson / Terra-Gen.

Source: https://www.energy-storage.news/edwards-sanborn-california-solar-storage-project-world-largest-bess-battery-system-fully-online/

Largest BESS in Switzerland

- Ingenbohl substation, Schwyz: 28 MWh of energy storage balancing energy to Swissgrid

Source: https://www.energy-storage.news/private-funding-puts-switzerlands-largest-grid-stabilising-megabattery-into-action//

In the news

Source: https://www.youtube.com/watch?v=gLmP0tPac34

Semi-truck carrying lithium-ion batteries overturns, sparks fire in San Pedro

By Tim Pulliam
Friday, September 27, 2024

Este artículo se ofrece en Español →

A semi-truck carrying large lithium-ion batteries overturned Thursday in San Pedro, sparking a fire while also forcing a closure of the 47 Freeway and the Vincent Thomas Bridge.

Source: https://abc7.com/post/semi-truck-carrying-lithium-ion-batteries-overturns-sparks-fire-san-pedro/15360889/

Hecate Energy 2.4GWh California project rejected while San Diego votes against BESS moratorium

By Andy Colthorpe

October 3, 2024

Source: https://www.energy-storage.news/hecate-energy-2-4gwh-california-project-rejected-while-san-diego-votes-against-bess-moratorium/

Third battery fire at the same site in Germany

It's the third time in two months that a battery fire has broken out on the premises of Suncycle in Germany.

AUGUST 13, 2024 SANDRA ENKHARDT

ENERGY STORAGE UTILITY SCALE STORAGE GERMANY

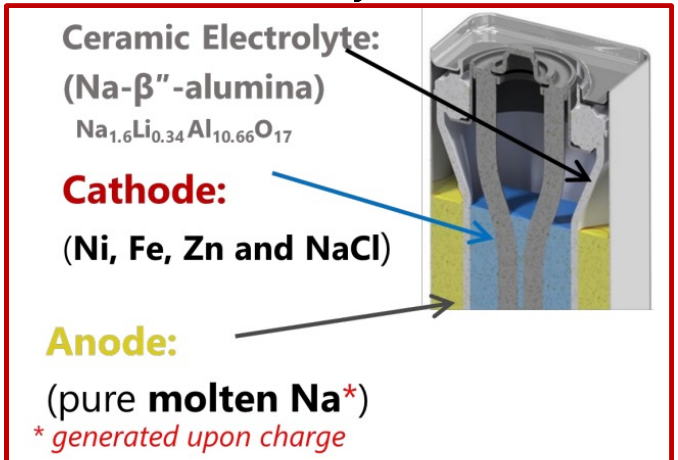
The cause of the fire is still unclear

Image: Johannes Krey, https://jkftv.de

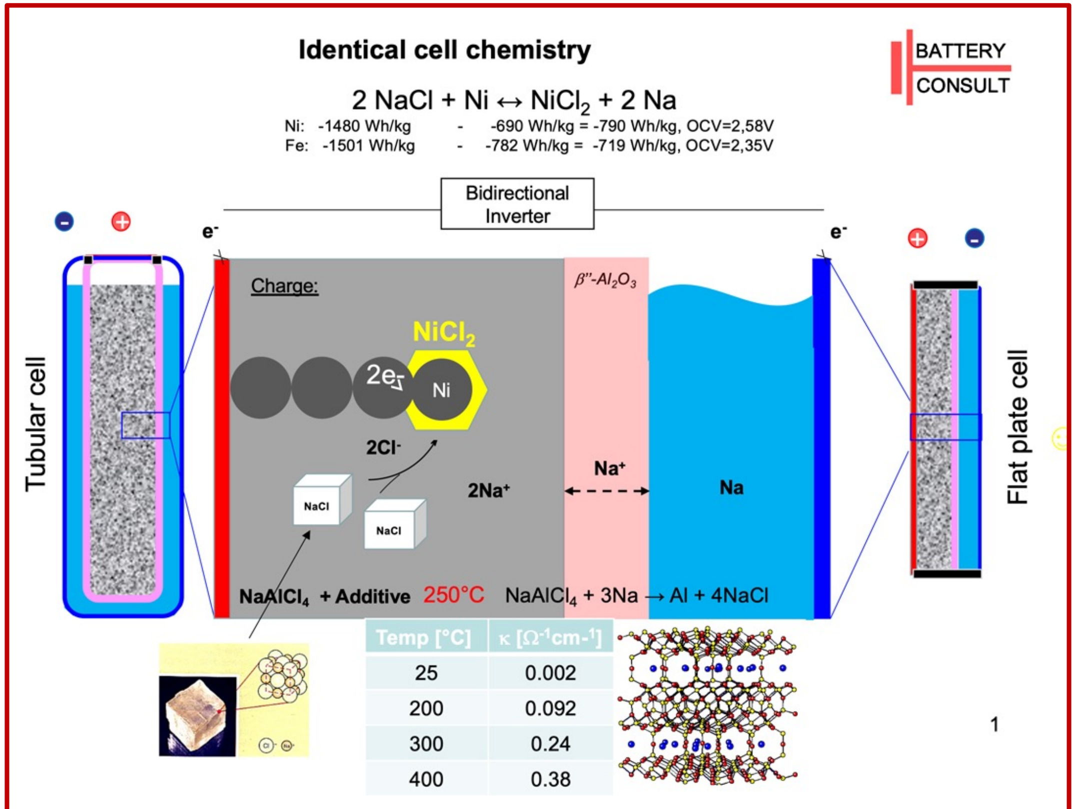
Source: https://www.pv-magazine.com/2024/08/13/third-battery-fire-at-the-same-site-in-germany/

Molten-salt batteries

- Typical materials include nickel and common salt
- They operate at temperatures of 300 °C, offering 150 Wh/kg and up to 4,000 cycles
- Competitive cycle costs of <0.02-0.04 $/kWh/cycle



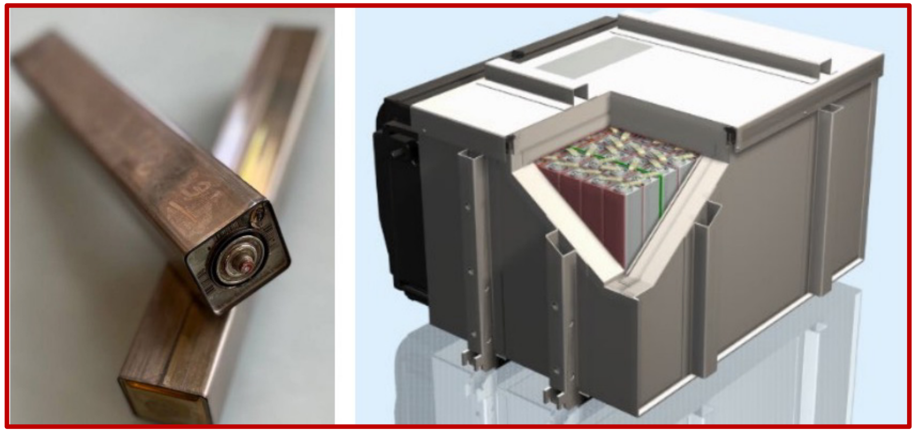
Source: M. Heinz,et al. Electrochimica Acta,464, 2023, 142881

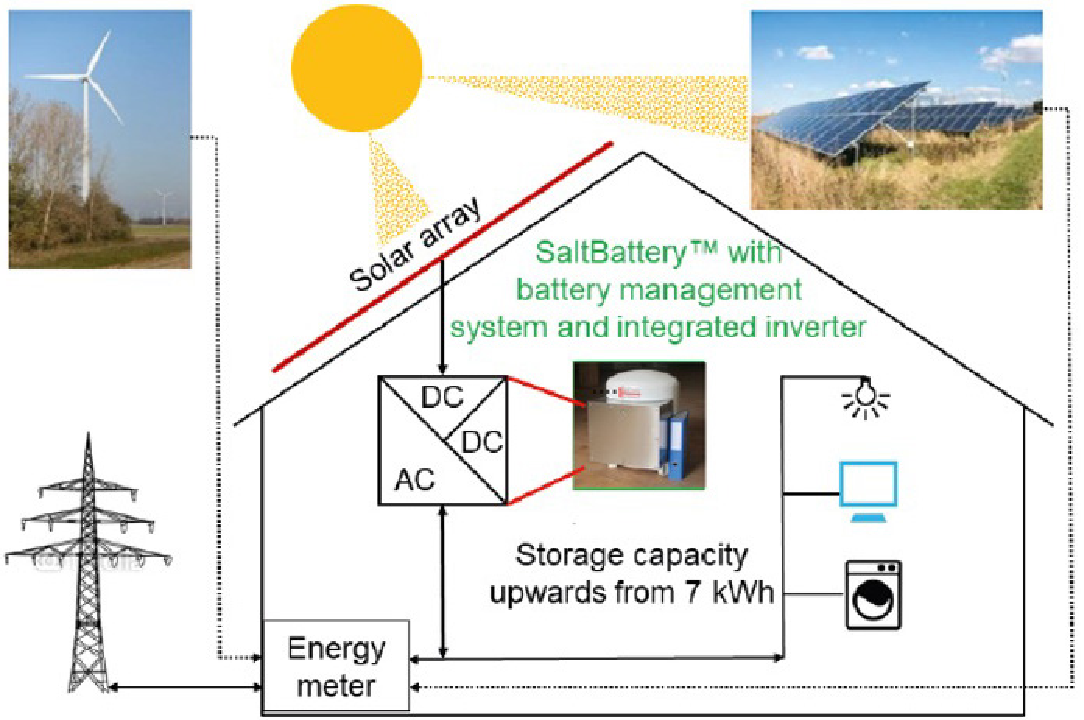


Temp [°C]	κ [$\Omega^{-1}cm^{-1}$]
25	0.002
200	0.092
300	0.24
400	0.38

Source: https://www.batteryconsult.ch/?page_id=362

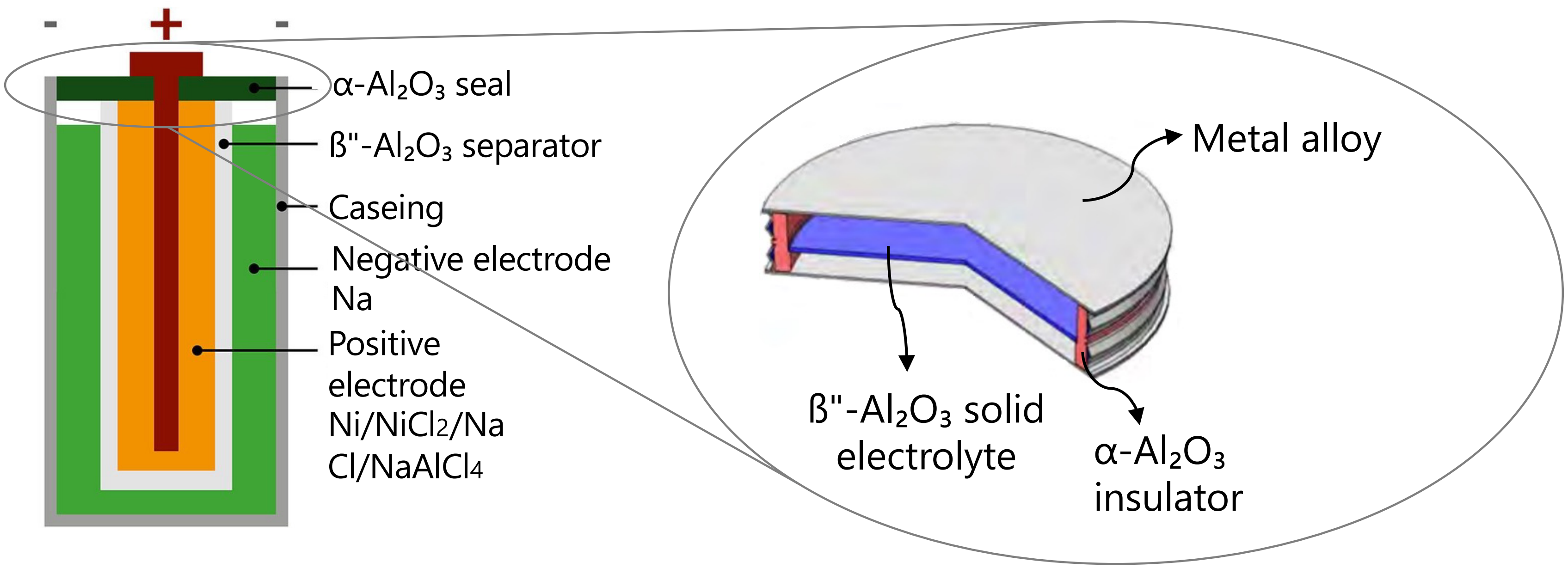
Molten-salt batteries





Source: https://www.batteryconsult.ch/?page_id=362

Joining of ceramic to metal in molten-salt batteries



How can the joining process be optimized to reduce the overall cost of each battery cell?

The LISA project: laser joining in molten-salt batteries

Innovation project supported by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Innosuisse – Swiss Innovation Agency

LISA

Laser jo**I**ning of ceramic-metal in **S**altBatteries **A**pplication

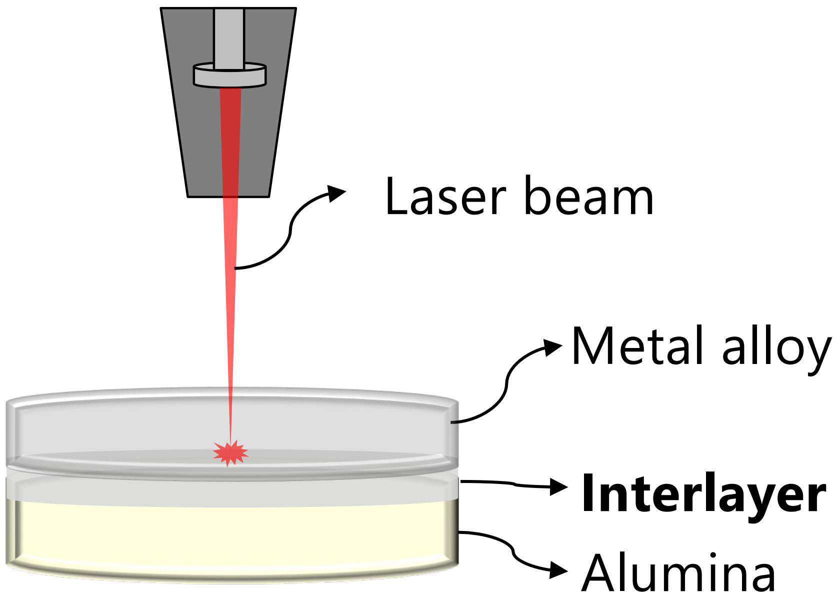
The objective of this project is to develop new lower cost ceramic-metal sealed joints with significantly better repeatability, efficiency, and shorter process times.

Empa
Materials Science and Technology

SWITZERLAND INNOVATION
PARK BIEL/BIENNE

BATTERY CONSULT

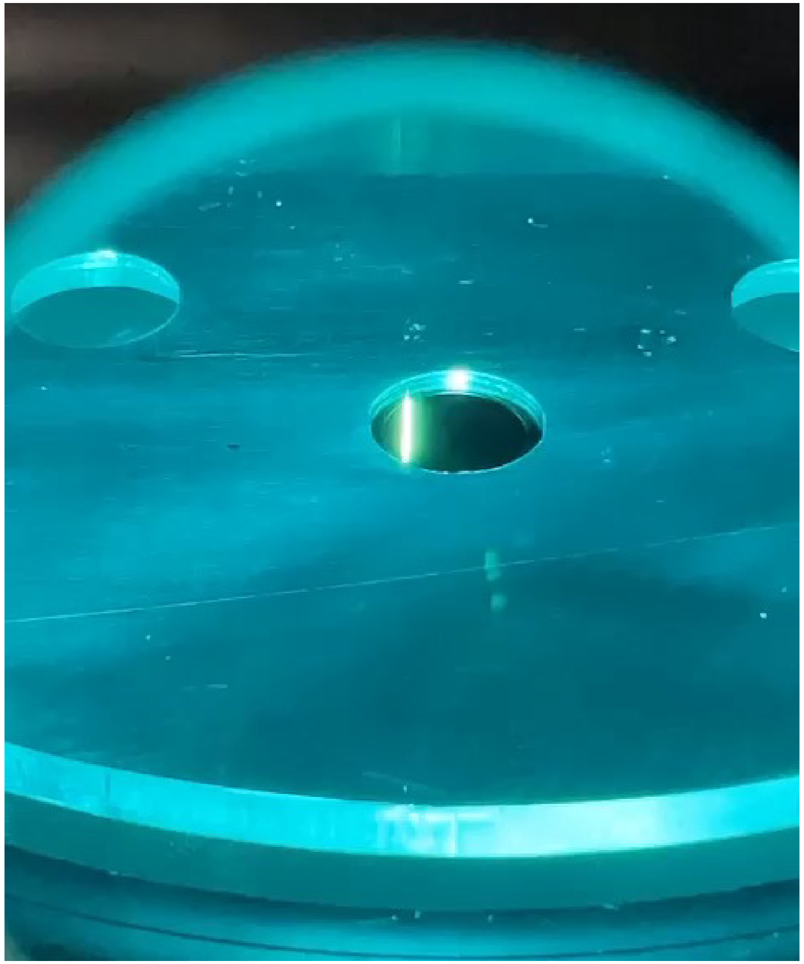
The LISA project: laser joining in molten-salt batteries

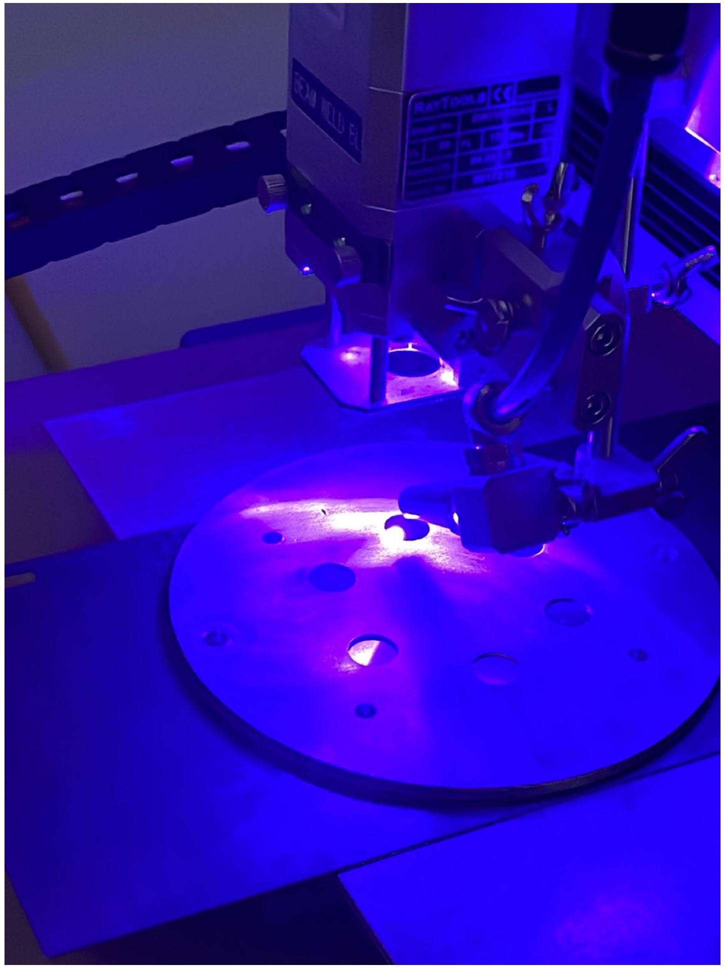


- Suitable thermal expansion
- Good adhesion to alumina
- Sodium resistance
- Thermal stability
- Reduced brazing temperatures

Laser glass sealing
Laser brazing using metal fillers

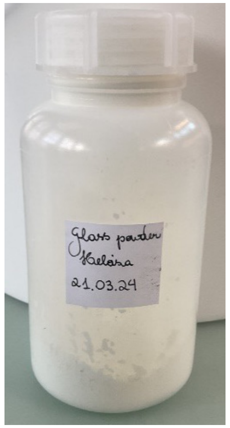
The LISA project: laser joining in molten-salt batteries



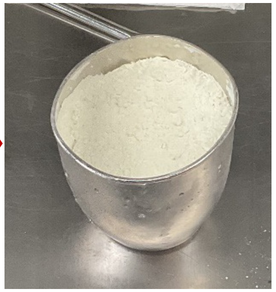


Glass development for joining

- Tailored glasses for joining with customized sealing temperature and corrosion resistance
- Aluminoborosilicate glasses with active metals as Ti, Nb, V, Ta, Zr, La, and Hf

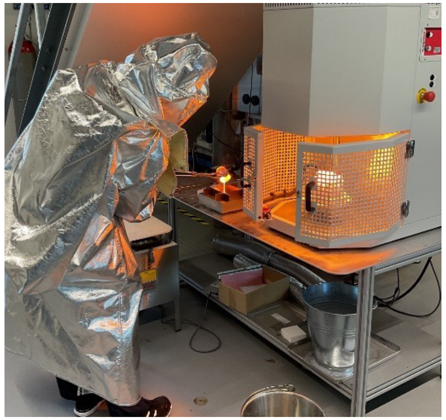


Glass powder after weight raw materials and rolling mill overnight

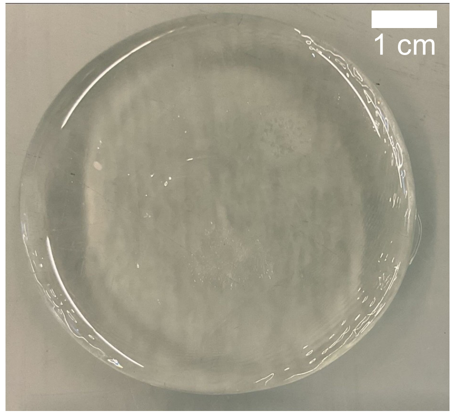


Glass powder inside the Pt crucible

Heating in the glass furnace

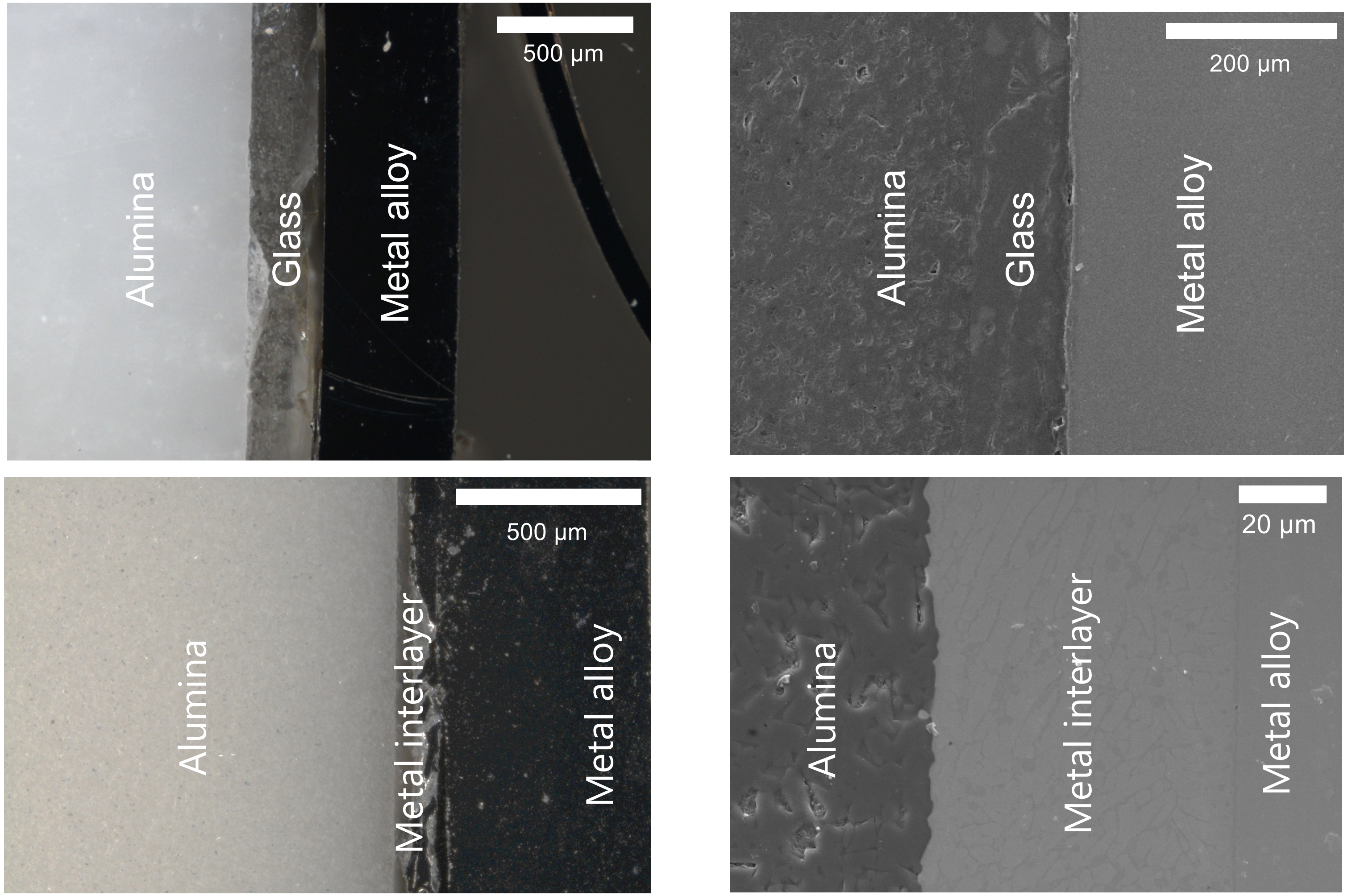


Quenching of glass on metal plate

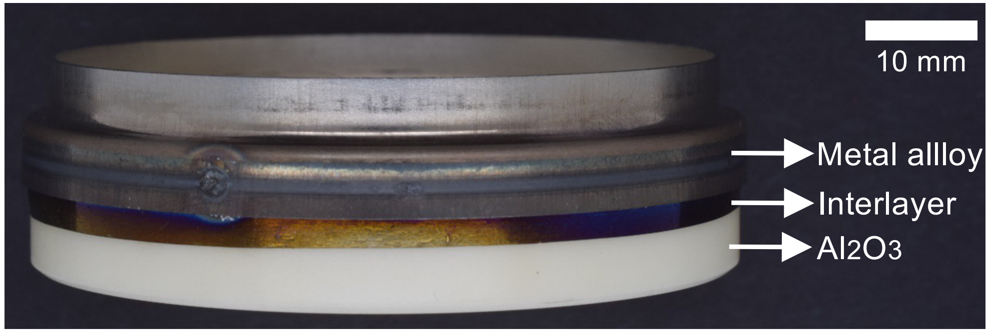


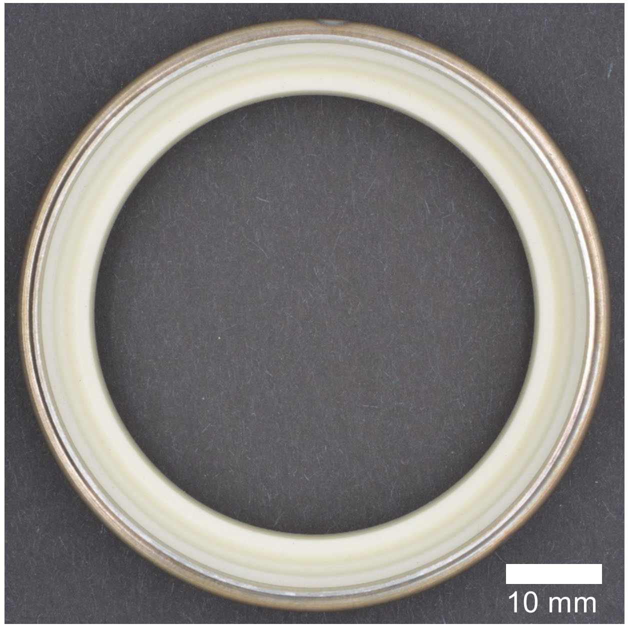
Glass after quenching approx. 80 g of powder

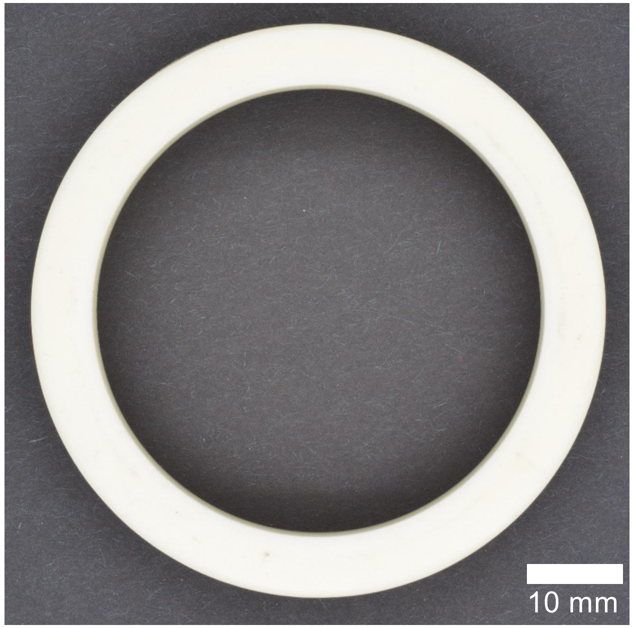
The LISA project: microscope results



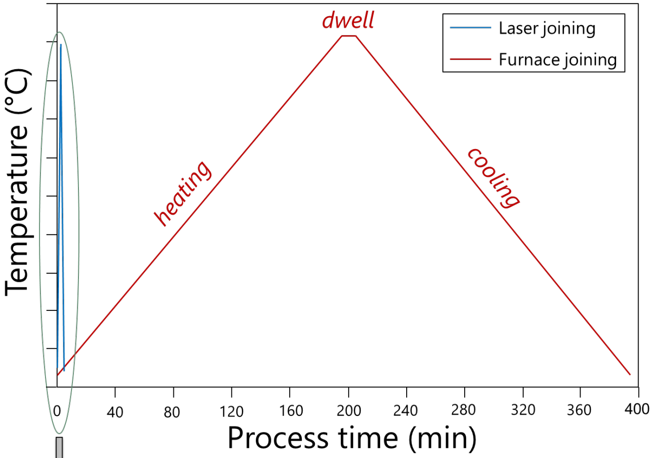
The LISA project: application in salt battery components

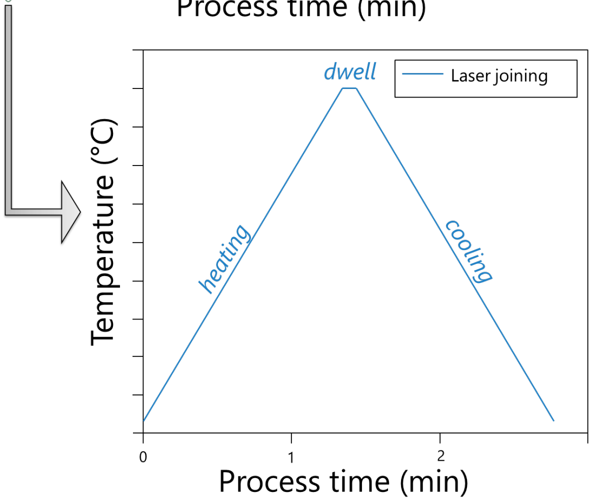






The LISA project: application in salt battery components





Laser joining

0.031 kWh

An infrared laser with a power of 220 W applied for 3 min and efficiency of 35% was considered.

Furnace joining

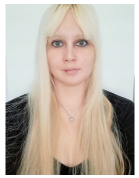
3.96 kWh

A continuous furnace with a volume of 1 m^3, heated to 1200 °C for 8 h with 80% of efficiency was considered.

By using laser joining instead of furnace joining, it is estimated that energy savings of 39,290 kWh can be achieved in a month when processing 10,000 cells, resulting in a cost reduction of approximately 10,000 CHF.

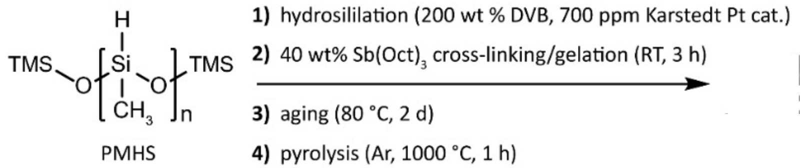
Ceramic-based Composites Group at Empa

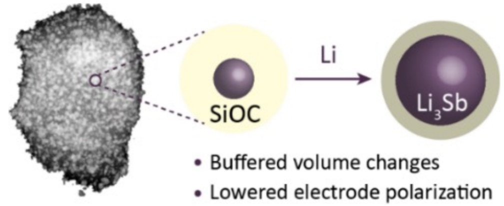
- Research on Energy Storage
- Teamleader Dr. Gurdial Blugan

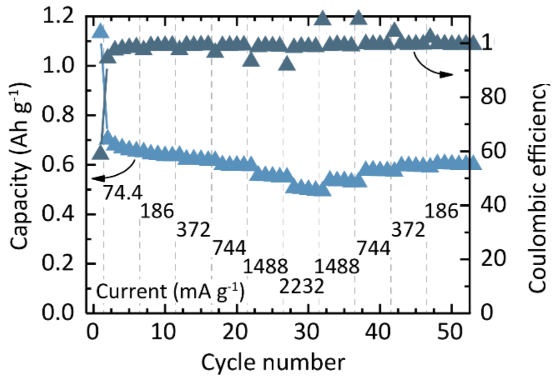


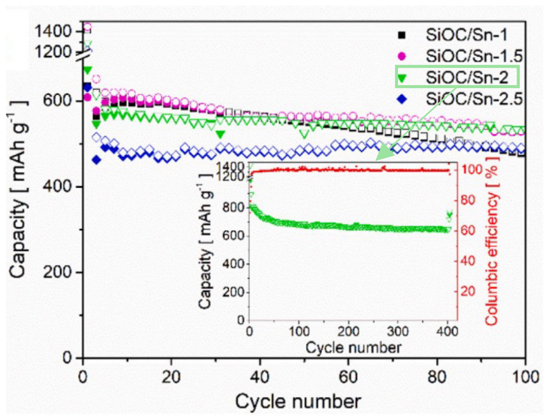
Anodes for Li-ion batteries

- SiOC-Sb/Sn nanocomposite anodes
- Next generation of silicon-based anodes
  - SiOC successfully stabilizes Li storage in Sb and Sn
  - High rate capability: energy density 3 times greater than graphite at higher charging rates









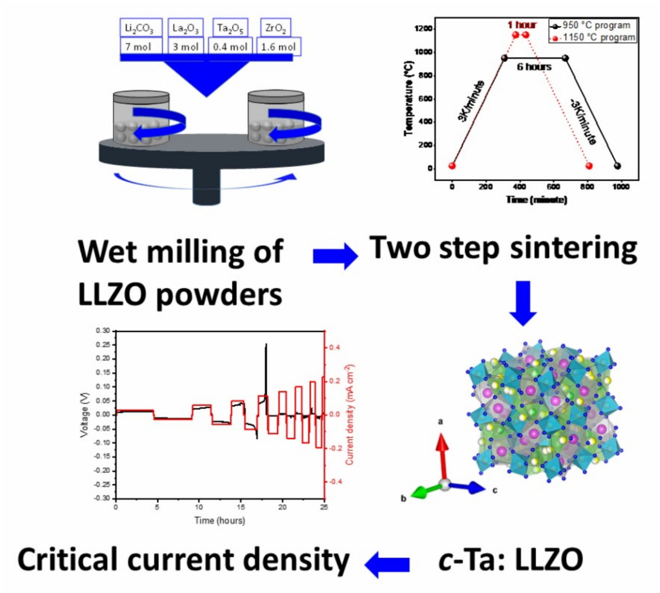
▶ Low-cost single source functionalized polyethoxysiloxane precursor

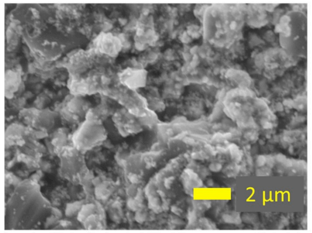
- Next generation of silicon-based anodes

Dubey RJC, Sasikumar PVW, Krumeich F, Blugan G, Kuebler J, Kravchyk KV, et al. Silicon Oxycarbide-Tin Nanocomposite as a High-Power-Density Anode for Li-Ion Batteries. Advanced Science. 2019:1901220.
Dubey RJC, Sasikumar PVW, Cerboni N, Aebli M, Krumeich F, Blugan G, et al. Silicon oxycarbide-antimony nanocomposites for high-performance Li-ion battery anodes. Nanoscale. 2020;12(25):13540-7.
Blugan G, Kovalska N, Knozowski D, Sasikumar PVW, Malfait WJ, et al. Polymer derived SiOC/Sn nanocomposites from a low-cost single source precursor as anode materials for lithium storage applications. Journal of Energy Storage. 2024;89(111676).

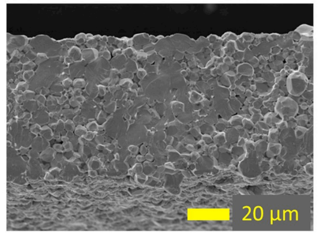
Solid state batteries

- Ta doped Lithium Lanthium Zirconium Oxide-LLZO solid state electrolytes



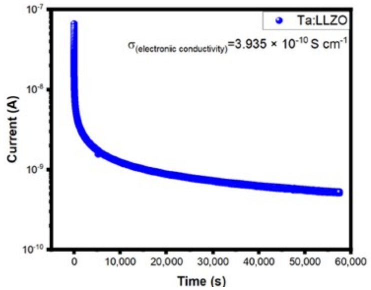


Calcined at 950°C

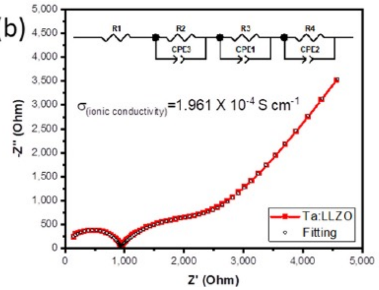


Sintered at 1150°C

(a)



(b)

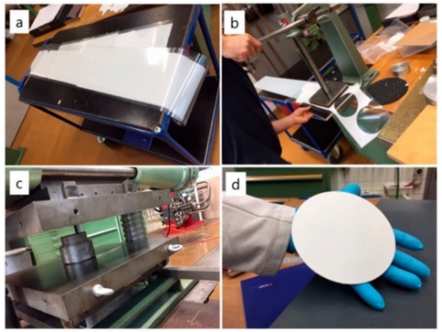


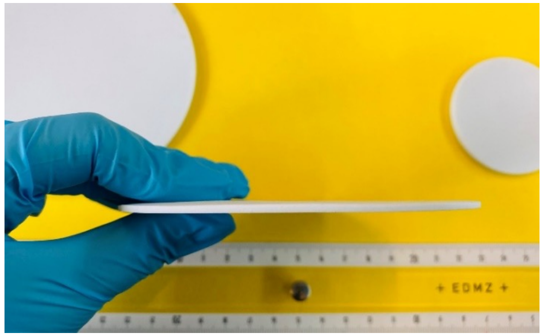
- Fire resistant solid state lithium ion battery
- Can be sintered in air in normal furnace at 1150°C to 96% density

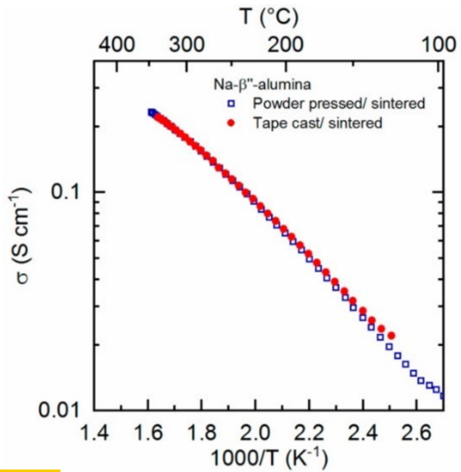
Karuppiah, D., Komissarenko, D., Yüzbasi, N.S., Liu, Y., Warriam Sasikumar, P.V., Hadian, A., Graule, T., Clemens, F., Blugan, G., 2023. A Facile Two-Step Thermal Process for Producing a Dense, Phase-Pure, Cubic Ta-Doped Lithium Lanthanum Zirconium Oxide Electrolyte for Upscaling, Batteries

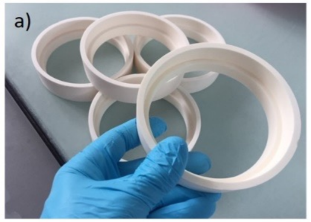
Na-Ni salt batteries

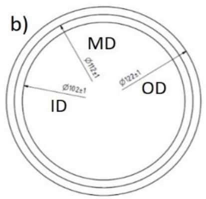
- Large planar β-Al_2O_3 based cells







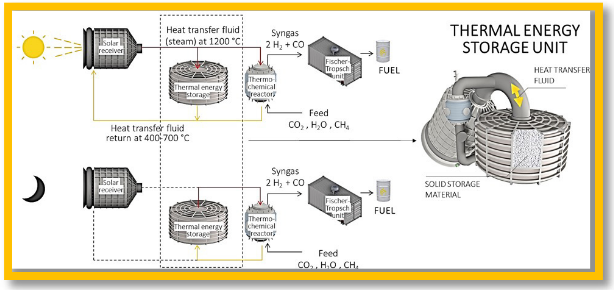




- High strength of electrolyte with same performance by adding ZrO_2
- Higher current densities of taped planar cell over today's tubular designs

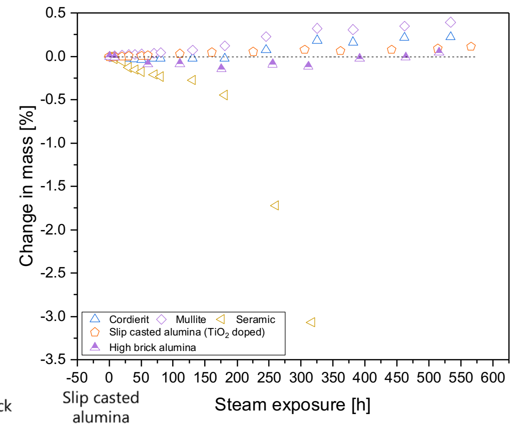
Ligon, S.C., Bay, M.-C., Heinz, M.V.F., Battaglia, C., Graule, T., Blugan, G., 2020. Large Planar Na-β″-Al2O3 Solid Electrolytes for Next Generation Na-Batteries. Materials 13(2), 433.
Bay, M.-C., Heinz, M.V.F., Linte, C., German, A., Blugan, G., Battaglia, C., Vogt, U.F., 2020. Impact of sintering conditions and zirconia addition on flexural strength and ion conductivity of Na-β″-alumina ceramics. Materials Today Communications 23, 101118. doi.org/https://doi.org/10.1016/j.mtcomm.2020.101118

High temperature thermal energy storage

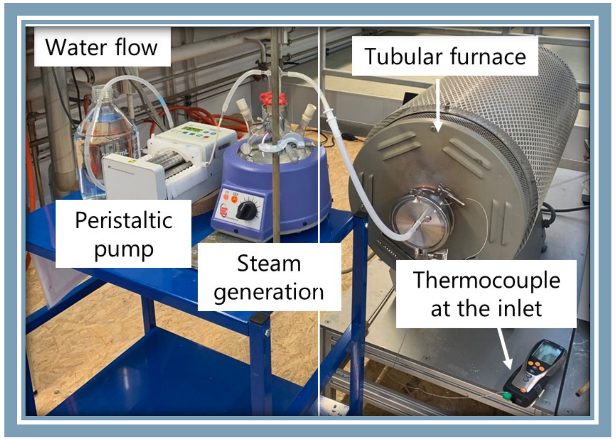


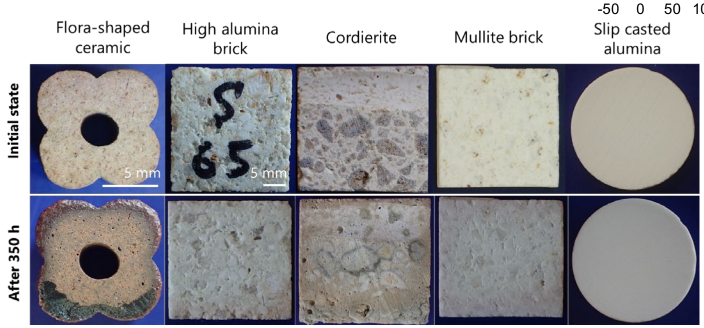
Prescreening and corrosion testing of commercial refractories and insulation materials > 500 h

- Mechanical and chemical compatibility in heat transfer fluid (steam) at up to 1200 °C
- Low cost (< 2 EUR/(kJ/K))
- High storage capacity
- High specific heat capacity (> 500 J/(kg*K))
- Robust against thermal shocks
- Al_2O_3 content 55-65% with Ca based cements to aid bonding and manufacture, 2nd phases critical to performance



Steam corrosion tests





Companies

Production method
- Vibrational casting
- Hydraulic pressing
- Extrusion

Yüzbasi, N.S., Graule, T., Blugan, G., 2023. Stability assessment of alumina and SiC based refractories in a high temperature steam environment as potential thermal energy storage materials. Open Ceramics 16. doi.org/10.1016/j.oceram.2023.100472. 100472.

Outlook

- Mega-batteries will play a crucial role in powering future grids by enabling large-scale energy storage, helping to stabilize fluctuations in renewable energy generation
- Various technologies offer distinct advantages and challenges
- Role of molten salt batteries in sustainable energy storage
- Technological advancements in battery manufacturing and cost reduction of molten salt batteries with the LISA project
- Empa is actively researching batteries for both electromobility and stationary energy storage applications

Thank you!

Dr. Heloisa Ramlow

Postdoctoral Research Fellow

Laboratory for High Performance Ceramics

Empa - Swiss Federal Laboratories for Materials Science and Technology

Überlandstrasse 129

8600 Dübendorf

Switzerland

Tel +41 58 765 4918

heloisa.ramlow@empa.ch

www.empa.ch