Gefördert durch:

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 · GGH induction · QUiCKFairs® · Coiltech

bayern innovativ · DLR · e-mobil BW · RWTH AACHEN UNIVERSITY · TUM

# Consortium Study – “Innovative Materials in Electric Motors”

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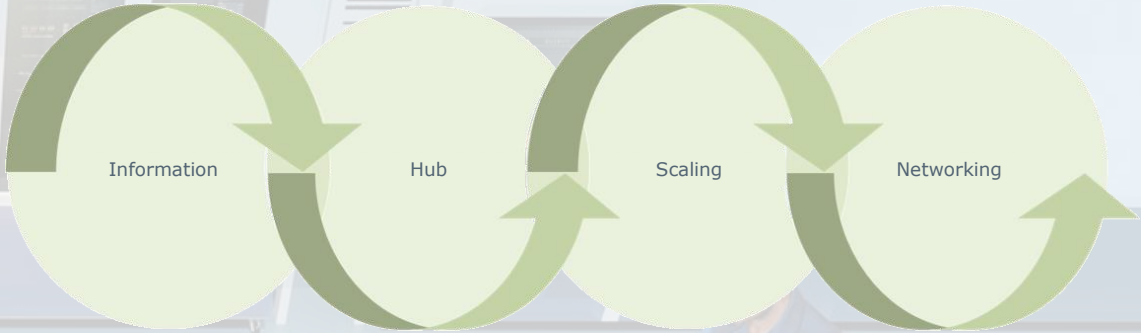
# “Scale-up E-Drive” Research Project

SCALE-UP E-DRIVE

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

e-mobil BW – Landesagentur für neue Mobilitätslösungen und Automotive Baden-Württemberg
bayern innovativ
DLR
TUM – Lehrstuhl für Fahrzeugtechnik
PEM | RWTH AACHEN UNIVERSITY

SCALE-UP E-DRIVE

| | | | |
|---|---|---|---|
| **Grantor** | BMWK | **Duration** | January 1st 2023 to June 30th 2025 |
| **Project Sponsor** | VDI \| VDE \| IT | **Funding Code** | 16THB0006E |

# Consortium Study – “Innovative Materials in Electric Motors”

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# “Scale-Up E-Drive” Transformation Hub

SCALE-UP E-DRIVE

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

## Demand

„The transformation of the automotive industry is creating a **high demand for product innovations**.“

## Supply

„Technology companies develop and offer **innovative solutions** for future electric motor technologies.“

**Successful use of new product technologies** is prevented by the current **lack of market access**.

## Approach

**The development and manufacturing of holistic technology demonstrators offer innovation driving companies a platform for the targeted presentation of their solutions.**

# “Scale-Up E-Drive” Transformation Hub

SCALE-UP E-DRIVE

“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

Coiltech

EPT ELEKTROMOBIL PRODUKTIONSTAGE

# Consortium Study – “Innovative Materials in Electric Motors”

SCALE-UP E-DRIVE

Manufacturing a Stator Primotype Using Innovative Materials and Processes

# “Innovative Materials in Electric Motors” Technology Demonstrator

SCALE-UP E-DRIVE

Objective and consortium

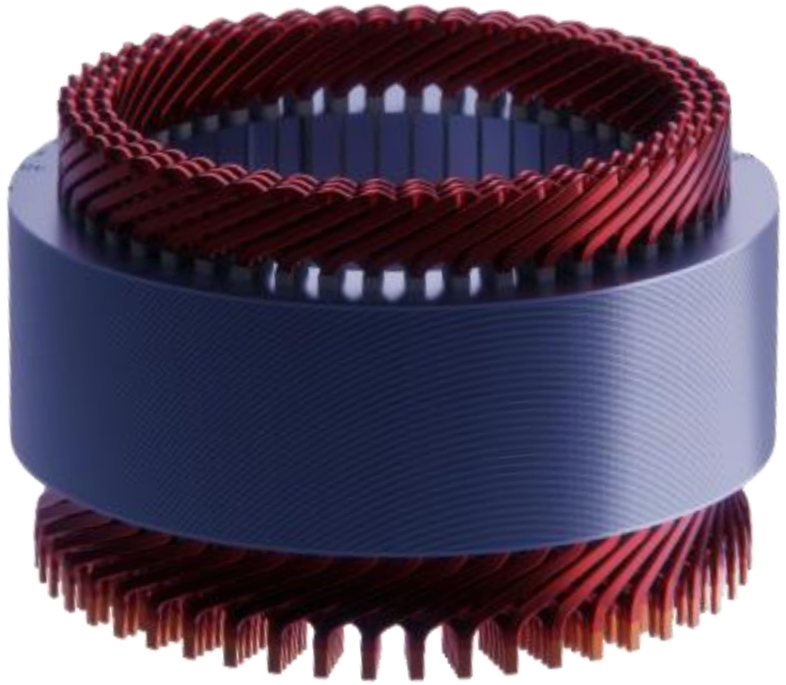
RÖSCHER GmbH

TRUMPF

PEM | RWTH AACHEN UNIVERSITY

WAFIOS

ELMOTEC STATOMAT
A Schaeffler Company



SWD

3M

SHWIRE Magnet Wires

A·M·S

Wickeder Westfalenstahl
Wickeder Group

LCD LaserCut AG

dap Digital Additive Production | RWTH AACHEN UNIVERSITY

WAELZHOLZ

GH GROUP induction

QUICKFairs®

Coiltech International Coil&Winding Exhibition

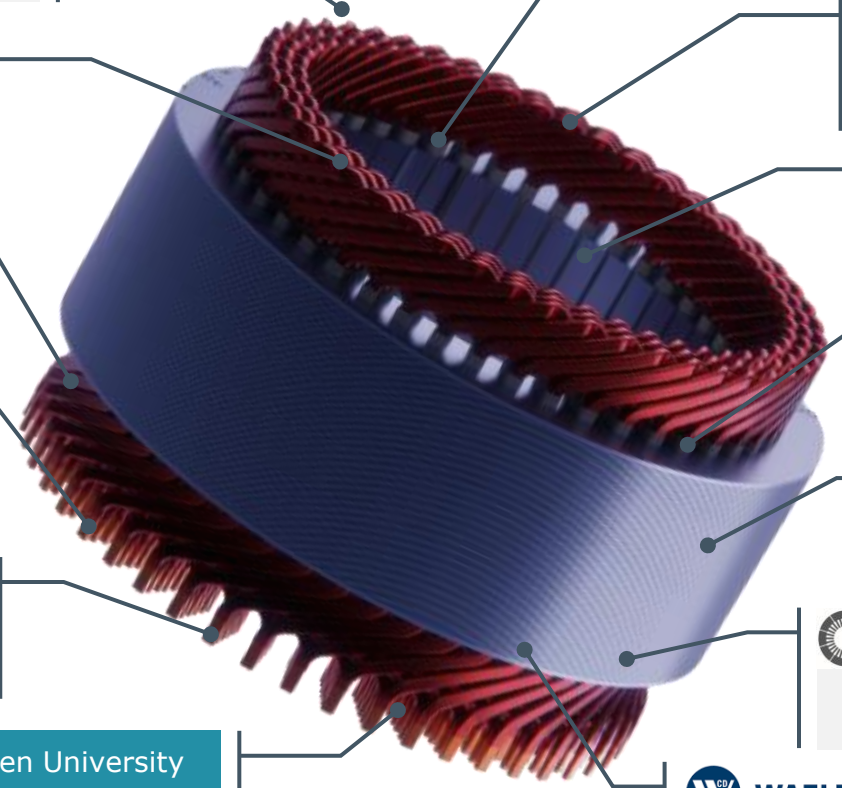
## Objective

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

SCALE-UP E-DRIVE

## Overview of the consortium’s contributions



**PEM of RWTH Aachen University**
Final assembly and project organization

**Schwering & Hasse Elektrodraht GmbH**
Copper wire with innovative insulation enamel

**Röscher GmbH**
Separating and twisting the wire ends

**AMS Anlagenbau GmbH & Co. KG**
Secondary insulation of the copper ends

**TRUMPF Laser- und Systemtechnik GmbH**
Contacting via laser welding

**dap at RWTH Aachen University**
Automated design and additive manufacturing of a busbar assembly

**Schaeffler ELMOTEC STATOMAT GmbH**
Folding and insertion of stator slot insulation

**WAFIOS AG**
Production of hairpins

**GH-Induction Deutschland GmbH**
Inductive heating of the lamination stack

**3M GmbH**
Expandable slot liner

**Wickeder Westfalenstahl GmbH**
Electrical steel composite process

**SWD AG & LCD LaserCut AG**
Sheet cutting, segmentation and packaging

**C.D. Wälzholz GmbH & Co. KG**
Raw material electrical steel

# Consortium Study – “Innovative Materials in Electric Motors”

SCALE-UP E-DRIVE

Manufacturing a Stator Primotype Using Innovative Materials and Processes

# “Innovative Materials in Electric Motors” Technology Demonstrator

SCALE-UP E-DRIVE

Key geometrical data

## *Key data of PEM’s reference stator design*

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

# Consortium Study – “Innovative Materials in Electric Motors”

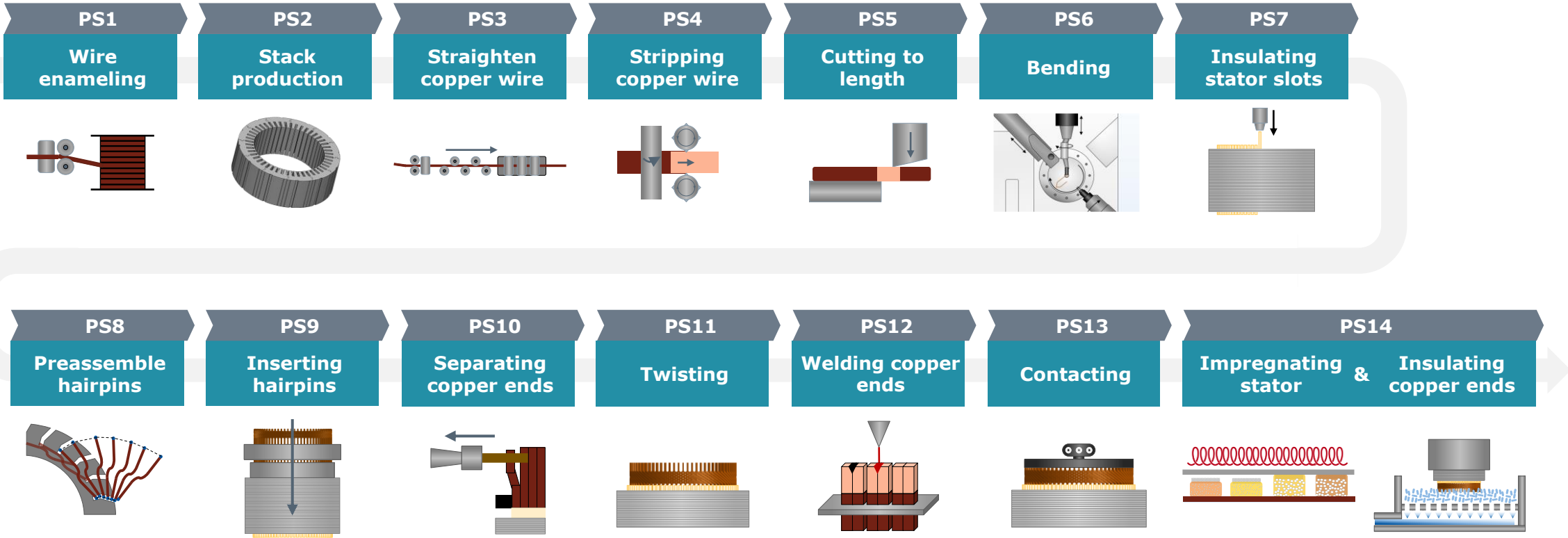
SCALE-UP E-DRIVE

Manufacturing a Stator Primotype Using Innovative Materials and Processes

# Materials and Production Processes

SCALE-UP E-DRIVE

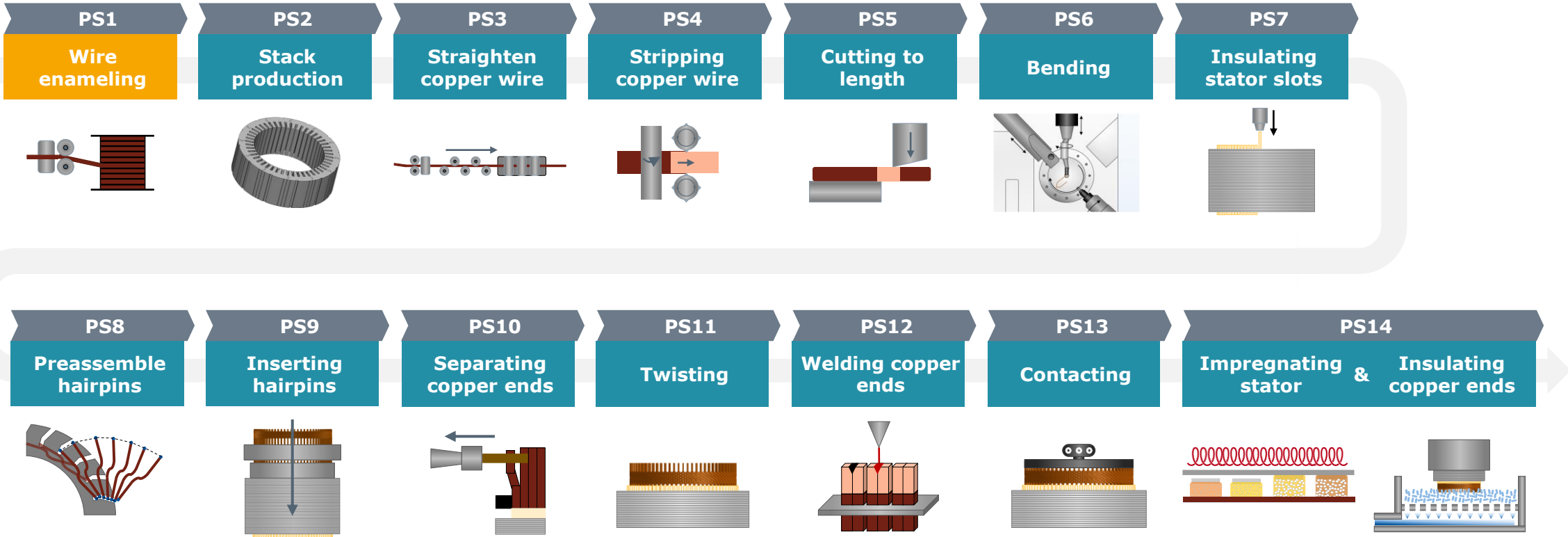
Process Chain for Demonstrator Manufacturing



# Wire Enameling

SCALE-UP E-DRIVE

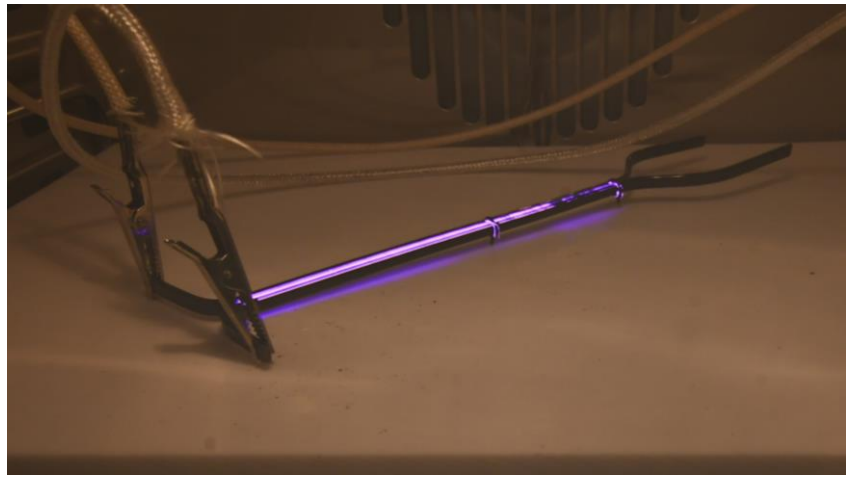
Process Chain for Demonstrator Manufacturing



# Magnet Wire

SCALE-UP E-DRIVE

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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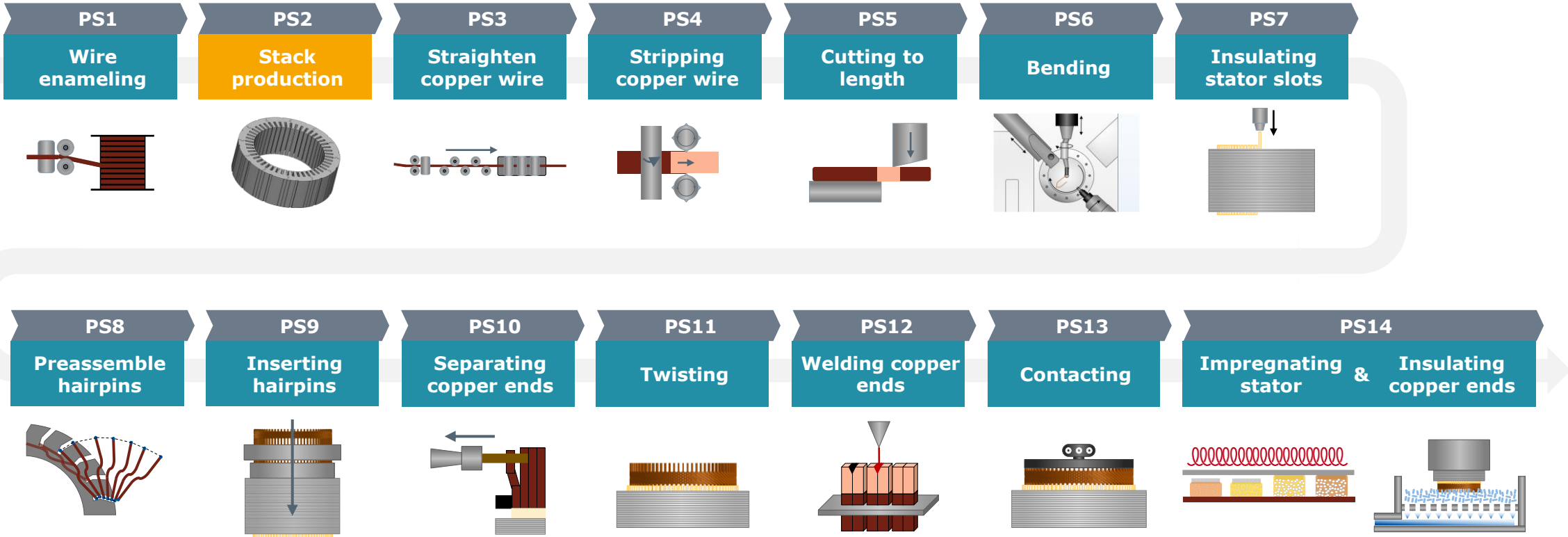
SHWIRE Magnet Wires

# Stack Production

SCALE-UP E-DRIVE

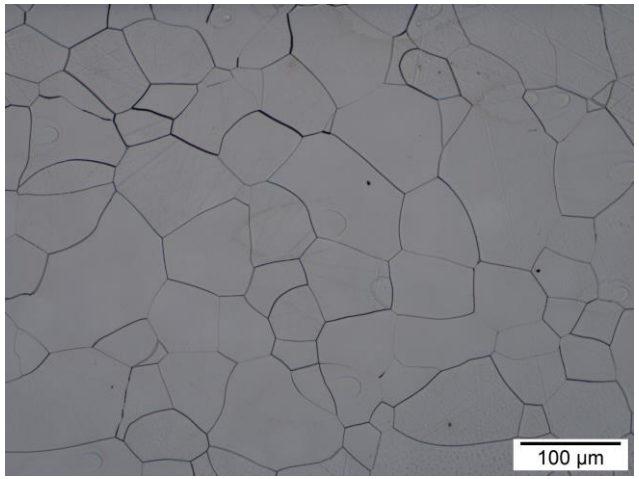
Process Chain for Demonstrator Manufacturing



# Electrical Sheet Production

SCALE-UP E-DRIVE

C.D. Wälzholz GmbH & Co. KG




**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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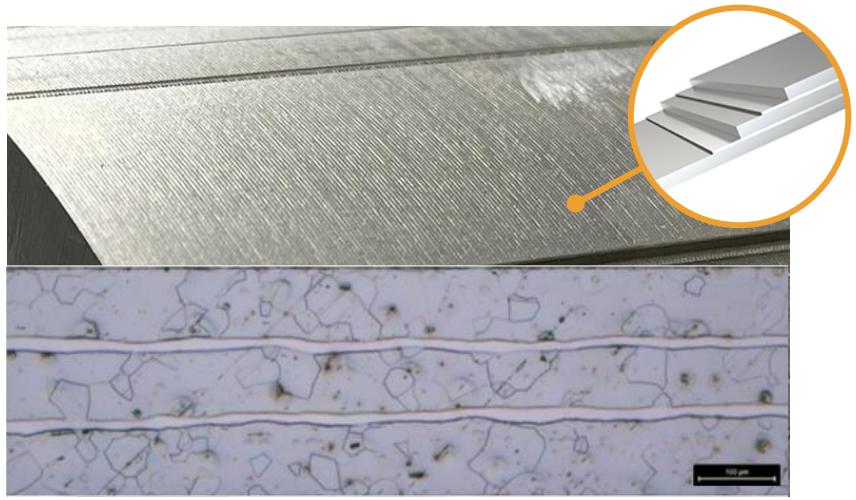
WAELZHOLZ

# Electrical Sheet Production

SCALE-UP E-DRIVE

## 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

Wickeder Group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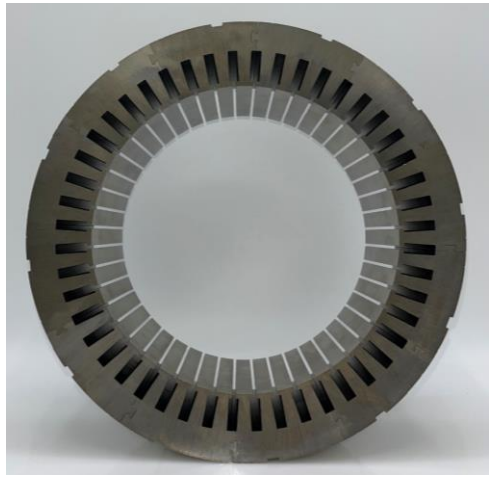
Wickeder Westfalenstahl
Wickeder Group

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

SCALE-UP E-DRIVE

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


LCD LaserCut AG

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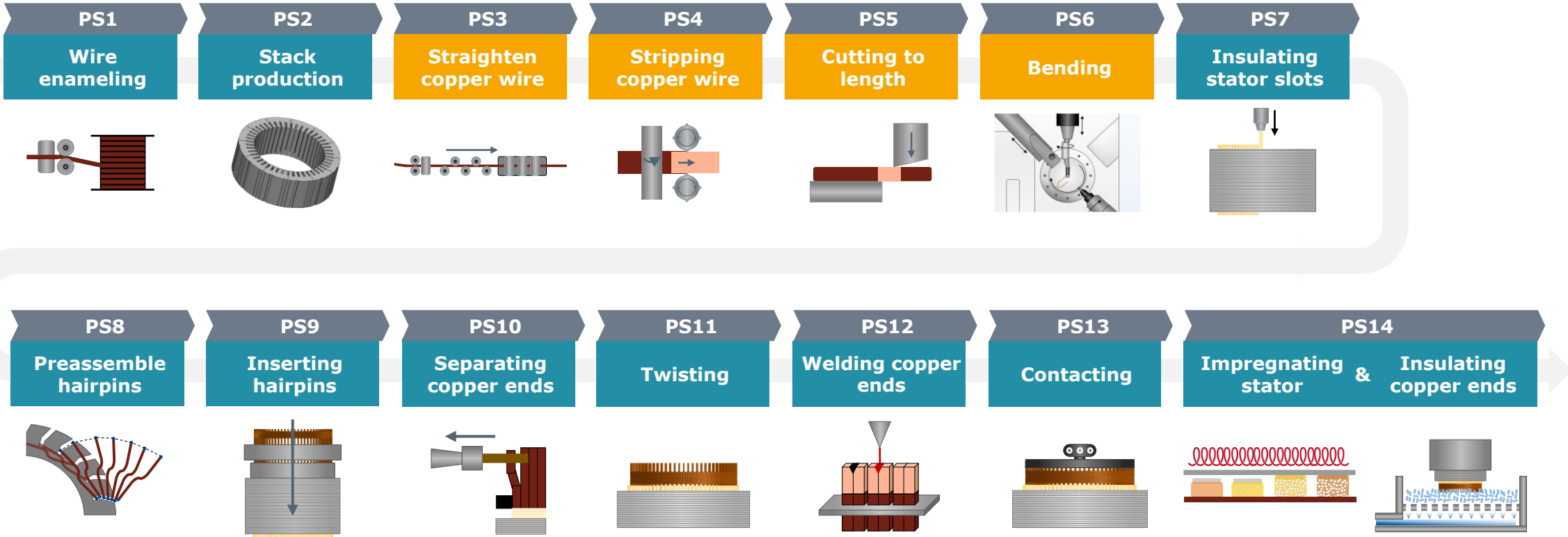
# Hairpin Production

SCALE-UP E-DRIVE

Process Chain for Demonstrator Manufacturing



# Hairpin Production – Straightening, Stripping, Bending, Cutting

SCALE-UP E-DRIVE

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, ...

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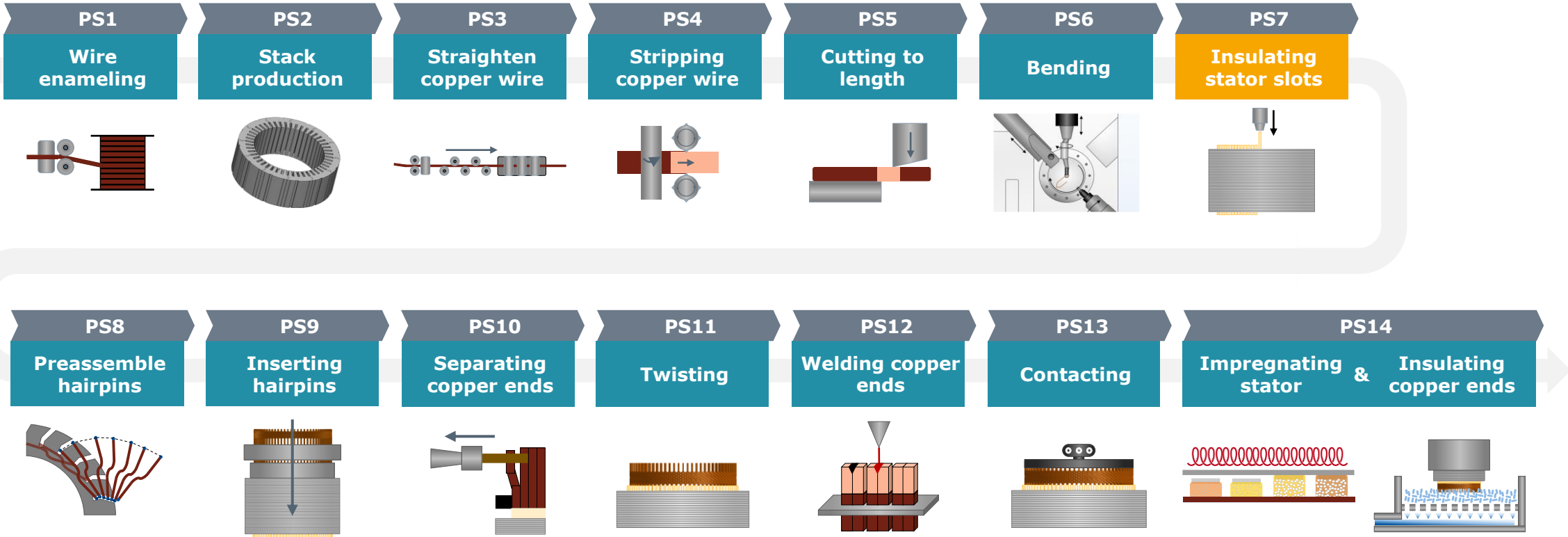
WAFIOS electrifies...

# Slot Insulation

SCALE-UP E-DRIVE

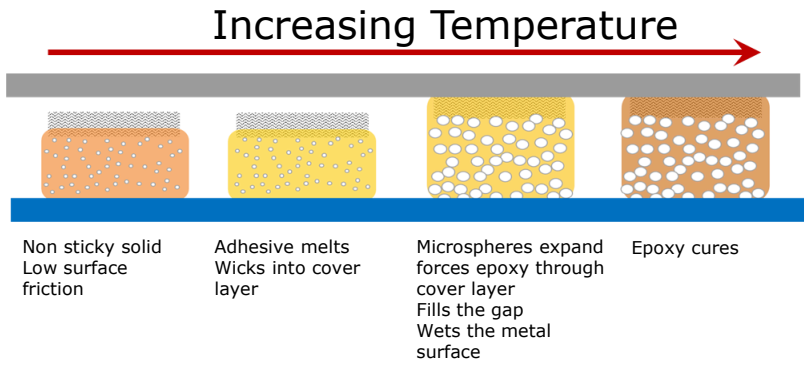
Process Chain for Demonstrator Manufacturing

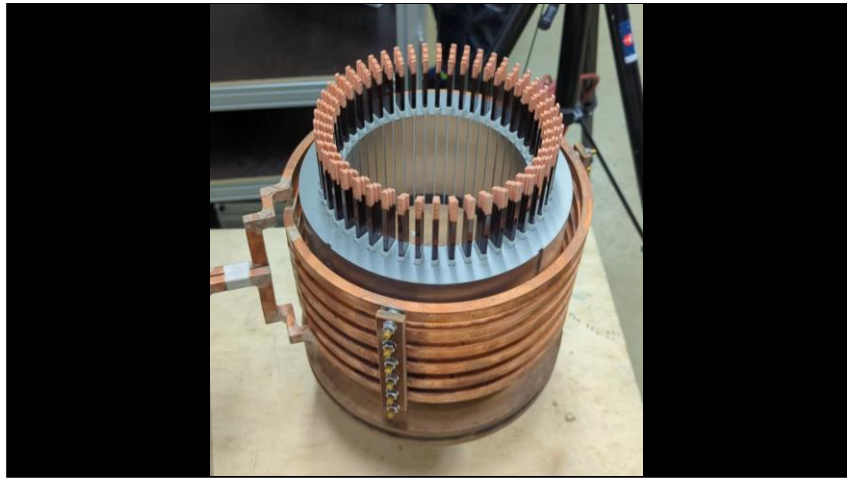


# Expanding Slot Liner

SCALE-UP E-DRIVE

3M Deutschland GmbH



**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)

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# Insulating Stator Slots – Folding and Inserting Slot Liner

SCALE-UP E-DRIVE

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**

Engineering Manager
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ELMOTEC STATOMAT
A Schaeffler Company

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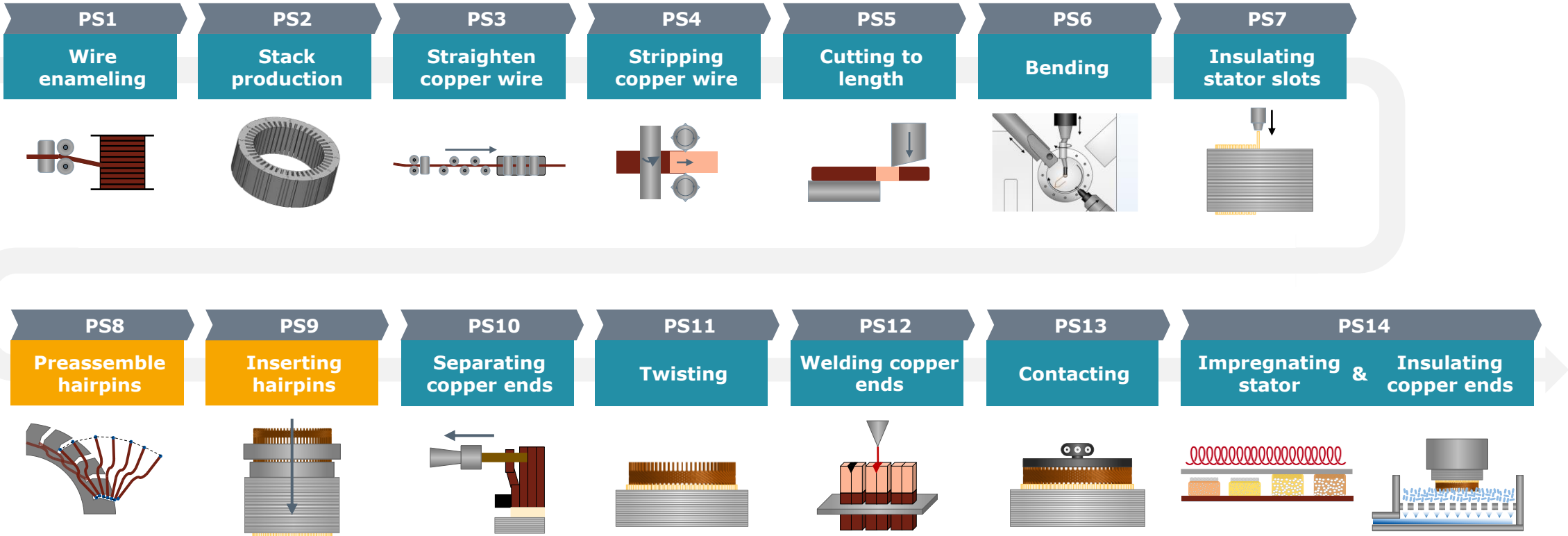
# Hairpin Pre-Assembly and Insertion

SCALE-UP E-DRIVE

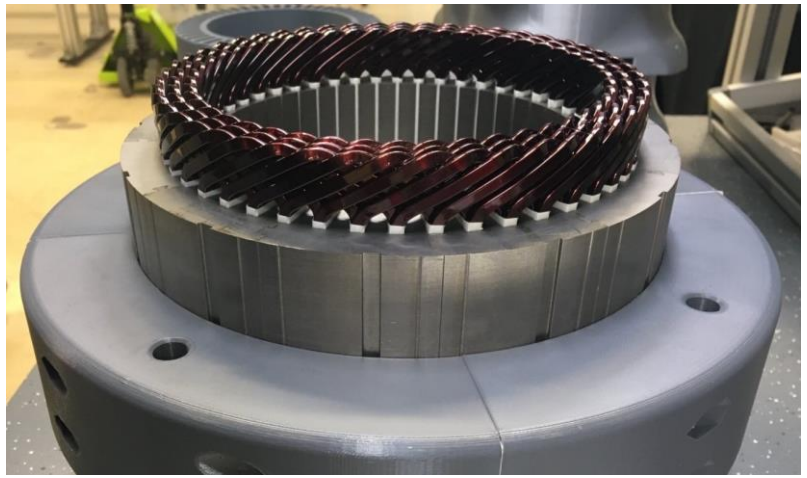
Process Chain for Demonstrator Manufacturing

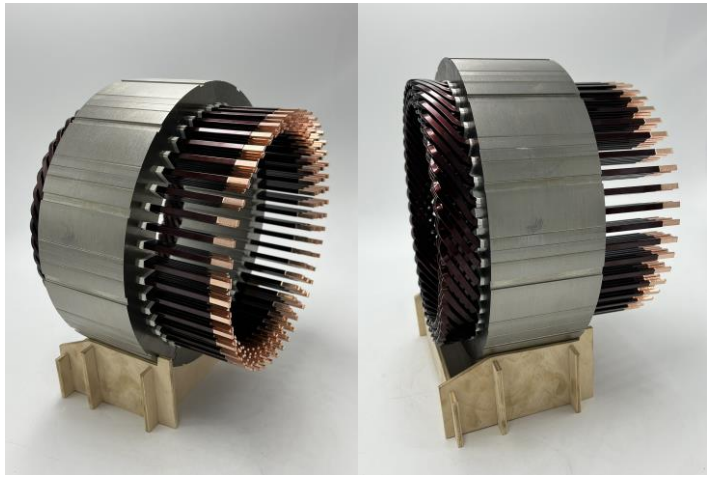


# Hairpin Pre-Assembly and Insertion

SCALE-UP E-DRIVE

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"
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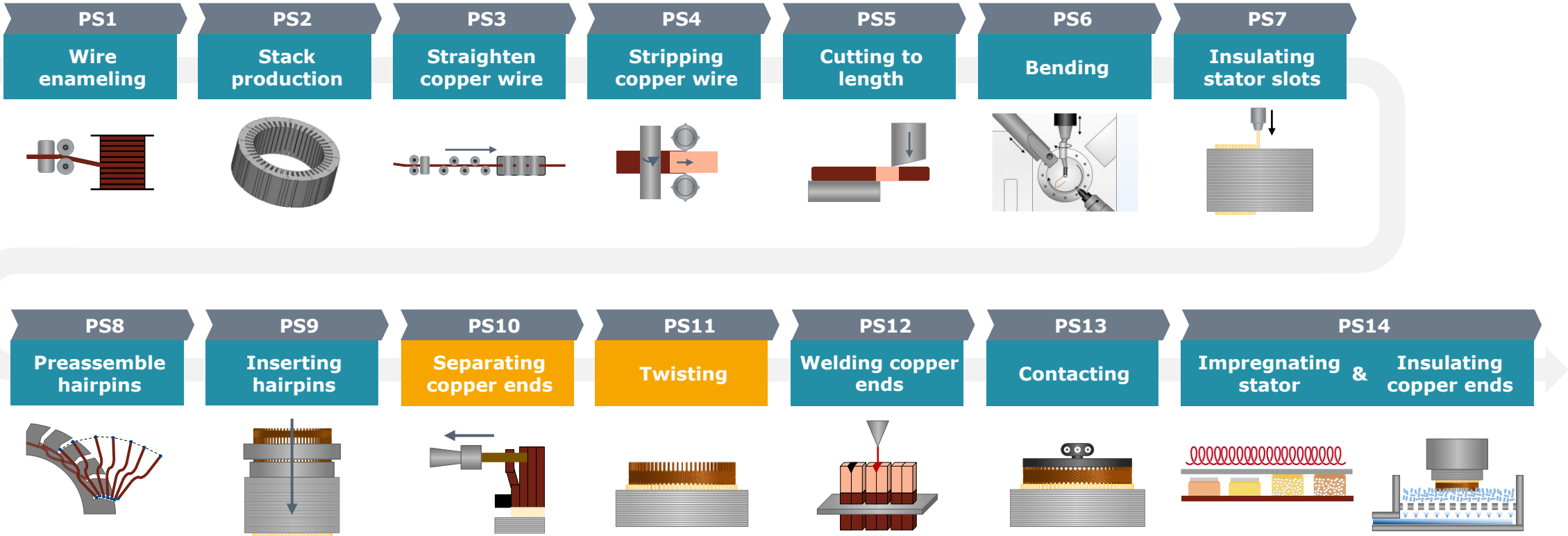
# Separating and Twisting Hairpin Ends

SCALE-UP E-DRIVE

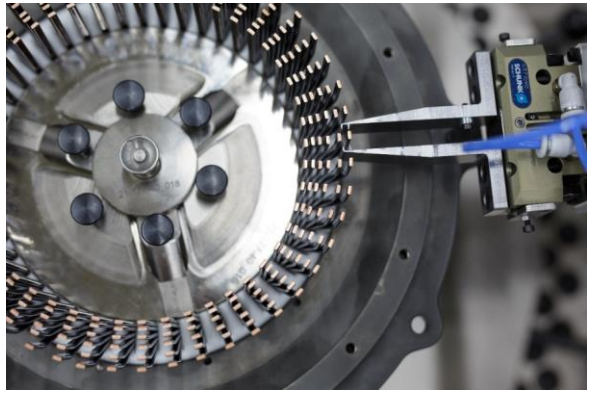
Process Chain for Demonstrator Manufacturing

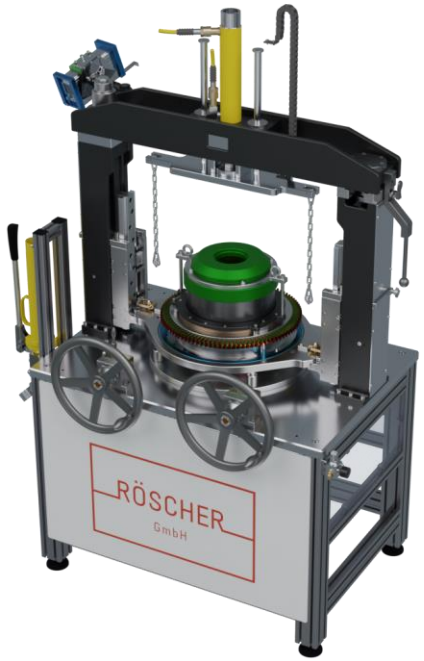


# Separating and Twisting Hairpin Ends

SCALE-UP E-DRIVE

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

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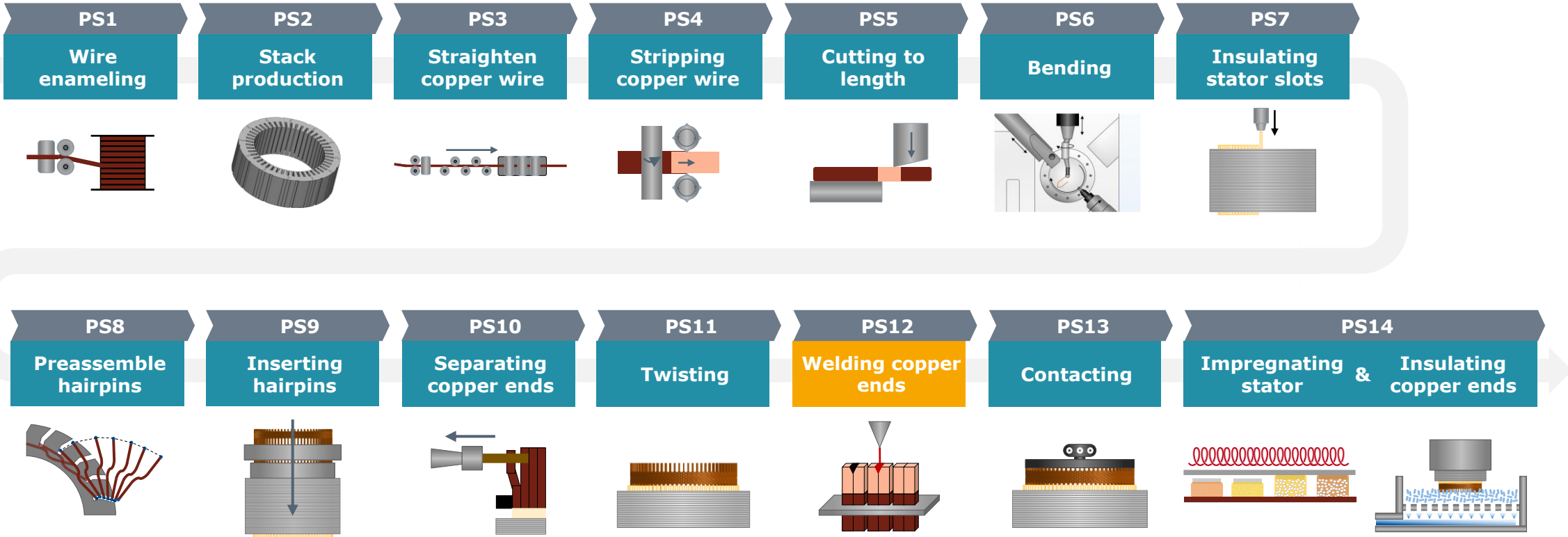
RÖSCHER GmbH

# Hairpin Welding

SCALE-UP E-DRIVE

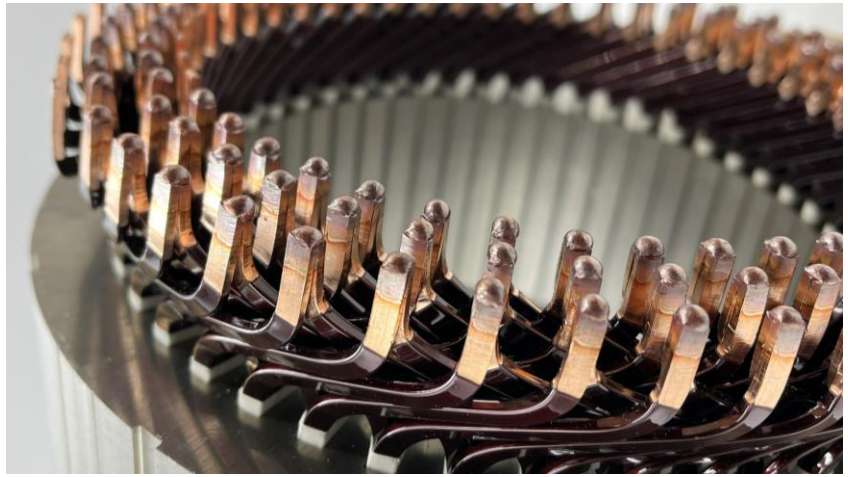
Process Chain for Manufacturing the Demonstrator



# Hairpin Welding

SCALE-UP E-DRIVE

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**
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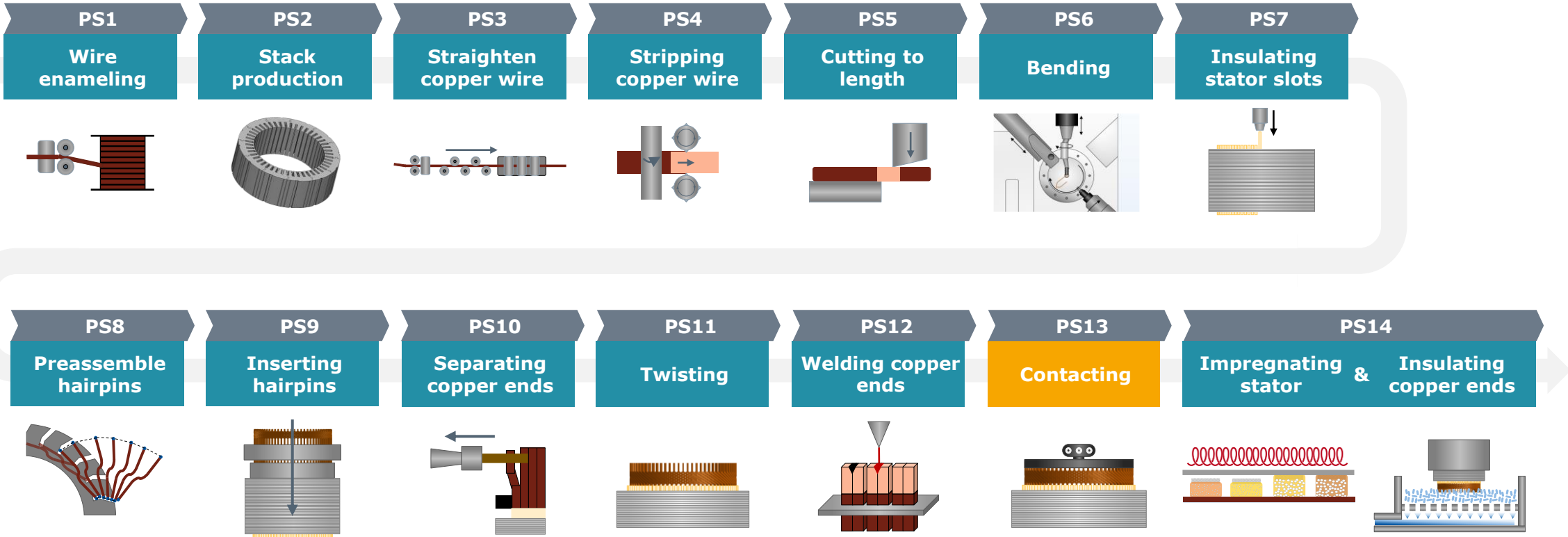
TRUMPF

# Contacting Busbars

SCALE-UP E-DRIVE

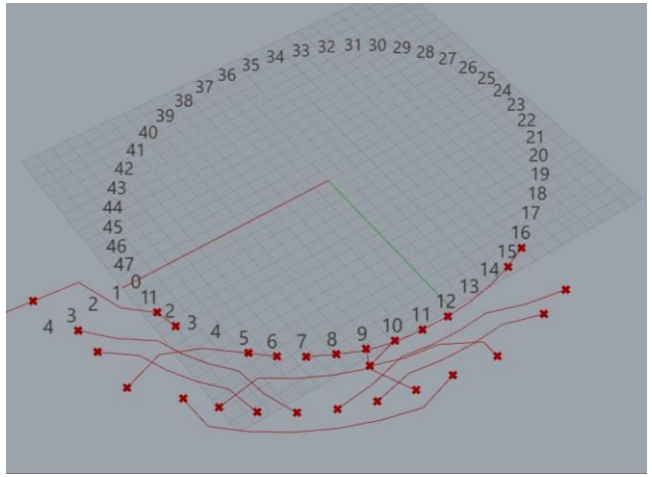
Process Chain for Demonstrator Manufacturing



# Contacting

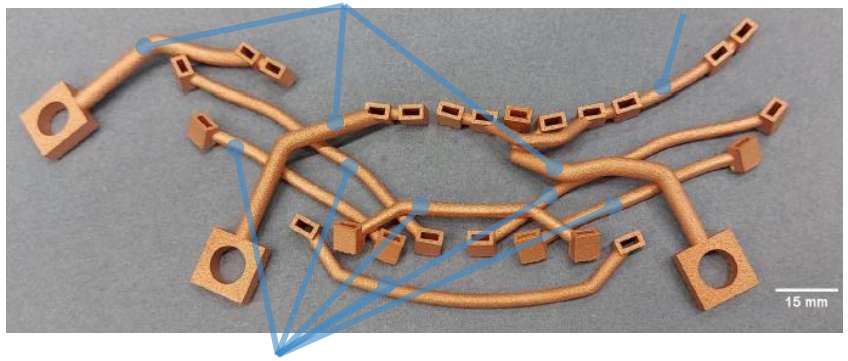
SCALE-UP E-DRIVE

Digital Additive Production (dap) at RWTH Aachen University



Phase connection

Neutral point




Substituted special pins

**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”
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dap Digital Additive Production | RWTH AACHEN UNIVERSITY

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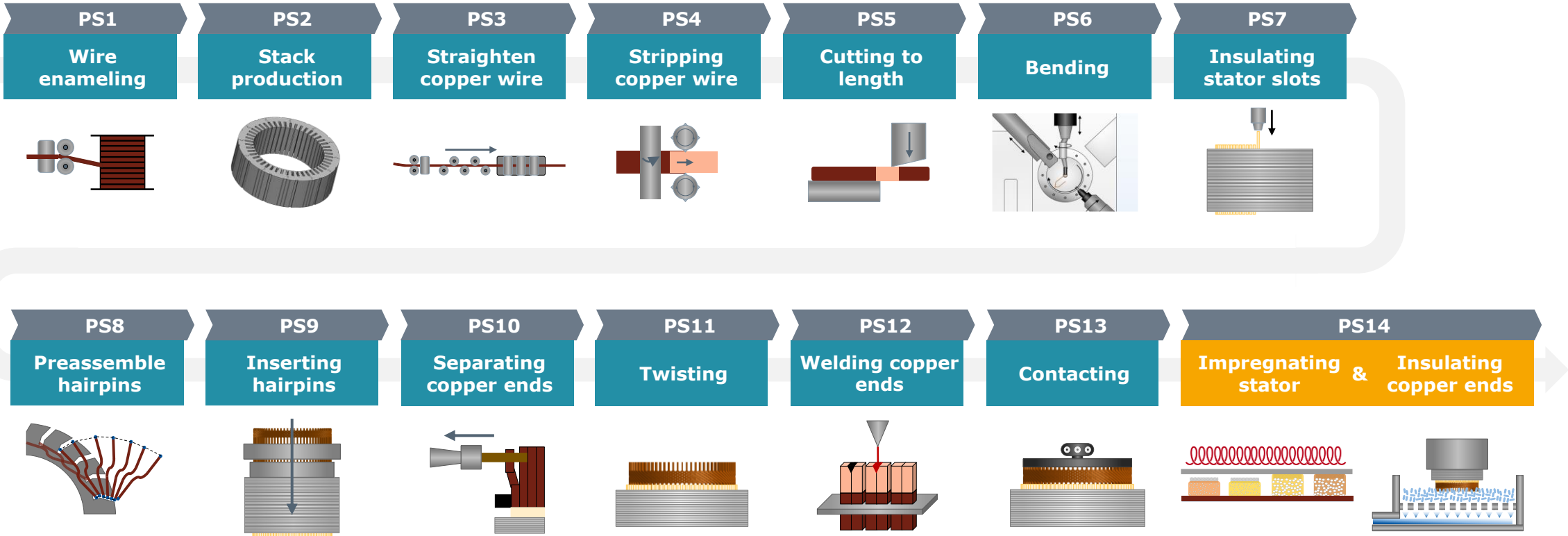
# Impregnation and Secondary Insulation

SCALE-UP E-DRIVE

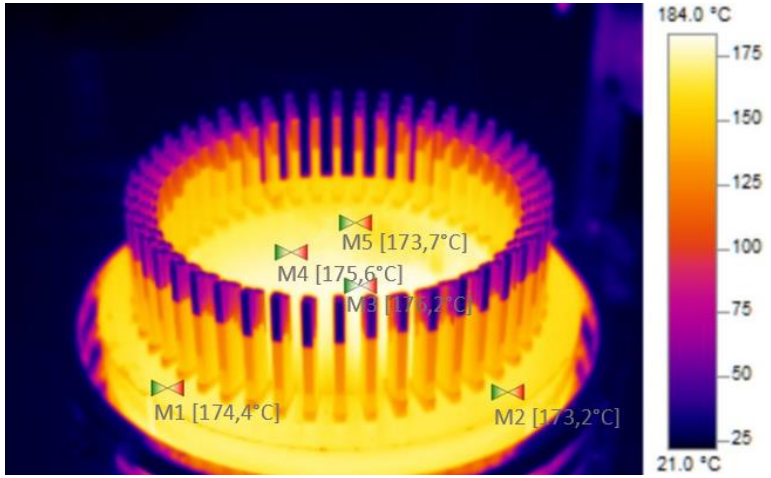
Process Chain for Demonstrator Manufacturing



# Preparation for Impregnation and Insulation – Inductive Heating

SCALE-UP E-DRIVE

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

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AMS Anlagenbau GmbH & Co. KG

**Process information:**

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

A·M·S

powder coating

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# Consortium Study – “Innovative Materials in Electric Motors”

SCALE-UP E-DRIVE

Manufacturing a Stator Primotype Using Innovative Materials and Processes

## For further information do not hesitate to contact us!


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SCALE-UP E-DRIVE

**Responsibility for content**


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