

## Composite Rotor Sleeves – Experimental Testing & Benchmarking

Thermoset and thermoplastic materials, direct winding and press-fit technologies

### Project Description

## Joint Partner Project: Composite Rotor Sleeves – Experimental Testing & Benchmarking

Thermoset and thermoplastic materials, direct winding and press-fit technologies

Within the international **AZL Network**, we jointly define industry-relevant topics with our partner companies—**rotor sleeves for electric motors** being a current priority. AZL has deep, hands-on experience in **designing, manufacturing and testing** composite rotor sleeves and regularly conducts one-to-one development projects.

In **August 2025**, we **finalised a Joint Partner Project** with **15 companies**, delivering a 384-page **market and technology study** on composite rotor sleeves. That project systematically compared **materials (thermoset and thermoplastic carbon-fibre systems)**, **design strategies processing methods**, **production scenarios and costs**, based on literature research, AZL know-how, expert interviews and CAE analyses.

As the next step, and based on discussions with companies across the value chain, we now propose an **experimental testing and benchmarking project**.

Its purpose is to **validate by manufacturing sleeves and extensive testing campaigns**, how **materials and manufacturing technologies** compare for **press-fit and direct winding** under **application-oriented test conditions**, and how they rank on both **technological and economic KPIs**. **Wet filament winding, towpreg winding and laser-assisted tape winding** are used as technologies for manufacturing.

AZL provides the required **traction-motor know-how, sleeve design, manufacturing and test infrastructure** in one place. With a **track record of 20+ Joint Partner Projects** involving **200 companies**, the AZL format delivers:

- **Comprehensive, decision-ready insights** generated efficiently in a shared pre-competitive setting,
- **Direct networking across the value chain** to accelerate implementation, and
- **High leverage on investment** through consortium-based R&D.

We would be delighted to welcome you to this next Joint Partner Project, which we describe in the following.

# 1 Objective and Methodology

## Objective

High-speed electric machines (EV traction motors, industrial drives, aerospace) require robust retention of permanent magnets and rotor components under extreme centrifugal loads and at elevated temperatures. **Composite rotor sleeves (CFRP)** enable higher RPM, tighter air gaps, and lower electromagnetic losses than metallic rings. In practice, selecting the right **material, design and manufacturing route** is use-case dependent: required speed and temperature envelope, duty cycle (quasi-static, cyclic/fatigue, creep), manufacturability (cycle time, tolerances), quality (voids, fibre-volume fraction, dimensional accuracy), and cost/CO<sub>2</sub> all interact.

Two sleeve/assembly strategies dominate:

- **Press-fit sleeves** manufactured as wound pipes, cut to length and pressed onto the rotor; and
- **Direct winding** (in-situ overwrap) on fixtures/rotors.

Both can be produced via **wet filament winding, towpreg winding, or thermoplastic tape winding**, using **thermoset (epoxy)** or **thermoplastic** matrices.

The following essential engineering questions will be answered by **experimental benchmarking** on defined rotor/sleeve configurations from a single, coherent source. These questions are critical for a comprehensive understanding of the **material–application–process** interaction:

### 1. Laminate design equivalence:

Which **laminates thickness** and **layup** are required, for different materials and manufacturing technologies, to achieve **equivalent performance** on representative rotors for press-fit and direct winding — e.g., comparing **resin classes** (high-performance, cost-performance; high-Tg/low-Tg), laminate configurations (e.g., cross layers to increase axial strength for press-fit), and **fibre-volume fraction** (high vs. intermediate)?

### 2. Application-oriented test methodology without rotation:

How can we define **fixtures and techniques** that enable efficient characterisation **without spinning rotors** — e.g., inner-pressure loading (replicating typical rotor designs and the radial expansion of single elements), also at **maximum operating temperatures** or under **cyclic loading** — to investigate **residual compaction pressure** after press-fit and after direct winding?

### 3. Correlation to CAE-based design:

How do test results correlate with **CAE predictions** — by comparing pre-stress, strength and long-term behaviour from simulation versus experiment?

### 4. Pre-stress levels and stability:

Which **pre-stress levels** can be achieved after manufacturing for press-fit and direct winding, and how does pre-stress **evolve** under **cyclic loading** and **temperature exposure** for different materials and wall thicknesses?

### 5. Limit-temperature behaviour:

How do sleeves with different **resin types** behave when briefly operated **slightly beyond the maximum defined operating temperature** — for example, what happens when a **thermoset** sleeve is exposed **slightly above its glass-transition temperature,  $T_g$**  (loss of stiffness/strength, interfacial shear, creep acceleration, recovery)? How does that compare to **thermoplastics** (behaviour around/above/below  $T_g$ ; and **below  $T_m$**  for semi-crystalline systems)?

### 6. Wall-thickness utilisation:

What is the effect of **wall thickness** on the usable (effective) material properties of the real sleeve — i.e., how much of the **nominal material performance** is actually **utilised** in the thick-walled sleeve under **pre-stress**, operating load and temperature?

## Methodology

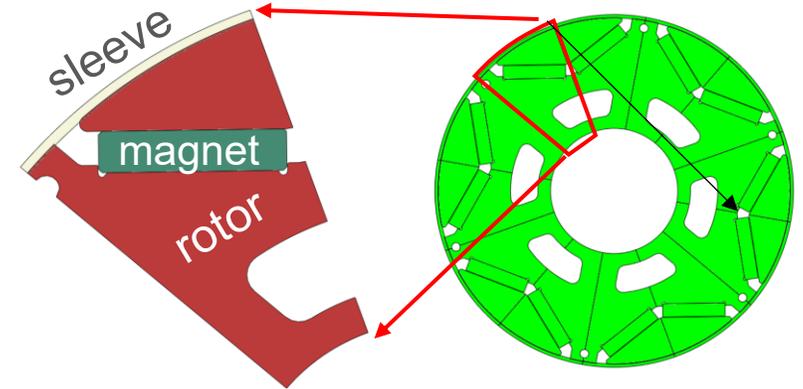
*The project follows the methodology described below. The precise conduction of the project, e.g. the selection of materials and fine planning of testing campaigns, will be coordinated according to specific interests of the project participants.*

- **Define representative use cases** for rotors of interest to the consortium, including **decision-grade KPIs** (safety factor, stiffness retention, creep rate, dimensional stability) that drive OEM/Tier choices.
- **Consider two design temperatures**, e.g. **150 °C** and **180 °C**.
- **Consider two pre-stress levels**, derived from **two maximum-speed scenarios**.
- **Select representative material classes** for wet winding, towpreg and thermoplastic tape, e.g.:
  - high-performance fibres vs. industrial-grade fibres;
  - premium thermoplastic tapes vs. cost-performance tapes;
  - high-temperature resins vs. lower-temperature resins (e.g., **epoxy with  $T_g > 180\text{ °C}$  /  $< 150\text{ °C}$ , PPS, Nylon, PEEK**).

- **Manufacture sleeves with three wall-thickness levels**, each executed as **press-fit** and as **direct-wound** variants. Technologies used:
  - Press-fit (tubes, cut to rings):
    - wet filament winding,
    - towpreg winding,
    - laser-assisted thermoplastic tape winding
  - Direct winding:
    - towpreg winding,
    - laser-assisted thermoplastic tape winding
- **Design and build an application-oriented, representative Radial-Load Rig** (emulating forces generated by rotor elements **without rotation**) for efficient testing, using split-disc test as reference for test rig development and validation of test procedure.
- **Design and build a device/fixture for pre-stress analysis**, to quantify initial pre-stress and **relaxation** after manufacturing and after **stress/temperature exposure** for both press-fit and direct-wound sleeves.
- **Test under static loading** of all variants at **room temperature** and at **elevated temperature** (representative radial-load rig).
- **Perform selected creep/relaxation tests** at elevated temperature, including **post-excursion recovery** after over-temperature events.
- **Perform selected cyclic-loading tests** (split-disc).
- **Conduct an economic and technological evaluation** of production-related KPIs (cycle times, production-cost scenarios).

# Background

- Electric motors are playing an increasing role in automotive mobility, where efficiency is of highest importance.
  - The same applies for many industrial and household applications.
  - Composite rotor sleeves allow permanent magnet motors with high rotation speeds and very low Eddy current losses, leading to higher motor efficiencies over a wider operating range.
  - The design optimisation, manufacturing and assembly processes for rotor sleeves were extensively studied in a previous AZL Joint Partner Project, showing high future potential of these components.
- ***Building on this comprehensive benchmarking study (2025, 15 partners), the new project validates key findings through manufacturing and experimental testing of rotor sleeves with different materials in different production processes under application-oriented conditions.***



Partners of the previous rotor sleeve project:



# Project Objectives

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- Provide insight into the manufacturing details and process optimizations for different manufacturing processes, including:
  - Wet winding
  - Towpreg winding
  - Thermoplastic tape windingMaterial quality evaluation for each process
- Provide insight into the different assembly processes, alternative layups and prestress levels for:
  - Press fit assembly
  - Direct winding
- Provide experimentally derived and validated data on different materials, like different strength and stiffness carbon fibre composite materials. Doing so by relevant component testing. Building trust in CAE predictions. Providing insights into failure modes and corresponding sleeve configurations/manufacturing conditions.
  - Quantify pre-stress levels and stability for press-fit and direct-wound sleeves.
  - Evaluate limit-temperature and over-temperature behaviour for different resin types.
  - Assess wall-thickness effects on usable material properties.
  - Correlate experimental data with CAE-based pre-stress and strength predictions.
- Detailed cost insight update, using experimentally derived data for the different materials and processes.

# Project Details Summary Overview

## Material classes

- Thermosets & Thermoplastics

## Rotor Armouring strategies

- Press-Fit & Direct Winding

## Manufacturing Technologies

- Wet-Filament Winding, Towpreg-Winding, Tape-Winding

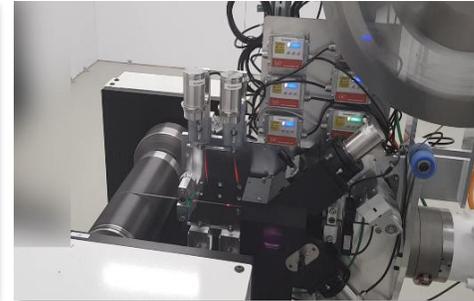
## Characterisation Methods

- Split-Disc
- Analysis of pre-stress and stress development on representative rotor fixture,
- Radial-load test rig for static, cyclic and temperature dependent analysis
- Typical composite laminate analysis ( $T_g$ , void content, microscopy, etc)

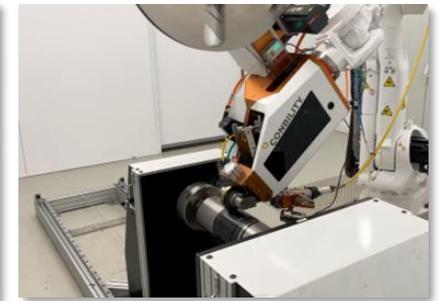
Technology and cost evaluation in terms of production-related KPIs



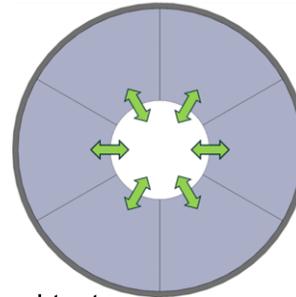
Wet Filament Winding, Thermoset  
Exemplary picture, source: IKV Aachen



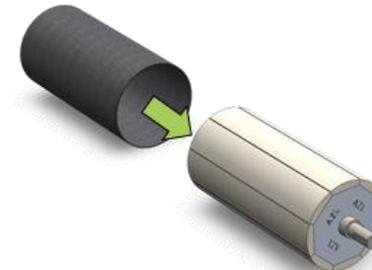
Towpreg Winding, Thermoset  
Exemplary picture, source Conbility



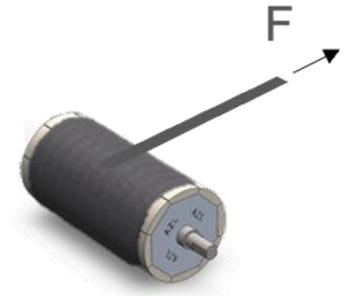
Tape Winding, Thermoplastic  
Exemplary picture, source Conbility



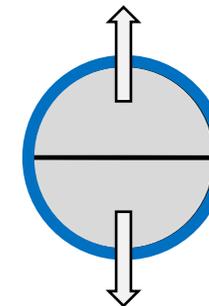
Radial-load test



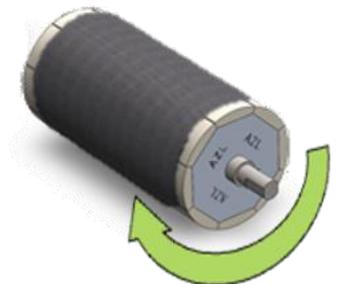
Press-Fit



Direct Winding



Split-Disc  
Exemplary picture, source: IKV Aachen



Spin-testing

# Deliverables and Methodology

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## Deliverables

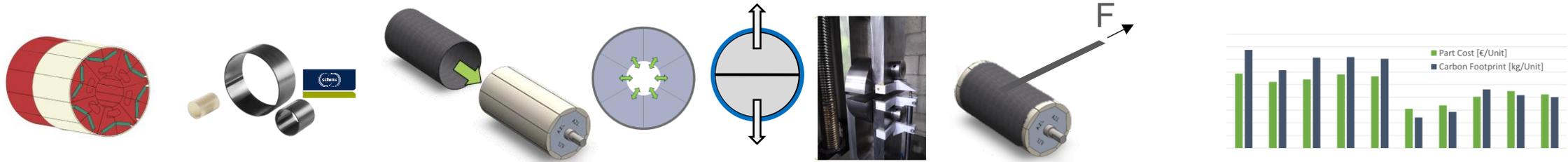
- Benchmarking matrix, linking sleeve performance KPIs (e.g. strength, pre-stress retention, creep-rate, etc.) to material and process parameters
- Development and validation of a radial-load test rig enabling non-rotating test scenarios
- Quantified impact of laminate design (layup structure, fibre volume content)
- Quantified assessment of creep and relaxation behaviour post over-temperature exposure
- Evaluation of press-fit vs. direct winding approaches
- Assessment of surface quality, dimensional accuracy, mechanical performance (thermal, cyclic and long duration load)
- Cost comparisons between different solutions and process routes
- Comparative CAE-to-test correlation matrix for strength and pre-stress predictions
- Recommendations for rotor sleeve design and production process, according to a variety of rotor characteristics (RPM, temperature, diameter, etc.)
- Final presentation and comprehensive technical report

## Methodology

- Definition of various application and production scenarios
- Design of suitable sleeve configurations to fulfil the requirement of the application scenarios
- Manufacturing and testing
- Evaluation of KPIs

NOTE: Partners can bring their own materials for evaluation and benchmarking

# Work Packages



## WP1

### Definition of concepts to be made and tested

- Joint definition of relevant use cases (wall-thickness, design temperatures (e.g. 150 °C/180 °C), etc.)
- Selection of material systems of interest:
  - carbon fibre types
  - thermoset and thermoplastic resins
- Design of reference components:
  - Diameter, speed, load profiles.
  - Laminate structures and prestress levels for different materials
- Design of validation tests:
  - Split disk test
  - radial-load test rig for static/cyclic loading at various temperature levels
  - Influence of test temperature and long-term loading

## WP2

### Press-fit manufacturing and testing

- Setup of manufacturing processes for all three process technologies (wet winding, tape winding, towpreg winding)
- Manufacturing of press fit tool and sleeve specimens for press-fit evaluation
- Analysis of the press-fit process
- Characterization:
  - Void content, dimensions, accuracy, static stiffness/strength
- Pre-stress quantification before and after cyclic/thermal exposure
- Limit-temperature tests

## WP3

### Direct winding manufacturing and testing

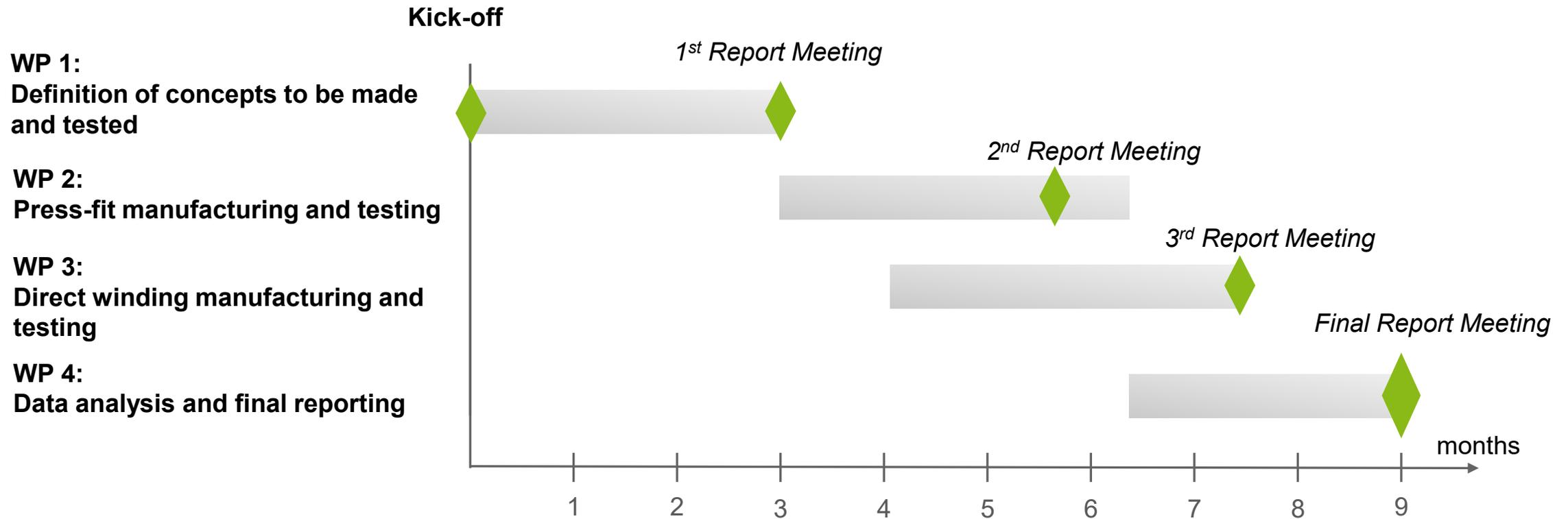
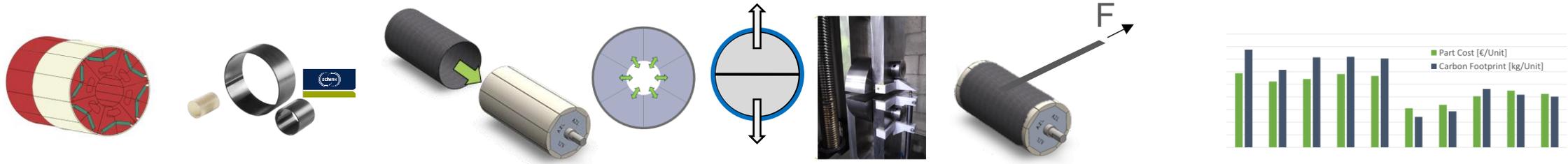
- Adaptation of winding setups for high-tension direct winding
- Evaluation of pre-stress build-up and operation behaviour using a representative test method
- Characterisation:
  - Void content, dimensions, accuracy, static stiffness/strength
- Pre-stress quantification before and after cyclic/thermal exposure
- Limit-temperature tests
- Strength, long term durability testing under thermal and dynamic conditions (influence temperature and long duration load either in WP2 or WP3)

## WP4

### Data analysis and final reporting

- CAE correlation validation and refinement
- Benchmarking and comparative evaluations
- Cost analysis update based on experimentally derived performance and process parameters
- Recommendations and final reporting

# Planning



# CONTACT US WITH YOUR REMARKS AND QUESTIONS



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# Annex A: Previous Projects

Expertise in over 15 successfully completed initiatives with interational industry consortia



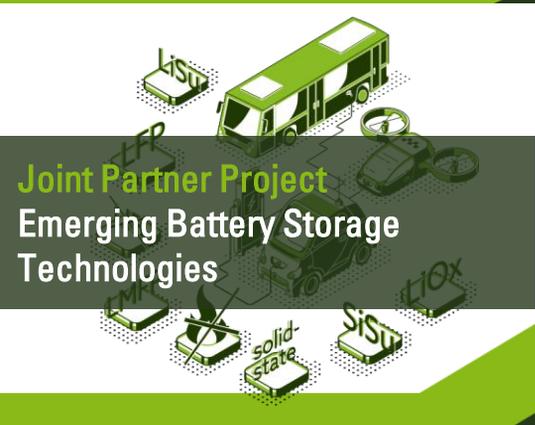
Joint Partner Project  
Propellers & Rotors



Joint Partner Project  
Rotor Sleeves for Electric Motors



Joint Partner Project  
Thermal Propagation in BEV  
Battery Casings



Joint Partner Project  
Emerging Battery Storage  
Technologies



Joint Partner Project  
Trends & Design Factors for  
Hydrogen Pressure Vessels



# Joint Partner Project

## Cost and CO2 Saving Lightweight Tailgate Concept Study



# Joint Partner Project

## Concept Study & Development of Cell-to-Pack Battery Casings



# Joint Partner Project

## Battery Casing Follow-Up: Bottom Impact Protection



# Joint Partner Project

## Battery Casing Follow-Up: Fire Protection



# Joint Partner Project

## Multi-Material Battery Casing



# Joint Partner Project

## Inductive Double Belt Press



## Joint Partner Project Ultra-Fast Manufacturing



## Joint Market & Technology Study New Potentials for Composite Technologies in Buildings & Infrastructure



## Joint Market & Technology Study Composites in the Furniture Industry



## Joint Market & Technology Study Potentials and Challenges of Thermoplastic Tapes for SME Injection Molders



## Joint Market & Technology Study Next Generation Mobility Solutions



## Joint Market & Technology Study Energy Storage Systems



## Joint Market & Technology Study High-Performance SMC



## Joint Market & Technology Study Bio-based Composites

