MATISSE structural batteries and multifunctional energy storage

AERO Hydrogen & Battery Summit

Friedrichshafen, 8 April 2025

Helmut KÜHNELT
Center for Transport Technologies
AIT Austrian Institute of Technology

Funded by the European Union

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

AFOSR EOARD project
"Multifunctional performance and cycle life of aeronautic structural batteries"

This material is based upon work supported by the Air Force Office of Scientific Research under award number FA8655-24-1-7393

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

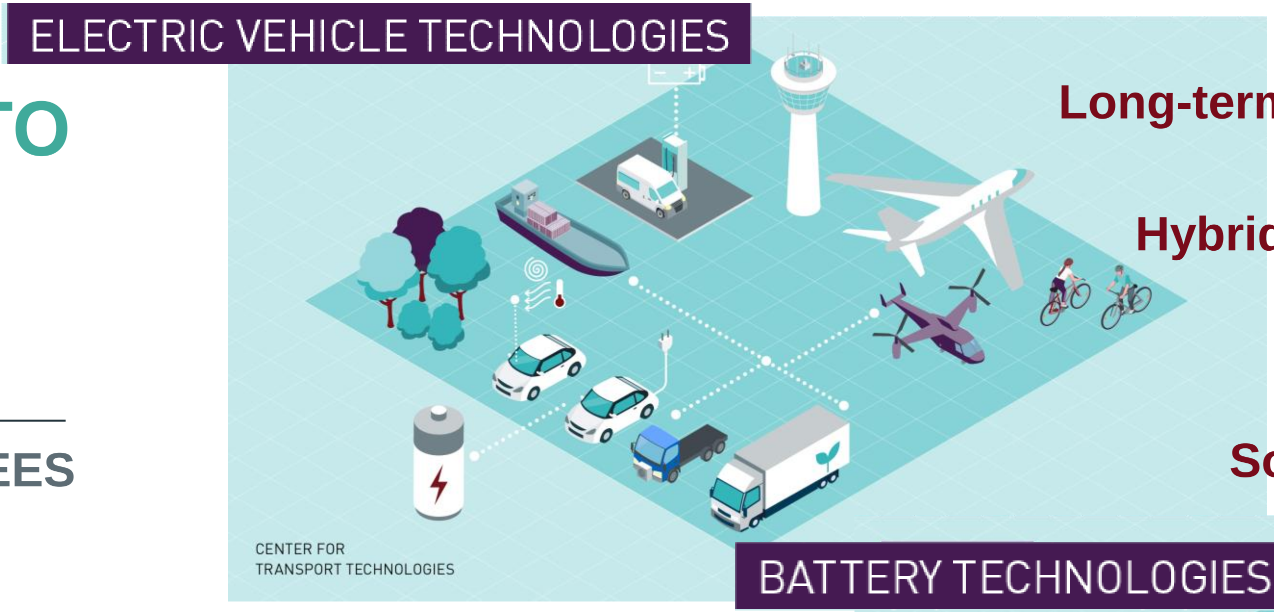
Austria‘s largest RTO

1.500

EMPLOYEES

199 M EUR

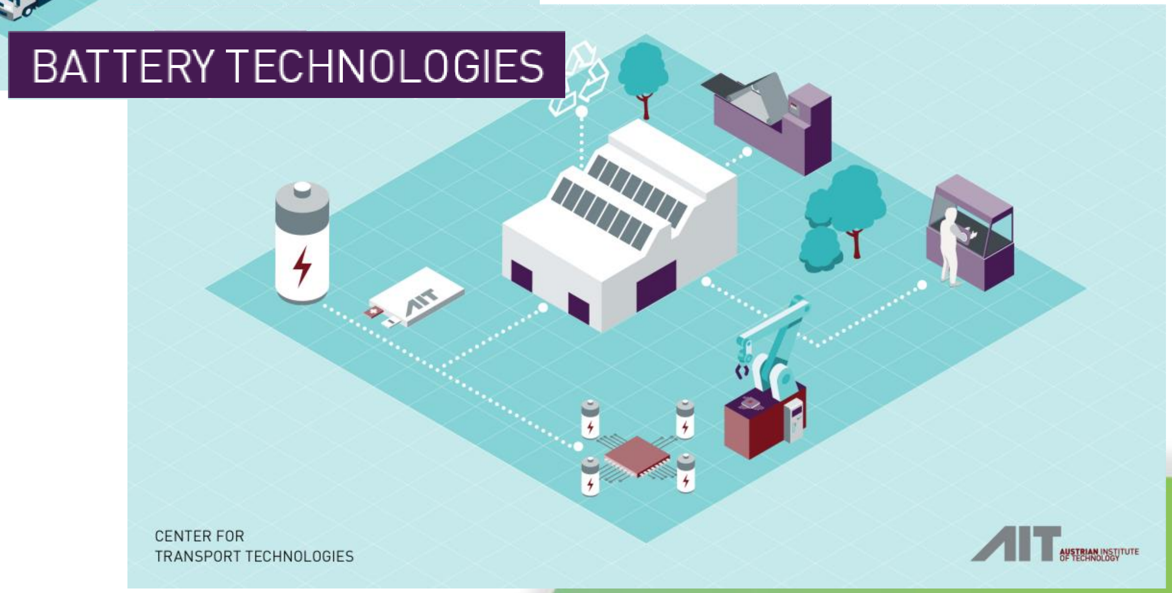
TOTAL REVENUES
as of YE 2023



Long-term expertise on B/HEVs

Hybrid Electric Aircraft Tech

Solid State Battery Tech



7 Centers

Transport Technologies
Energy
Health & Bioresources
Digital Safety & Security
Vision, Automation & Control
Technology Experience
Innovation Systems & Policy

AERO BATTERIES

CS-23

SotA – BE-LSA, 2 pax, 45 min, 2x14 kWh

CS-25

Heart Aerospace ES-30, ultra-short range, 30 pax, battery electric + GT range ext., X1 exp. a/c: 2024, EiS: 2030+

ATR EVO, regional, 70+ pax, -30% CO_2 (2/3 from HEP, up to 1 MW/side), EiS: 2035+

DLR concepts, REG/SMR, 50/150+ pax, battery electric + GT range ext., -10% LC costs, -80% climate impact

<u>SotA a/c BESS</u>

Cell: 230-280+ Wh/kg
C-to-M/P: 72/36 w/v%
<u>M/P: ~200 Wh/kg</u>
low/mid power
CS-23 / eVTOL

⇨

<u>Next gen a/c BESS</u>

Cell: 350-400 Wh/kg
C-to-M: 80+/50+ w/v%
<u>M: ~300 Wh/kg</u>
mid/high power
designed for CS-25

⇨

<u>2035 a/c BESS</u>

Cell: 450-500+ Wh/kg
C-to-M: >85/60 w/v%
<u>SYS REQ: 400+ Wh/kg</u>
HV MW & MWh
certified under CS-25

eVTOL

Prototype, 300 kg payload, 8 e-prop units + ICE

CS-23 Level 4

Microfeeder concept, 19 pax, FC+bat

<u>Airworthy Structural Batteries - Multi-funtional Energy Storage</u>

Integration eff.: >>100 wt%
zero volume impact
Requirements: MF performance, safety, compatibility, scalability, manufacturability

WHAT IS AIT DOING IN AERO BATTERIES?

Advanced LiB technologies for **aeronautic applications**

HIGHSPIN

Gen 3b - HV-LNMO
→ 400 Wh/kg

EV cell and module, **aero cell & module**

non-propulsive + **small aircraft propulsion**

HELENA

HyLiST

Gen 4b - ASSB LiM anode
→ 500 Wh/kg

EV cell and **aero cell**

hybrid/full-electric propulsion (REG)
+
non-propulsive (SMT/LR)

Propulsion battery for **hybrid electric aircraft**

IMOTHEP – GETTING HYBRID ELECTRIC

ORCHESTRA

HECATE

NEWBORN

- CS-23 level 4 and CS-25 aircraft
- Advanced high-energy Li-ion and solid-state battery technologies
- Compliant with EASA battery airworthiness requirements (MOC-3 SC-VTOL as proxy for upcoming CS-25)

Aero-fit structural battery and **MF energy storage**

MATISSE

SOLIFLY

USAF-SB

- Develop SB as future aircraft performance technology
- Built-in safety + high energy + scala-/process-/manufacturability
- Enable technology adoption by aviation industry

HORIZON EUROPE

CLEAN AVIATION

AFOSR

Batteries Europe

BEPA Batteries European Partnership Association

BATTERY 2030+

AIT STRUCTURAL BATTERY PORTFOLIO

SOLIFLY

Semi-SOlid-state LI-ion batteries FunctionalLY integrated in **composite structures** for next generation hybrid electric airliner

2021 – 2023 **CleanSky2 THT** GA 101007577 1.35 M€ EU funding

doi.org/10.3030/101007577

zenodo.org/communities/solifly

Clean Sky 2 — Funded by the European Union

MATISSE

Multifunctional structures with **quasi-solid-state Li-ion battery cells** and **sensors** for the next generation climate neutral aircraft

2022 – 2025 **HORIZON EUROPE** GA 101056674 3.47 M€ EU funding

www.matisse-project.eu

www.linkedin.com/company/matisse-project

Funded by the European Union

USAF-SB

Multifunctional performance and cycle life of aeronautic structural batteries

2023 – 2025 **AFOSR EOARD** FA8655-24-1-7393 240 k€ funding

Results

Structural battery electrochemistry and cell design

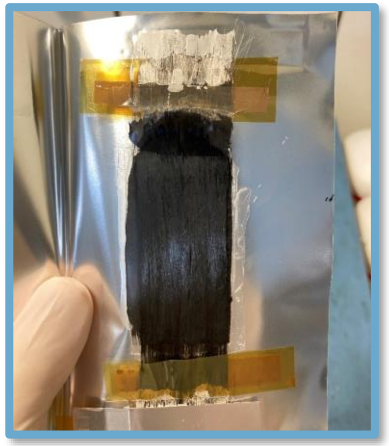
- **Two pathways – two SB cell concepts**
  - Structurally reinforce a battery cell
    → focus on high energy density
  - Store electrical energy in structural material
    → focus on high strength
- **Safe structural electrochemistry**
  - non-flammable ionic liquid-thermoplast structural electrolyte, reinforced with filler particles
  - high-energy NMC / graphite composite electrodes
- **Optimizing for concurring targets**
  - multifunctional performance
  - safety
  - processability – scalability
  - compatibility with aeronautic composite materials and manufacturing processes

AIT's RMS cell
GED = ~50 Wh/kg
E = ~10 GPa

NMC811 | IL-PVdF-HFP | graphite

Roll-to-roll processing on pilot line

Electrolyte | Cathode | Anode



UNIVIE's CCF cell
GED = ~6 Wh/kg
E = ~10-15 GPa

NMC111 | IL-Nylon | LTO

SotA: ~40 Wh/kg, using LFP, separator, conventional liquid electrolyte (flammable)

Results

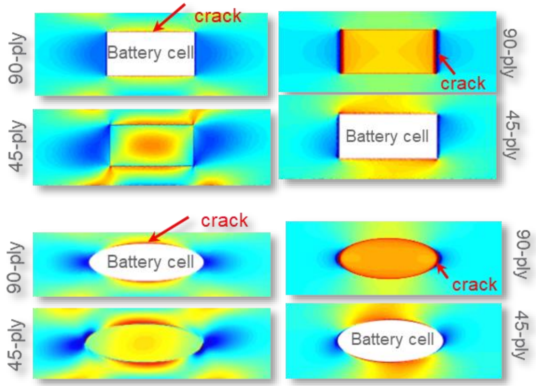
Structural integration

- SB integration into **high-strength solid CF laminates**
    - quasi-isotropic ply stacking sequence
    - SB replaces ±45° and 90° plies, matching the plies' thickness
- Study numerically the impact of **cell shape** on **rigidity** and **onset of damage**
- **SB cell tensile strength ≈ transverse strength of CF**
- **Elastic-plastic behavior of SB cell beneficial (in impact)**

SB integration into UD CF

MF Composite Manufacturing

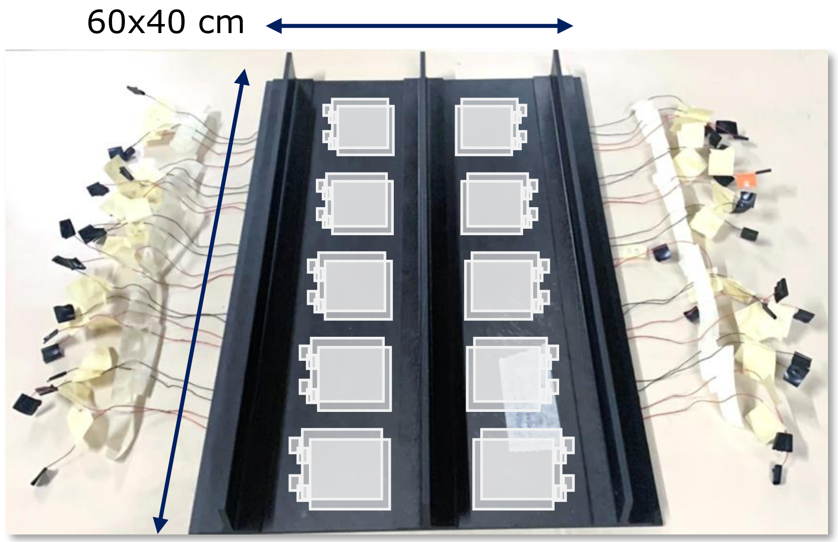
- Standard CF-epoxy material (AS4/8552) used by industry (e.g. Airbus)
- Production of MF structure in non-specialized workshop
- Autoclave curing with **adapted curing cycle** (T_{max} 130°C, duration ▲▲), applicable to any epoxy-based composite material on the market



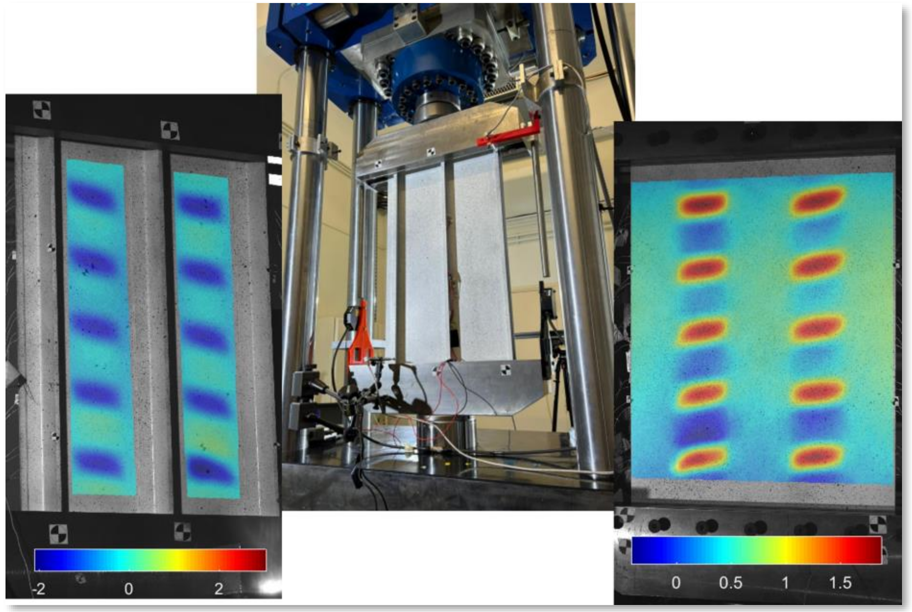
Onset of damage

Structural Battery Demonstrator

- **first aeronautic-grade multifunctional stiffened panel** with 20 AIT multilayer SB cells in skin (7x8 cm, 0.6 mm thickness, total 8 Wh)
- **80%** of SB cells functional after curing, all monitored SB cells functional after testing
- Panel tested under compression: maximum buckling loading: **18 tons**
- Weight impact: **+2.6%,** global rigidity: **-0.2%** (compared to monofunctional reference)
- to be improved & studied further: electrical-mechanical SB–CF integration, SB cell performance and cycle life under mechanical loads



SOLIFLY demonstrator: High-strength composite panel with 20 AIT RMS cells in skin

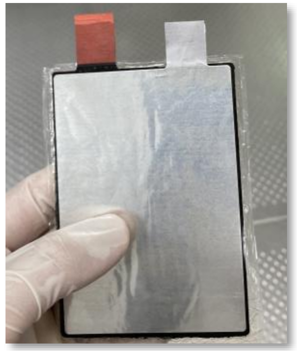


SOLIFLY demonstrator tested under compression at ONERA's multi-instrumented bench

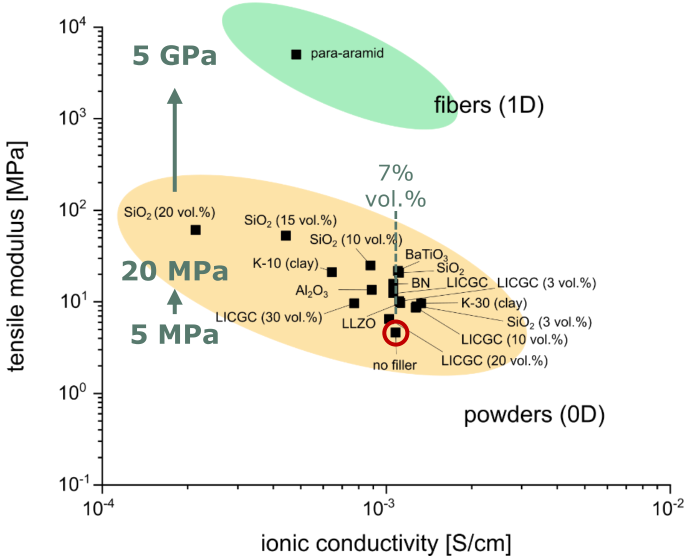
Recent developments

SB electrochemistry

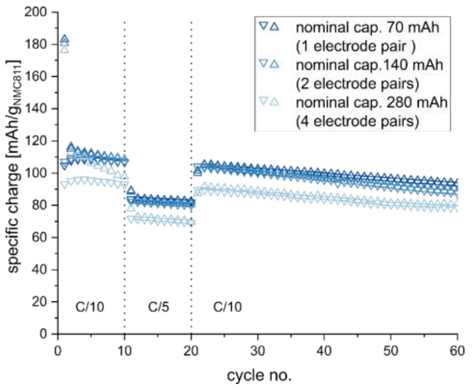
- GED → 96 Wh/kg (+92%), up to C/2
- improved mechanical strength of electrolyte (weakest link)
- High repeatability of multilayer cells
- Curable up to 120-130°C



MF properties of SB electrolyte
with fillers



Cycling of single and multilayer cells



Smart SB cell

Integration of **sensing and health monitoring** with **structural battery**

- CMUi = µ-chip based digital measuring system
- powered by SB
- monitors cell and structure:
  - 12 external sensors for electrical, thermal, mechanical measurements
  - EIS
  - in-chip data aggregation

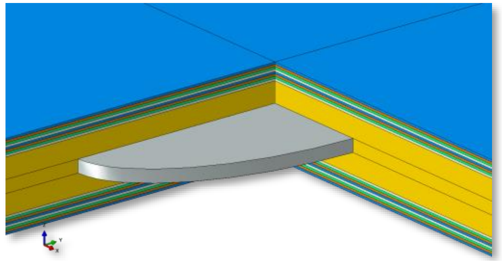
Smart SB cell prototype

public

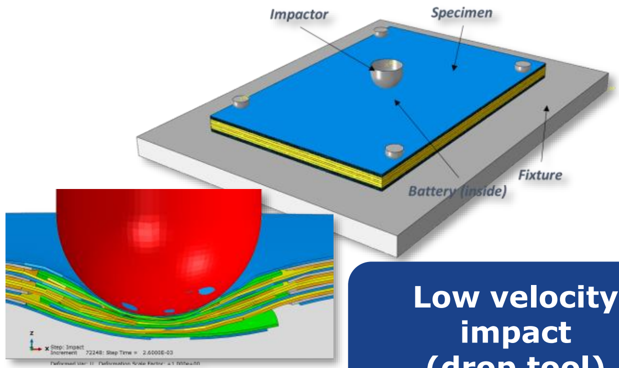
Recent developments

Structural integration

- Integration in **sandwich** CF structures
- study **impact** damage (exp+num)
- **structural health monitoring** (FBG+CMUi)



SB integration into sandwich core



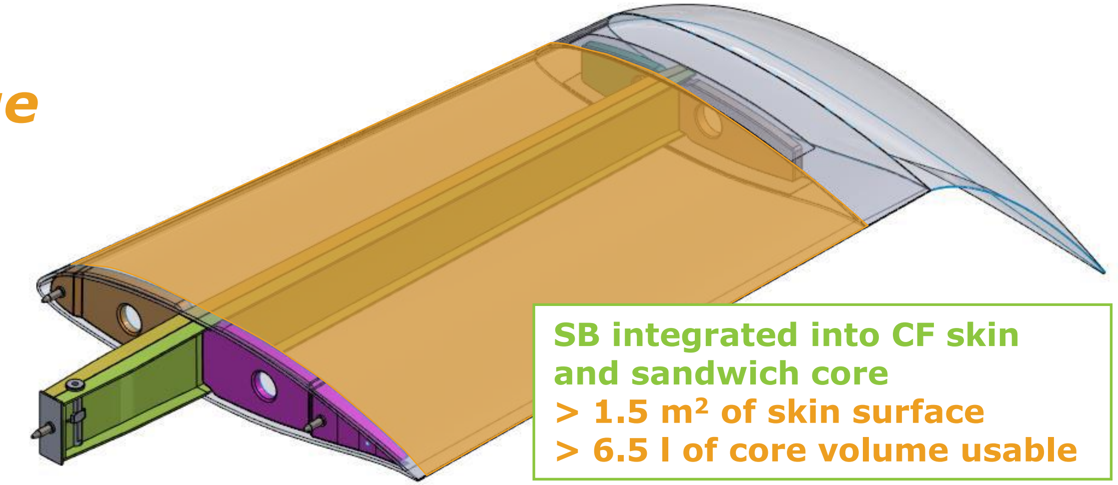
Low velocity impact (drop tool)

Materials and processes

- **Auto-of-autoclave** UD CF material (increasing relevance for CS-25 aircraft)
- Control better **manufacturing processes** of multifunctional structures with **SHM** and **CMU**
- Explore **innovative materials and processes** for SB integration
    - High thermally conductive thermoset
    - UV-curable materials
    - Low-temperature thermoplastics

Demonstration

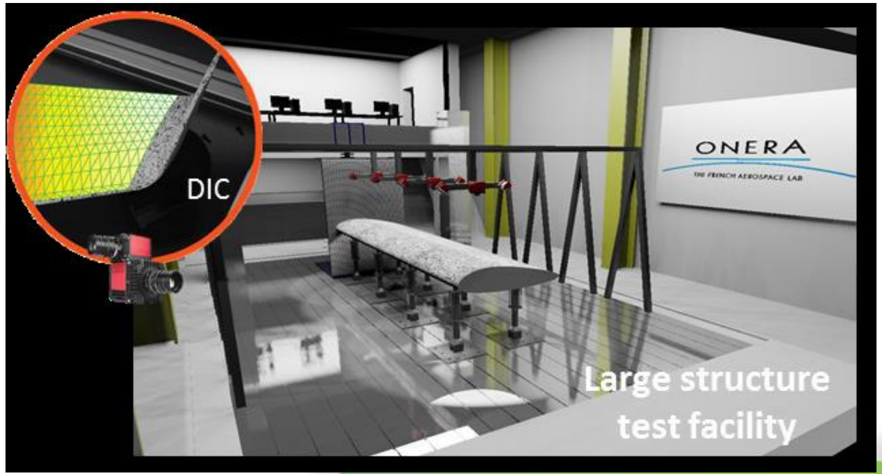
Full-scale detachable wingtip
with multifunctional energy storage
for Pipistrel Velis electro



SB integrated into CF skin and sandwich core
> 1.5 m² of skin surface
> 6.5 l of core volume usable

© Pipistrel

PIPISTREL
AIT
ONERA
THE FRENCH AEROSPACE LAB
CIRA
Italian Aerospace Research Centre
IAI



Multi-instrumented testing at ONERA's new large structure test facility JERICHO

- deliver **multifunctional structure demonstrator** capable of power delivery and management, and safety monitoring
- **qualify the technology at TRL 4**

SB integration feasibility

Cell level data		GED [Wh/kg]	VED [Wh/l]	ΔGED [Wh/Δkg] SB-solid CF
SotA – MATISSE		**96**	**213**	**334**
Improved	Reduced weight of passive components	190	345	1500
Improved	+ Si-C anode	250	495	1360
Improved	+ Li-metal anode	375	960	980

At the **cell level,** SB could reach the **GED and VED** of advanced Li-ion battery cells.

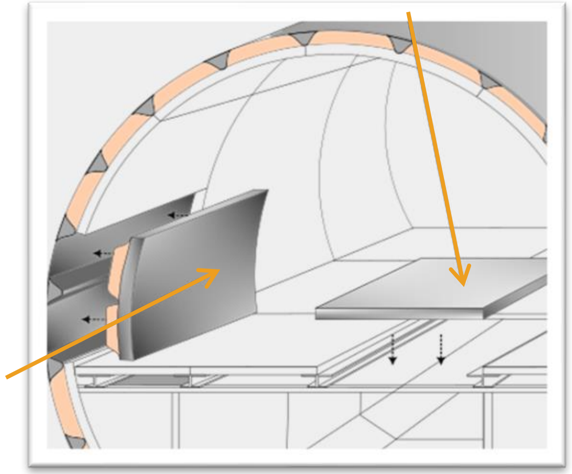
SB – solid CFRP structures

+ **1-1.5 kWh/Δkg at system level**
+ zero volume impact

– **structural penalty**: reduced strength, delamination risk
– cell vs structure lifetime, repair-/recyclability
– **in external structures:** sub-zero temperatures at higher altitudes

SB – sandwich CFRP structures

+ **20-25% system weight reduction**
+ zero volume impact
+ **in interior panels:**
  - temperature-controlled environment
  - modularization enables replaceable decentralized energy storage
  - HM with smart SB
  - enabled by AIT's safe electrochemistry



At the **aircraft level** (hybrid and more electric REG/SMR/LR):

- SB could store up to **3-4 kWh/pax** or **0.2/0.6/1.8 MWh** or **20-30%** of the onboard electrical energy.
- complementary to conventional BESS, supplying secondary loads, reducing its weight impact, also via secondary effects

Thank you for your attention!

helmut.kuehnelt@ait.ac.at

www matisse-project.eu

matisse-project

Funded by
the European Union

Further reading

- **ZENODO.org**: SOLIFLY & MATISSE Communities

- Krammer, M., Montes, S., Kühnelt, H., Jiang, Q., Lager, D., Bismarck, A., Beutl, A. (2024). Multifunctionality and Processability of a Thermoplastic Based Gel Electrolyte Cell for the Realization of Structural Batteries. *JPhysChemC*, 10.1021/acs.jpcc.4c07301
- Laurin, F., Mavel, A., Saffar, F., Beutl, A., Kühnelt, H. (2024). Experimental and numerical evaluation of residual mechanical performance of carbon/epoxy laminated coupons after integration of solid battery cells for aeronautical applications. *CompSciTech*, 10.1016/j.compscitech.2023.110384
- Beutl, A. , Jiang, Q., Kühnelt, H., Bismarck, A. (2024). On the feasibility of thermoplastic materials for multifunctional energy storage solutions. *Proceedings of the ICCM23*, www.iccm-central.org/Proceedings/ICCM23proceedings/papers/ICCM23_Full_Paper_198.pdf
- Laurin, F., Beutl, A., Jiang, Q., Kühnelt, H. (2023). Concepts for integrating electrical energy storage into CFRP laminate structures for aeronautic applications. *J. Phys. Conf. Ser.*, 10.1088/1742-6596/2526/1/012062
- Kuehnelt, H. et al. (2022). Structural Batteries for Aeronautic Applications – State of the Art, Research Gaps and Technology Development Needs. *Aerospace*. DOI: 10.3390/aerospace9010007
- Kuehnelt, H., Mastropierro, F., Zhang, N., Toghyani, S., & Krewer, U. (2023). Are batteries fit for hybrid-electric regional aircraft? *J. Phys. Conf. Ser.*, DOI: 10.1088/1742-6596/2526/1/012026
- **SOLIFLY public deliverables:**
  - Airworthiness assessment for structural batteries. 10.5281/zenodo.13748207
  - Manufacturability, TRL assessment, TRL step-up and exploitation plan for structural batteries. 10.5281/zenodo.13748195
  - Technology roadmap for structural batteries. 10.5281/zenodo.13748463