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 Bundesministerium  
für Wirtschaft  
und Klimaschutz  
aufgrund eines Beschlusses  
des Deutschen Bundestages

SCALE-UP  
E-DRIVE

# Consortium Study “Innovative Materials in Electric Motors”

Manufacturing a Stator Primotype Using Innovative Materials and Processes

- Waelzholz | Wickeder Westfalenstahl | SWD | LCD LaserCut AG | ELMOTEC STATOMAT A Schaeffler Company | SHwire Magnet Wires | WAFIOS | RÖSCHER GmbH | TRUMPF | A.M.S | 3M | CGH induction | QUICKFairs® | Coiltech International Coil/Winding Exhibition
- bayern innovativ | DLR | e-mobil BW | RWTH AACHEN UNIVERSITY | TUM

# Consortium Study – “Innovative Materials in Electric Motors”

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Scale-up E-Drive – Introduction to the Research Project

4

Demonstrator’s Geometrical Key Data

2

Motivation for the Study

5

Materials and Production Processes

3

Overview of the Consortium

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Project Lead Contact



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# “Scale-up E-Drive” Research Project

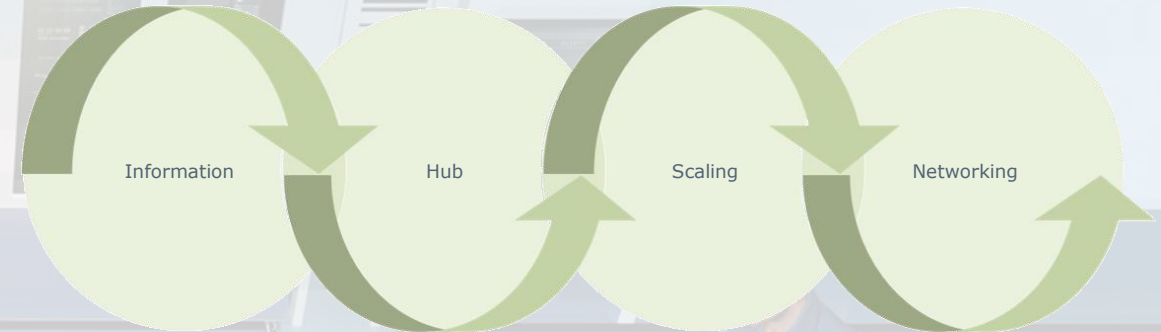
### Transformation Hub for Electric Drives

#### Challenge

- By 2030, up to **200,000 jobs will be lost** in the automotive industry due to the **shift away from internal combustion engines** to electric drives.
- Small and medium-sized enterprises (SMEs) with a high level of technological expertise in special applications of internal combustion engines are at **risk of missing the boat in the ongoing transformation.**
- The hub’s activities will provide SMEs with **targeted support** for the transformation.

#### Approach & Goals

- The **overarching goal** of the Scale-up E-Drive transformation hub is to **process current trends** and industry information and **make it accessible** to the players in the value chain of electric drives in Germany **on a non-discriminatory basis.**
- **PEM’s task** is to **prepare essential findings** from industry and research **for a broad audience** and to convey fundamental knowledge on electric drives in an interactive and practice-oriented manner.
- In addition, **new and existing players** in the value chain are **networked in innovative formats**, to jointly address central issues.



#### Project Partners



**Grantor**

BMWK

**Duration**

January 1<sup>st</sup> 2023  
to June 30<sup>th</sup> 2025

**Project Sponsor**

VDI | VDE | IT

**Funding Code**

16THB0006E



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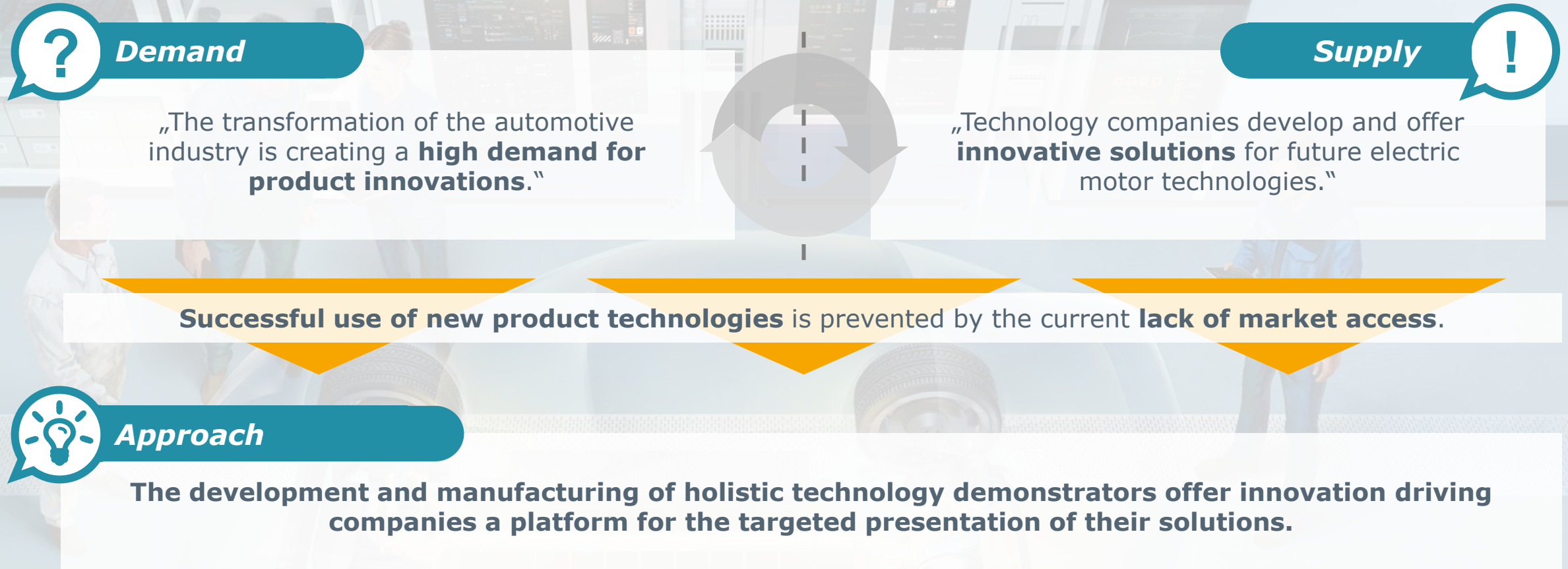
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# “Scale-Up E-Drive” Transformation Hub

Motivation for the Study – “Innovative Materials in Electric Motors” Technology Demonstrator



# “Scale-Up E-Drive” Transformation Hub

“Innovative Materials in Electric Motors” Technology Demonstrator



## What is shown?

Innovations for **individual components of electric motors** for traction applications



## What is done?

**Manufacturing of demonstrators** based on a **neutral reference design**, including process documentation and preparation of the results



## Who is the consortium?

Companies with a **product innovation with a physical proof-of-concept** and **valid property right**



## Where is it presented?

### Key events 2024:

- Coiltech Augsburg
- Electric Vehicle Production Days



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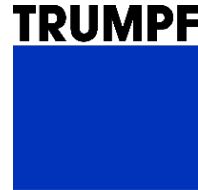




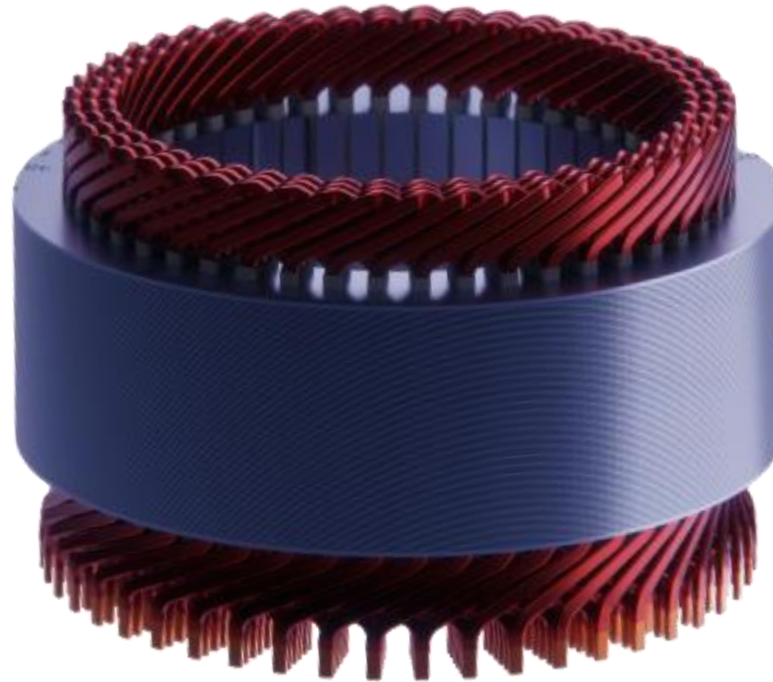
# “Innovative Materials in Electric Motors” Technology Demonstrator

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E-DRIVE

Objective and consortium



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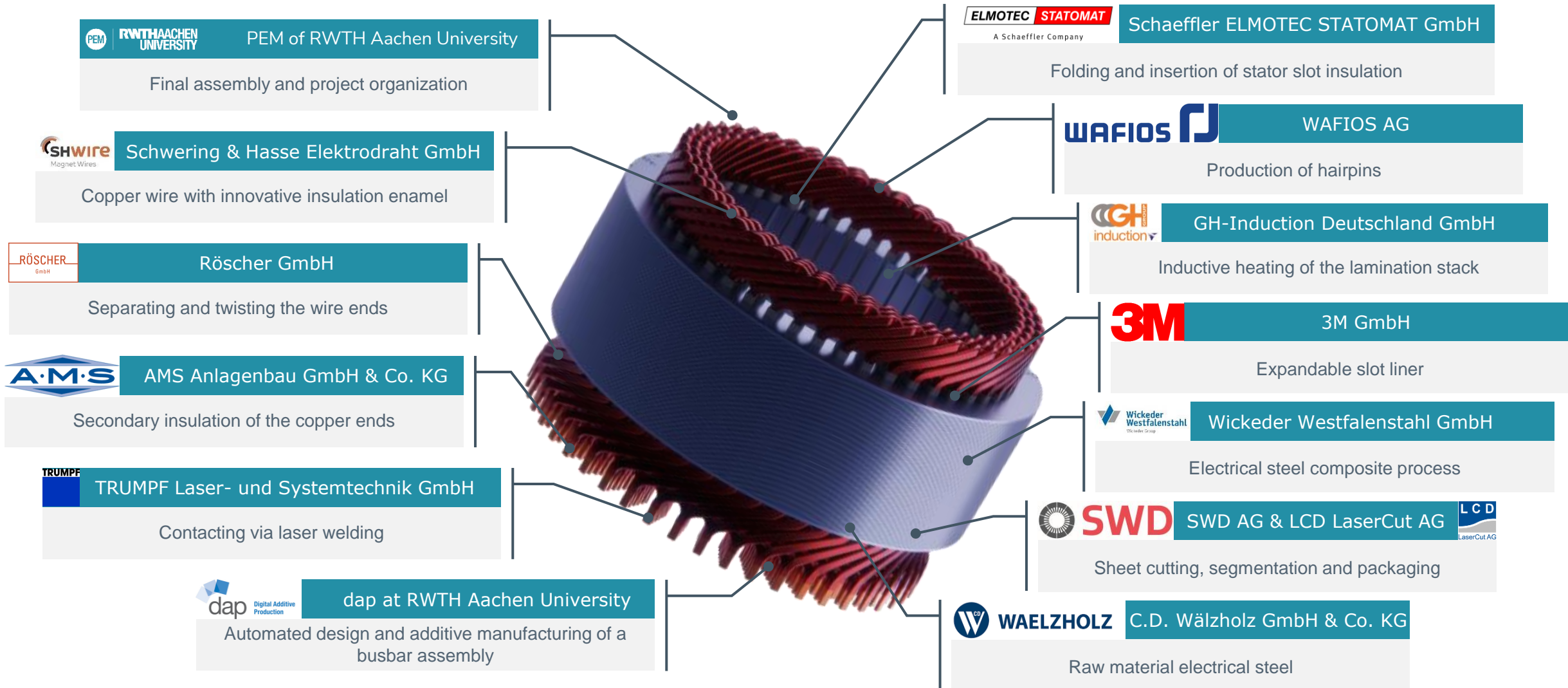


Construction of a **stator technology demonstrator** using **innovative materials** and **processes** as well as **exhibition at the “Coiltech 2024” key trade fair.**



# “Innovative Materials in Electric Motors” Technology Demonstrator

### Overview of the consortium’s contributions



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# “Innovative Materials in Electric Motors” Technology Demonstrator

Key geometrical data



## Key data of PEM's reference stator design

<b>Stack length:</b>	70 mm
<b>Outer diameter:</b>	215 mm
<b>Inner diameter:</b>	150 mm
<b>Winding head height:</b>	27 ± 2,5 mm (bending side) 37 ± 2,5 mm (welding side)
<b>Weight:</b>	approx. 12 kg
<b>Conductors per slot:</b>	6
<b>Slots:</b>	48



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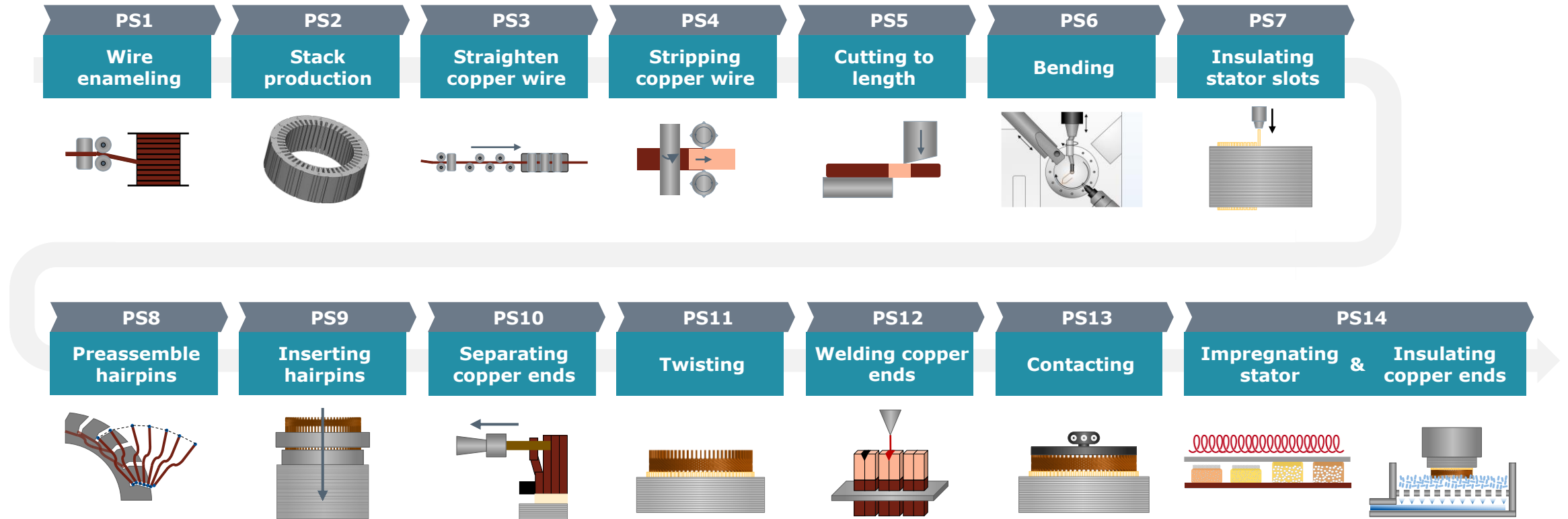
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Project Lead Contact



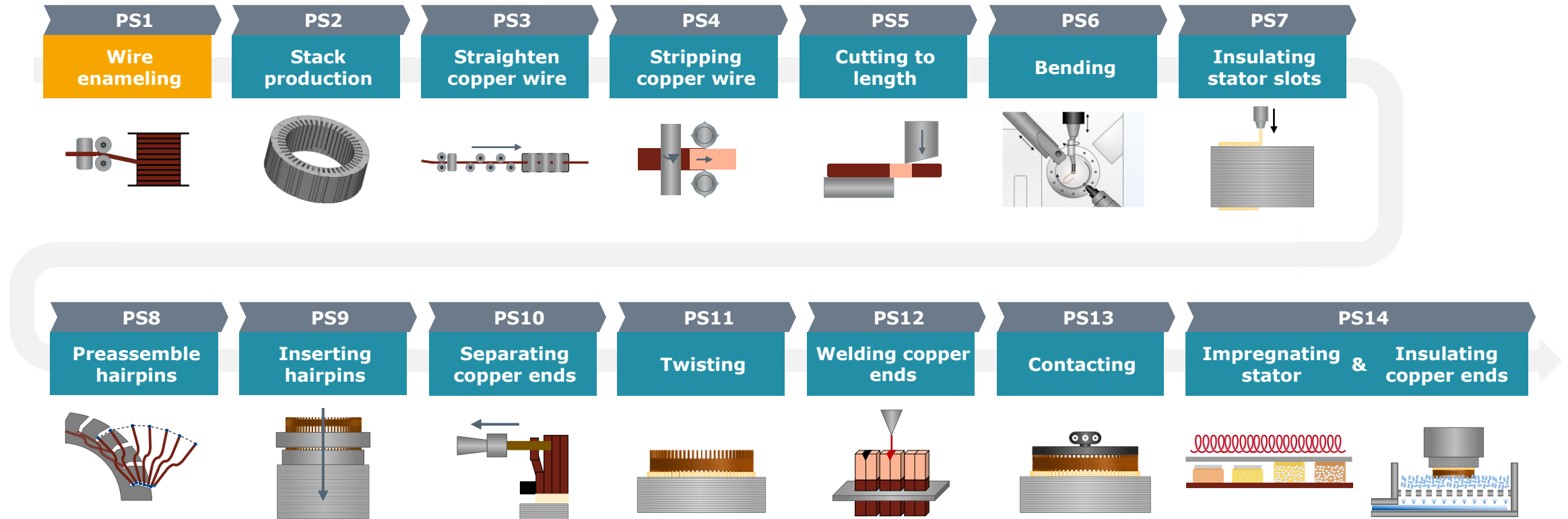
# Materials and Production Processes

## Process Chain for Demonstrator Manufacturing



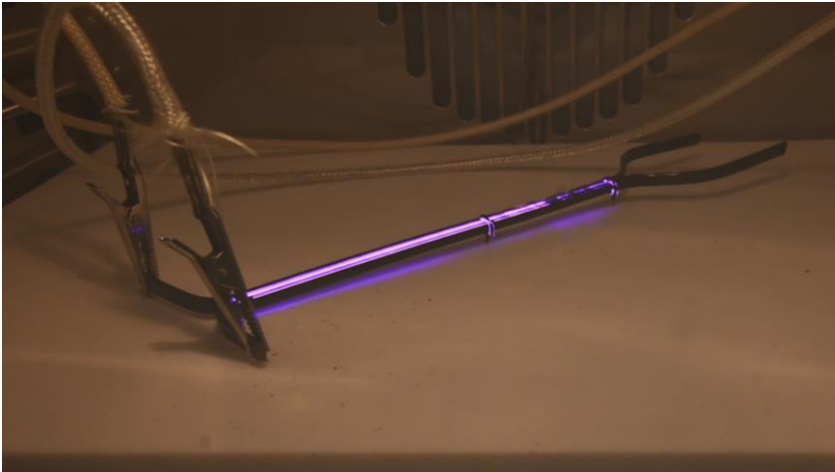
# Wire Enameling

## Process Chain for Demonstrator Manufacturing



# Magnet Wire

SHWire (Schwering & Hasse Elektrodraht GmbH)



## SHXLife Product information:

- **Durability:** 500x extended lifetime\* under partial discharge
- **Design flexibility:** Enables smaller safety margins
- **Increased efficiency:** Increased copper fill factor due to reduced layer thicknesses
- **Economy:** Makes 800V+ solutions are more cost-effective
- **Excellent quality:** Manufactured according to recognized SHWire 'Industry 4.0+' process technology



**Martin Krupa**

Product Management  
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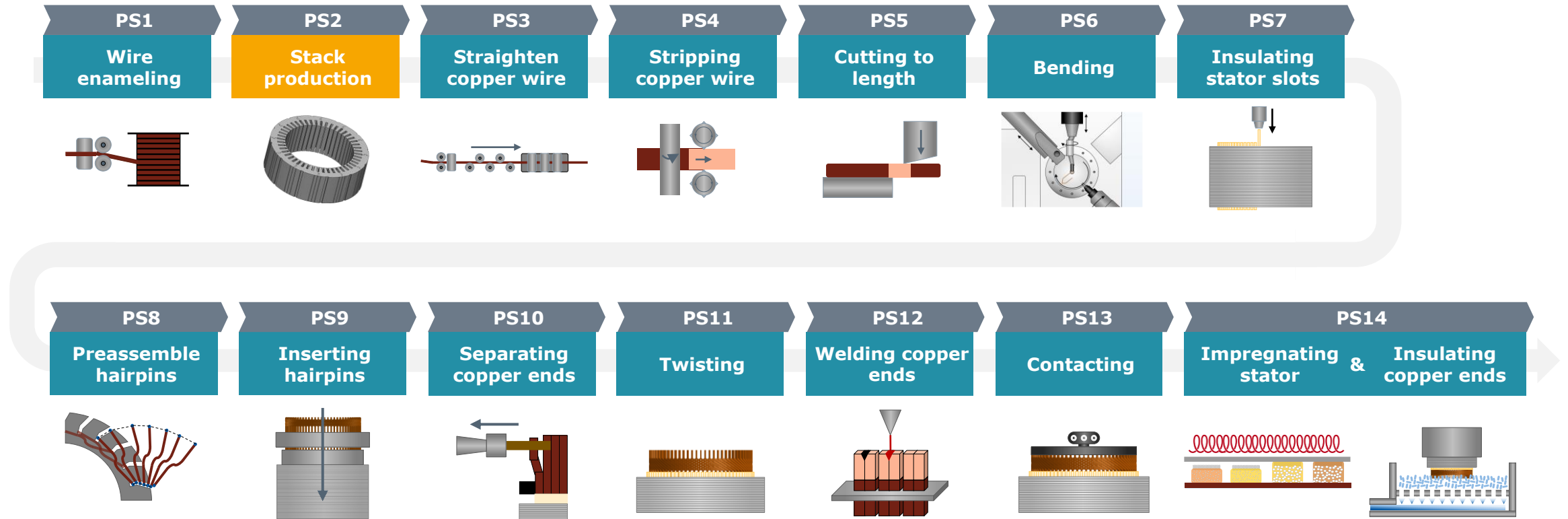
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# Stack Production

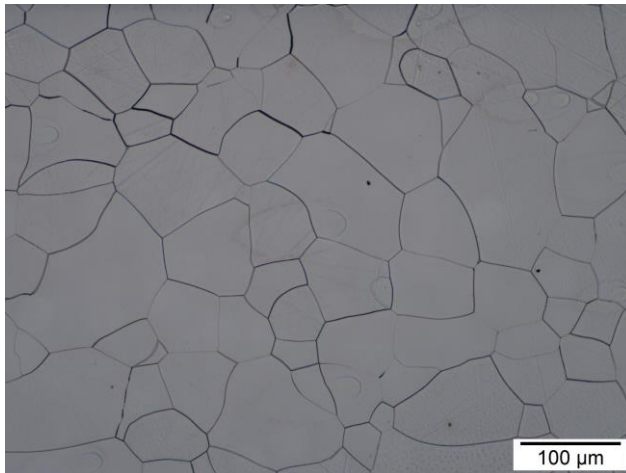
Process Chain for Demonstrator Manufacturing



# Electrical Sheet Production

C.D. Wälzholz GmbH & Co. KG

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## Process information:

- Cold rolling of the hot band to 1 mm thickness
- Final annealing in a continuous annealing furnace at 1,000°C under protective atmosphere to reach the desired magnetic and mechanical properties
- Average grain size in the horizontal line cutting method of approx. 52 μm by C.D. Wälzholz GmbH & Co. KG



**Dr.-Ing. Christoph Dahlmann**

Werkstofftechnik Elektroband  
C.D. Wälzholz GmbH & Co. KG

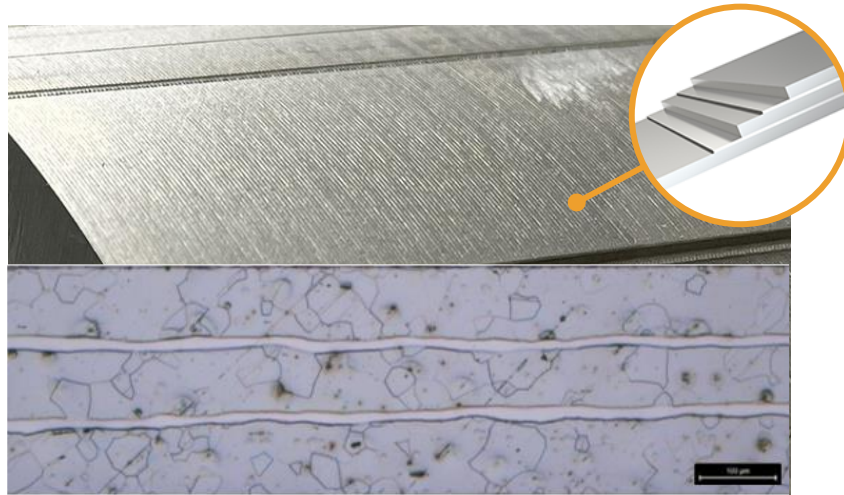
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# Electrical Sheet Production

Wickeder Westfalenstahl GmbH



## Product and process information:

- DEBAND® developed by Wickeder Westfalenstahl GmbH
- Composite material consisting of alternating ferromagnetic and non-ferromagnetic layers forming a sheet stack already layered in itself
- DEBAND® realizes thinnest electrical steel/functional layers in an optimally processable product (punching, punching and stacking, laser welding possible)
- The material used in this study comprises 3 quasi NO10 strips with a total thickness of 0.3mm
- Studies show increased efficiency in the higher frequency range (>400 Hz) compared to reference material
- Total losses reduced by up to 30% compared to the same quality as a single sheet



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### Dr. Dominique Korbmacher

Business Development  
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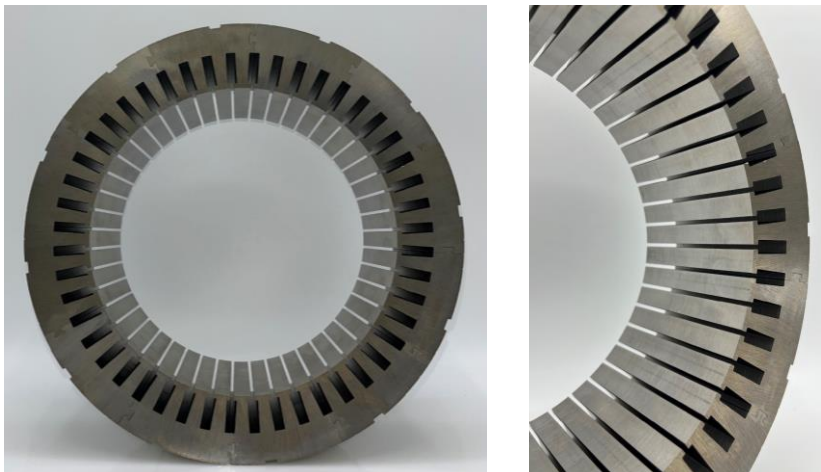
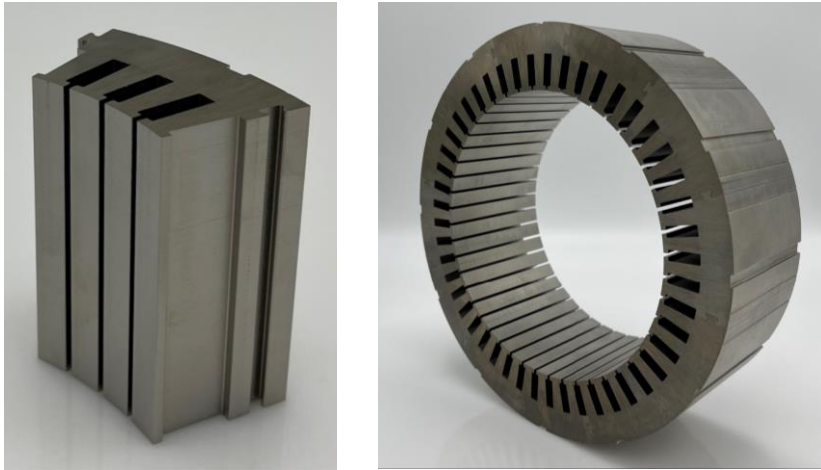
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**E-Mail** Dominique.Korbmacher@wickeder.de



# Stack Segment Production – Laser Cutting/Stamping, Stacking, Backlack Bonding

LCD LaserCut AG | SWD AG



## Process information:

- Engineering of a suitable segmentation geometry
- Lamination production via laser cutting or stamping
- Backlack bonding
- Full stator assembly
- Quality control of your part (geometry, mechanics, and magnetics)

## Process benefits:

- Up to 55% material savings for segmentation vs. conventional production  
Here: 12.25 kg savings @  $l_{Fe} = 70$  mm
- Maximum material flexibility for your electrical machine
- Full industrialization
- Best overall part tolerances reduction
- Segmentation is available for radial and axial flux motors with 3D segments



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LCD LaserCut AG

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SWD

Thomas Stäuble

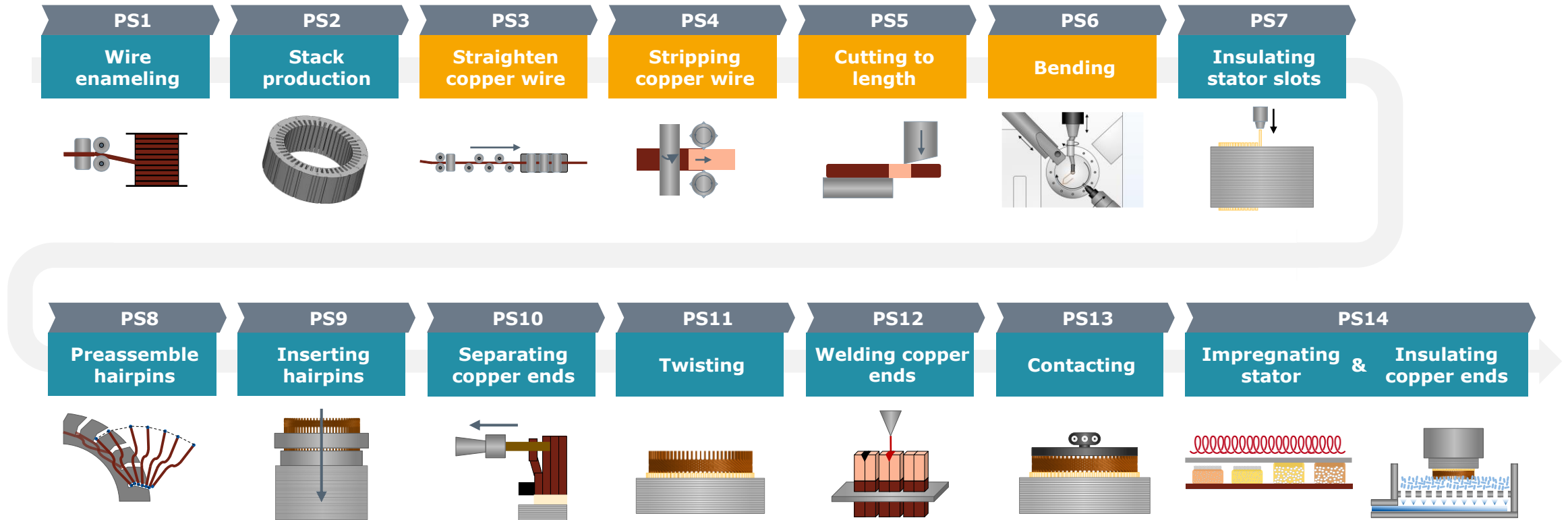
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# Hairpin Production

Process Chain for Demonstrator Manufacturing



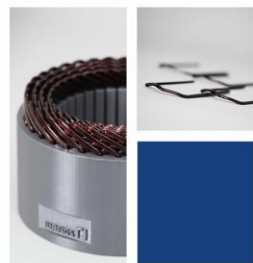
# Hairpin Production – Straightening, Stripping, Bending, Cutting

WAFIOS AG



## Process information:

- CNC bending of hairpins on the highly flexible FMU 40E bending machine
- Processing of a wide variety of innovative materials requires the use of the best and most flexible technology the market has to offer
- Tool-based CNC bending from WAFIOS AG is the perfect combination of a flexible CNC process and the precision of a tool-based process
- Possibility to process a wide variety of hairpin materials with the same tool, e.g.:
  - Geometry of the conductor (e.g. U-pin, I-pin, connection assemblies, continuous winding, etc.)
  - Conductor material (e.g. copper, aluminum)
  - Coating material (e.g. PAI, PEEK, PI, Kapton, etc.)
  - Hollow conductors, Litz wires, ...



**WAFIOS**   
electrifies...

FMU E series:  
Flexible CNC hairpin bending machinery

Copyright by WAFIOS AG 2022



**Martin Bauer**

Industry Manager, E-Mobility  
WAFIOS AG

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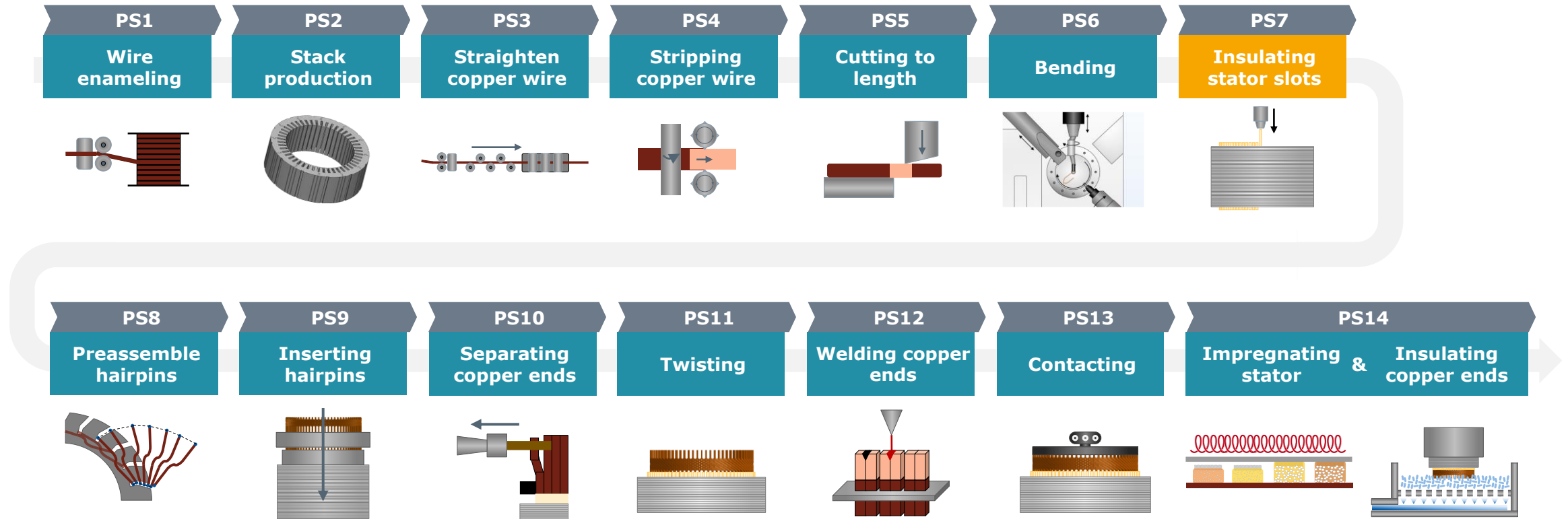
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**WAFIOS**   
electrifies...



# Slot Insulation

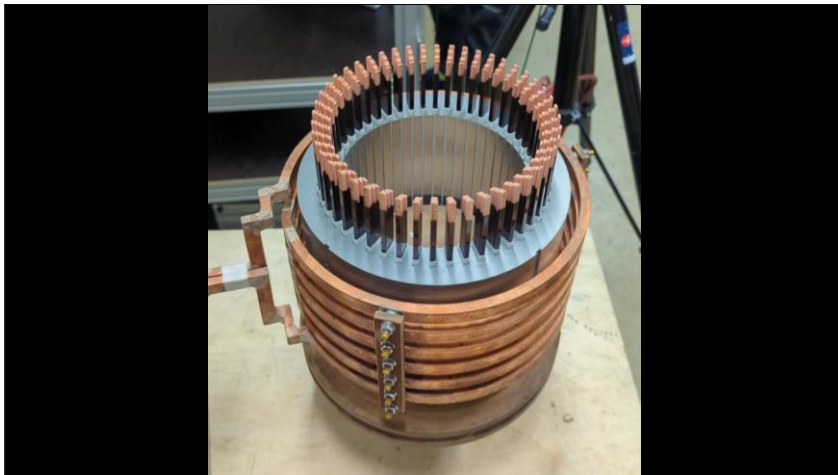
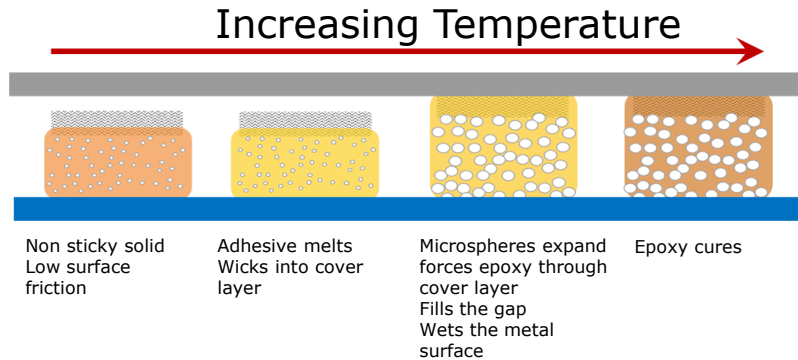
Process Chain for Demonstrator Manufacturing



# Expanding Slot Liner

3M Deutschland GmbH

SCALE-UP  
E-DRIVE



## Process information:

- 3M™ Expandable Slot Liner ESL-FC190
- Eliminates need for impregnation with varnish application in slots
- Smooth surface suitable for automatic insertion equipment
- Electrically insulating, mechanically protecting and securely holding the coils
- Process steps for application:
  - Expandable slot liner (ESL) inserted into slots
  - Coil winding inserted into the insulated slots
  - Heating for expansion of ESL (room temp. to 180°C, approx. 3 minutes)
  - Hold temperature for curing (180°C, approx. 10 minutes, curing time may be adjusted depending on temperature)



**Jürgen Schnusenberg**

Application Engineer  
3M Deutschland GmbH

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# Insulating Stator Slots – Folding and Inserting Slot Liner

Schaeffler ELMOTEC STATOMAT GmbH



## Process information:

- Use of an existing flexible all-round slot insulation machine (SIM)
- Application of flexible paper length for different stack length
- Folding of different paper forms (U-Shape/O-Shape/B-Shape)
- Usable for different materials: Nomex, laminate, PEEK, or foamed slot liners
  
- Trials here carried out based on 3D-printed product specific tooling
  - Transfer stamp (green)
  - Folding matrix (green)
  - Folding stamp (yellow)



**Dr. Jens Butschan**

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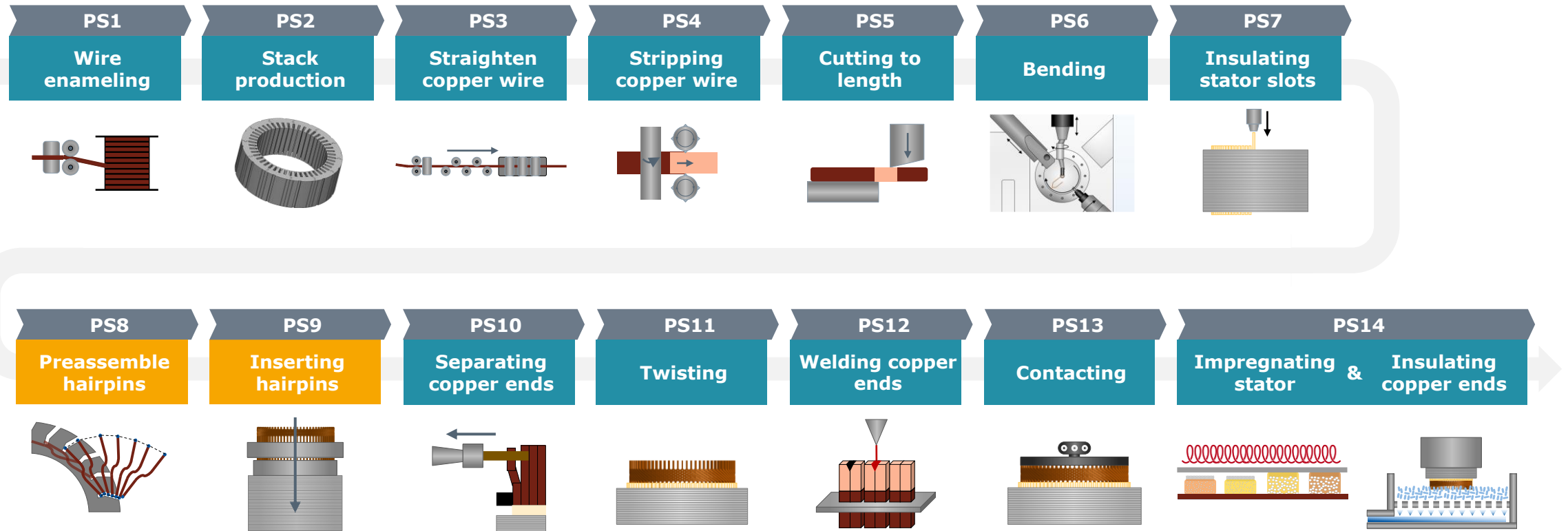


A Schaeffler Company



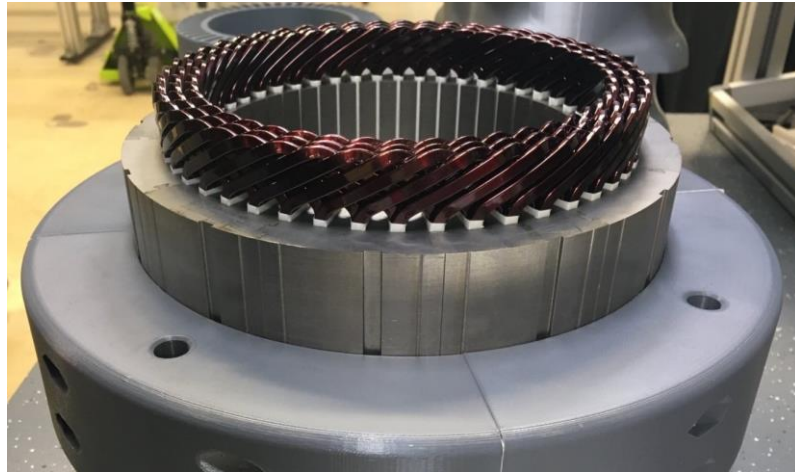
# Hairpin Pre-Assembly and Insertion

Process Chain for Demonstrator Manufacturing



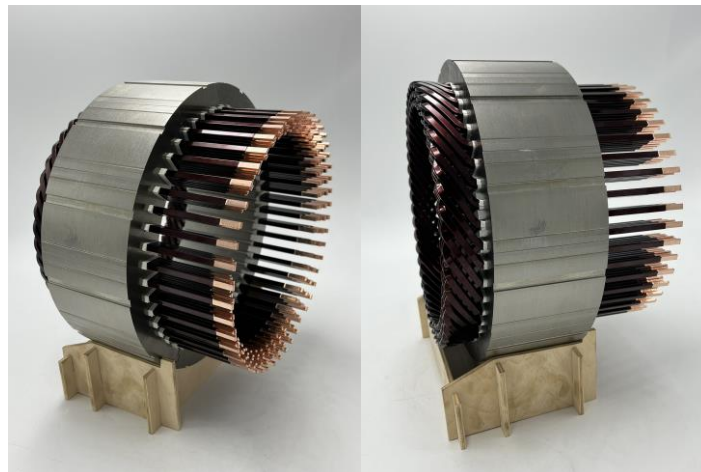
# Hairpin Pre-Assembly and Insertion

Production Engineering of E-Mobility Components (PEM) of RWTH Aachen University



## Process information:

- Manual pre-insertion of hairpins, layer by layer, from inner diameter to outer diameter
- Final insertion by pressing down all pins with hydraulic press
- Fixation of slot liner with self-developed, 3D printed spacers



**Till Augustin Backes, M. Sc.**

Research Associate “Electric Drive Production”  
PEM of RWTH Aachen University

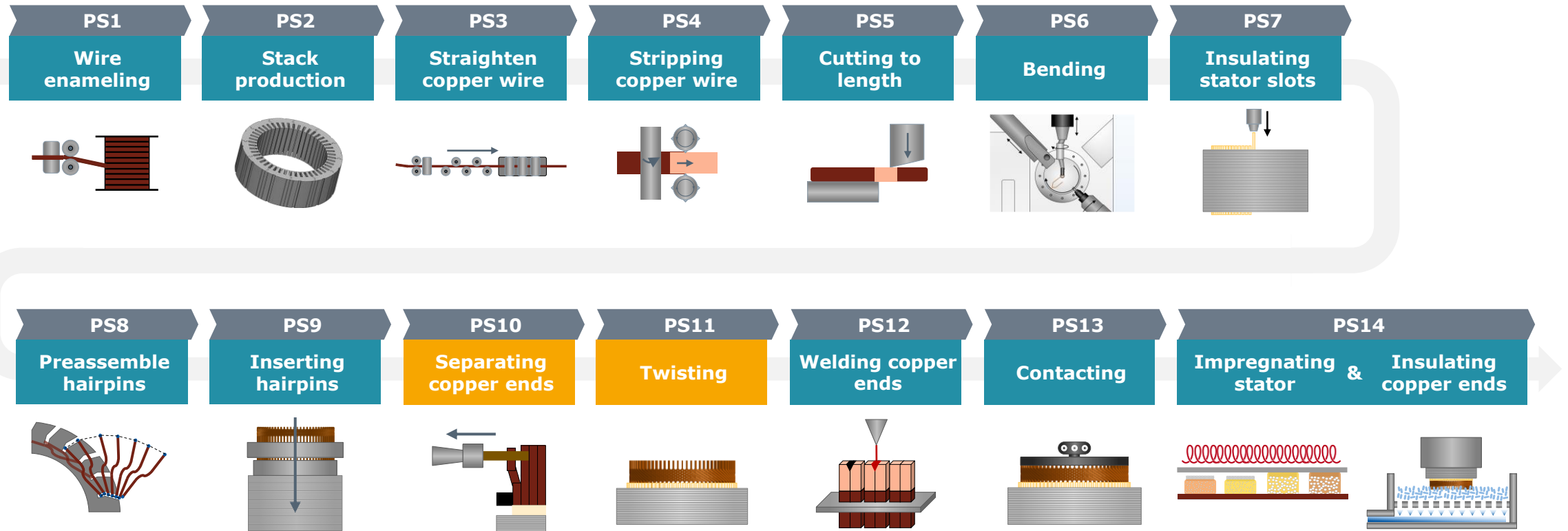
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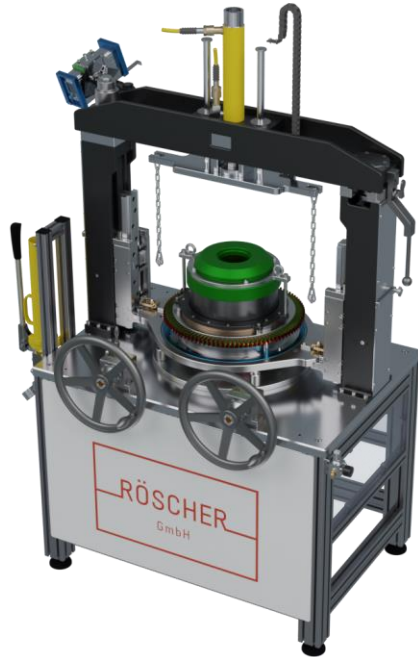
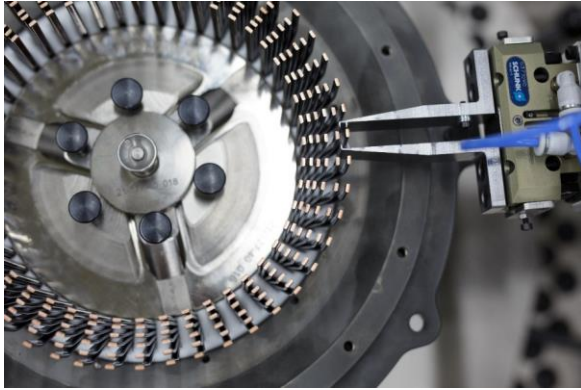
# Separating and Twisting Hairpin Ends

Process Chain for Demonstrator Manufacturing



# Separating and Twisting Hairpin Ends

Röscher GmbH



## Process information:

- Hairpin ends are separated layer by layer
- Tooling for twisting is fixed to stator
- Twisting is performed for two layers at a time
  
- Equipment used: manual machines for separating and twisting



**Dr. Gero Heusler**

CEO  
Röscher GmbH

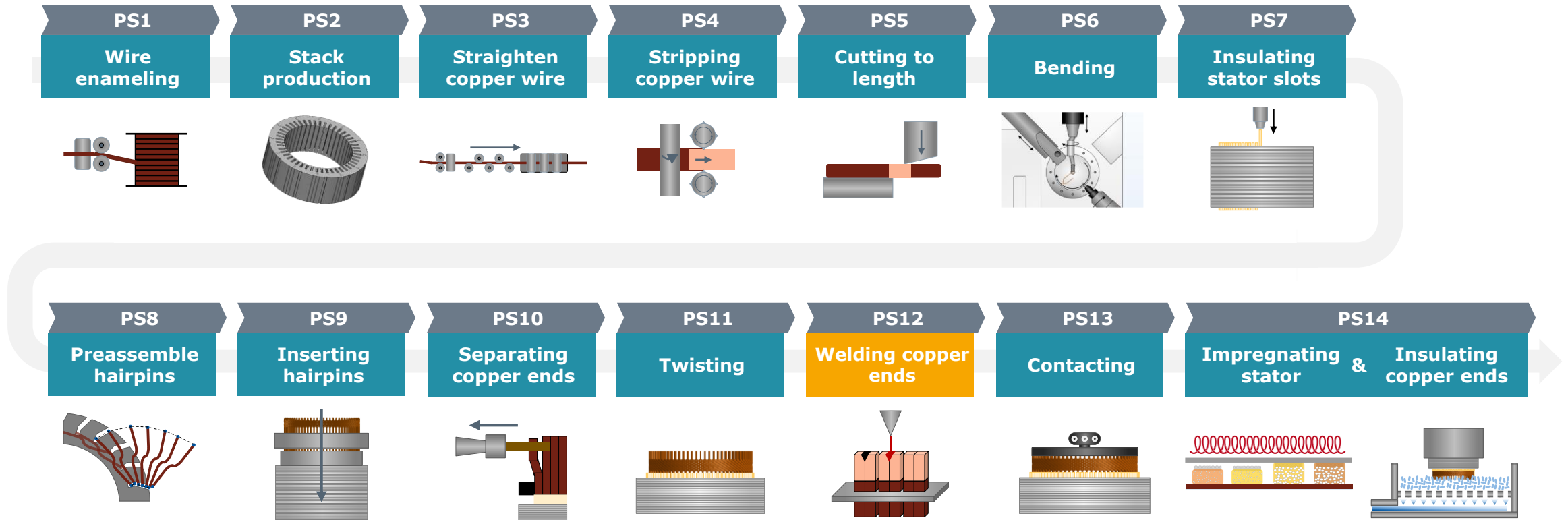
**Phone** +49 (0) 30 59 89 85 56  
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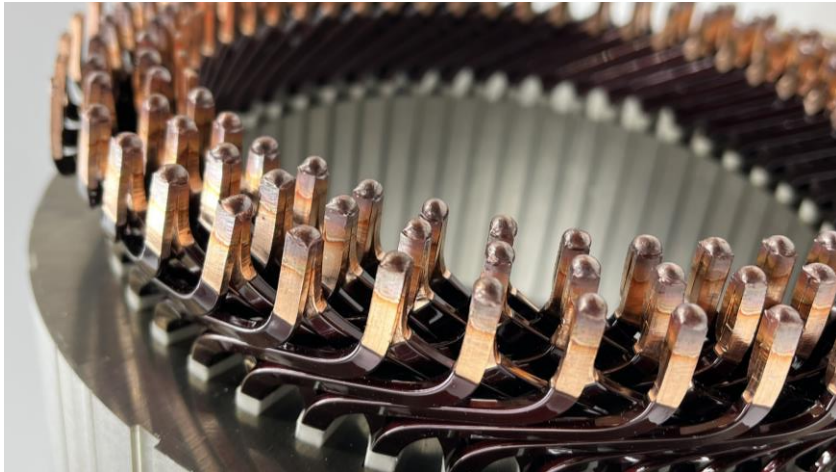
# Hairpin Welding

Process Chain for Manufacturing the Demonstrator



# Hairpin Welding

TRUMPF Laser- und Systemtechnik GmbH



## Process information:

- Laser welding of hairpins and busbars
- Typical laser power: 6 or 8 kW, depending on productivity specification
- TRUMPF Disk Laser with high beam quality 2mm x mrad, Fiberdiameter 50/200µm (2-in-1 Fiber), BrightLine Weld waveguide
- Scanning optics PFO33-3, new-generation 2D scanner
- VisionLine position tracking with A.I. and real-time position adaption for each regular pin and busbar weld
- Typically, no shielding gas in use
- Welding time for regular pins: 100 ms
- Laser stripping possible with TruMicro ns-pulsed lasers (2 kW average power, 100 mJ pulse energy), typical processing time (10 mm stripping length) <0.5 s



**Matthias Beranek IWE**

Industry Manager E-Mobility, Electrified Powertrain Expert  
TRUMPF Laser- und Systemtechnik GmbH

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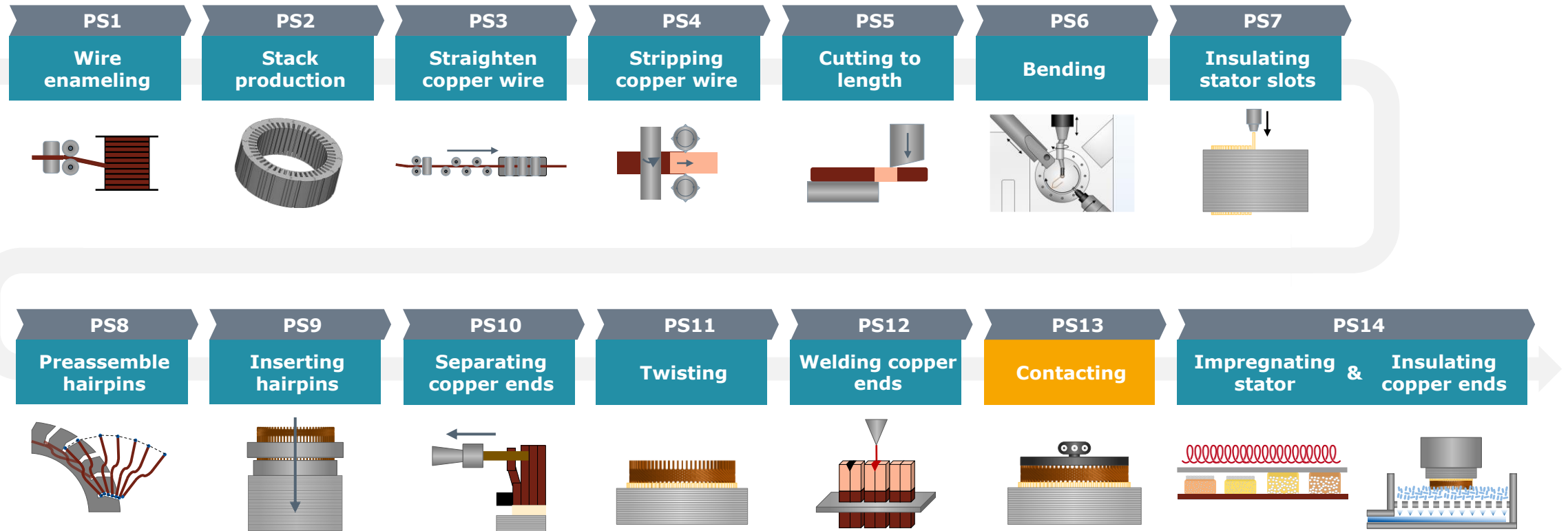
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**TRUMPF**



# Contacting Busbars

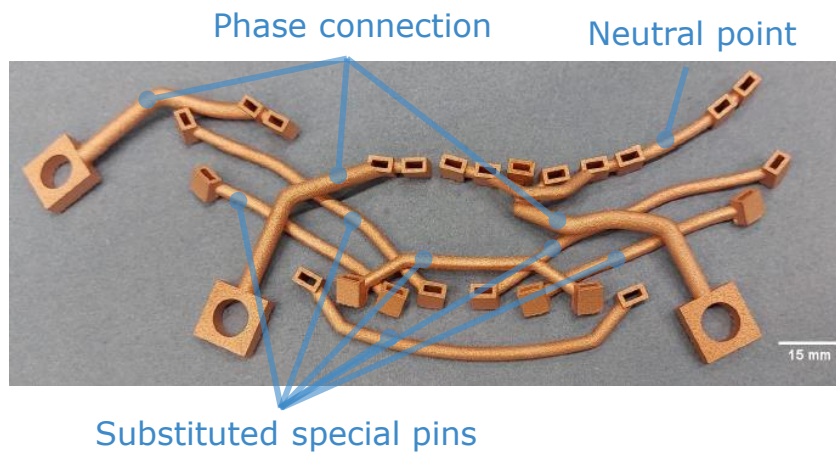
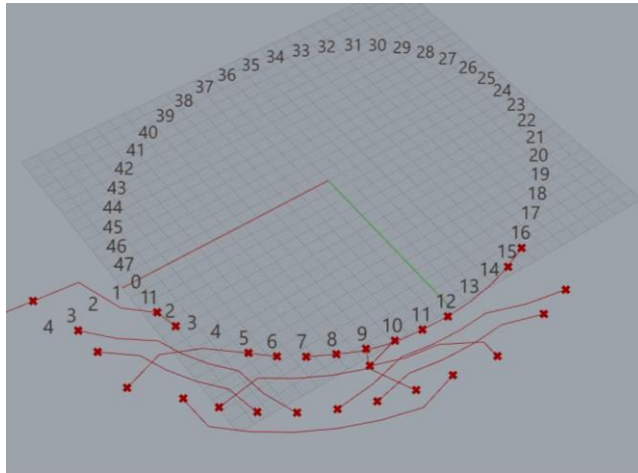
Process Chain for Demonstrator Manufacturing





# Contacting

Digital Additive Production (dap) at RWTH Aachen University



## Process information:

- Transfer of winding complexity of hairpin stators into the busbar assembly
- Automated design generation of busbar assemblies based on data-driven design modeling, considering electrical and production boundary conditions
- Optimized design space using numerical optimization algorithms
  - Shortest path algorithm
  - All connections areas to the hairpin winding in the same layer for welding
- Input: Winding scheme/busbar connection points and general stator and wire parameter
- Utilization of production potential offered by additive manufacturing



**Carsten Putz, M. Sc.**

Group Lead “Data Driven Design”  
dap at RWTH Aachen University

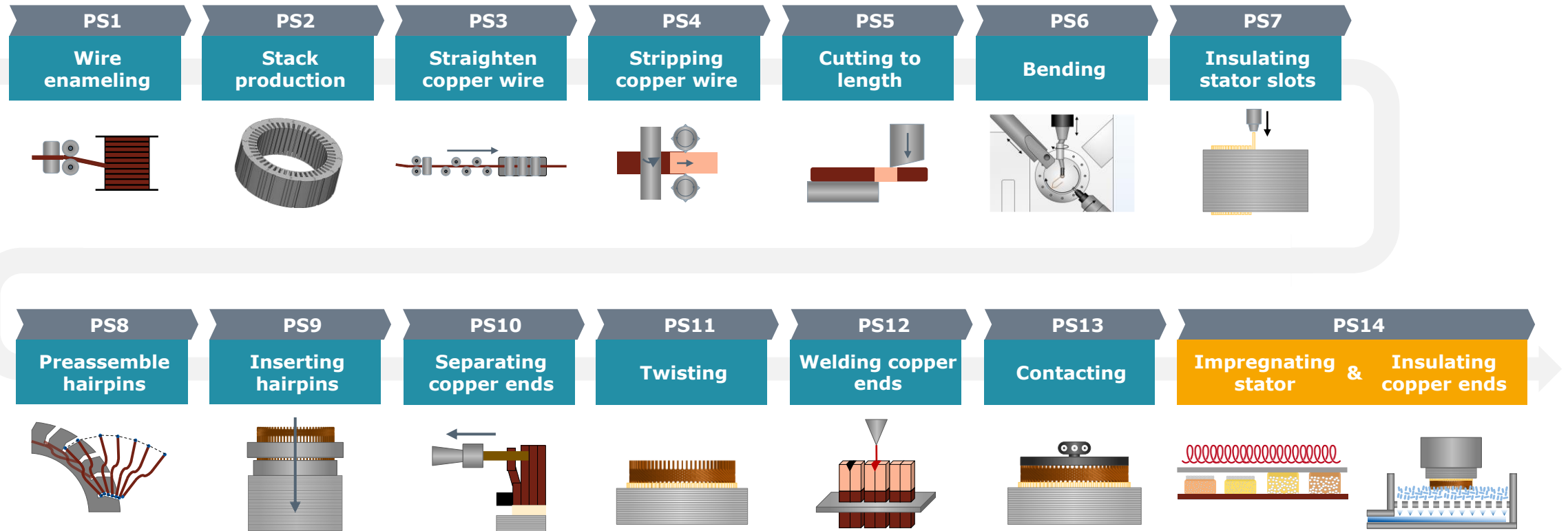
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# Impregnation and Secondary Insulation

Process Chain for Demonstrator Manufacturing



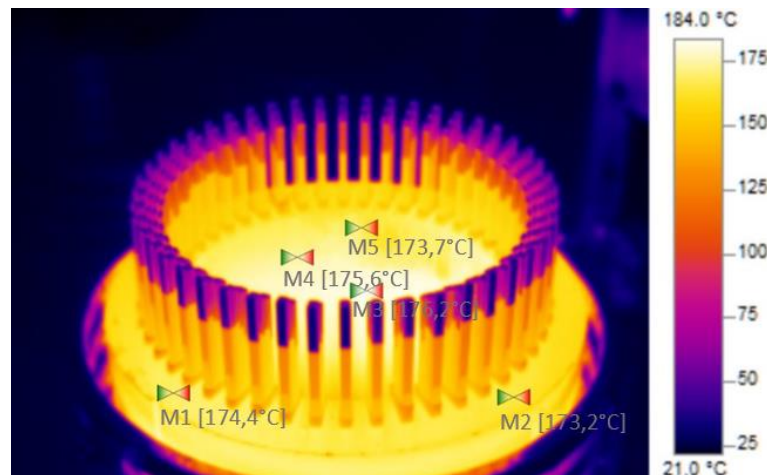
# Preparation for Impregnation and Insulation – Inductive Heating

GH-Induction Deutschland GmbH



## Process information:

- Overall target: Heating stator to expand ESL and simultaneously prepare for powder insulation
- Target temperature: Stator heating from 20°C to 180°C
- Required temperature incline: 60°C to 70°C heating per minute
- Type of heating: Inductive heating with outer ring inductor
- Heating process:
  - Step 1: Heating from 20°C to 60°C, 3M ESL is soft
  - Step 2: Heating from 60°C to 120°C, 3M ESL expand
  - Step 3: Heating from 120°C to 180°C, 3M ESL hardens
  - Step 4: Keep temperature at 180°C, cure 3M ESL completely



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# Powder Impregnation

AMS Anlagenbau GmbH & Co. KG

SCALE-UP  
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## Process information:

- Pre-heating, possible by
  - Circulation oven
  - Induction
  - Resistance heating
- Whirl sintering (powder coating)
- Curing in circulation oven



**Dominik Sterwerf**

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**Project Lead Contact**



For further information do not hesitate to contact us!



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Gefördert durch:



aufgrund eines Beschlusses  
des Deutschen Bundestages

SCALE-UP  
E-DRIVE



# “Scale-up E-Drive“ Transformation Hub

SCALE-UP  
E-DRIVE

“E-Drive Production Technology“ Pitch Center

## PITCH CENTER E-Drive Production Technology Aachen, July 19<sup>th</sup>, 2024

Present your developments and solutions in the field of production technologies for electric drives and get it touch with OEMs!



The Pitch Center Committee

**SCHAEFFLER**

**Thomas Pfund**

Schaeffler Automotive Buehl  
GmbH & Co. KG  
President Business Unit E-Motors

**MAHLE**

**Dr. Marco Warth**

MAHLE New Mobility Solutions GmbH  
Vice President Product Dev. Engine  
Systems and Components (ED)

**DAIMLER  
TRUCK**

**Thomas Mohr**

Daimler Truck AG  
Senior Manager InnoLab eDrive  
Operations



**Jan Knau**

BMW Group, Head of Production System  
Department, Production Strategy for  
Motors and Electric Drives

The Pitch Center is an event of the Scale-up E-Drive transformation hub, funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).