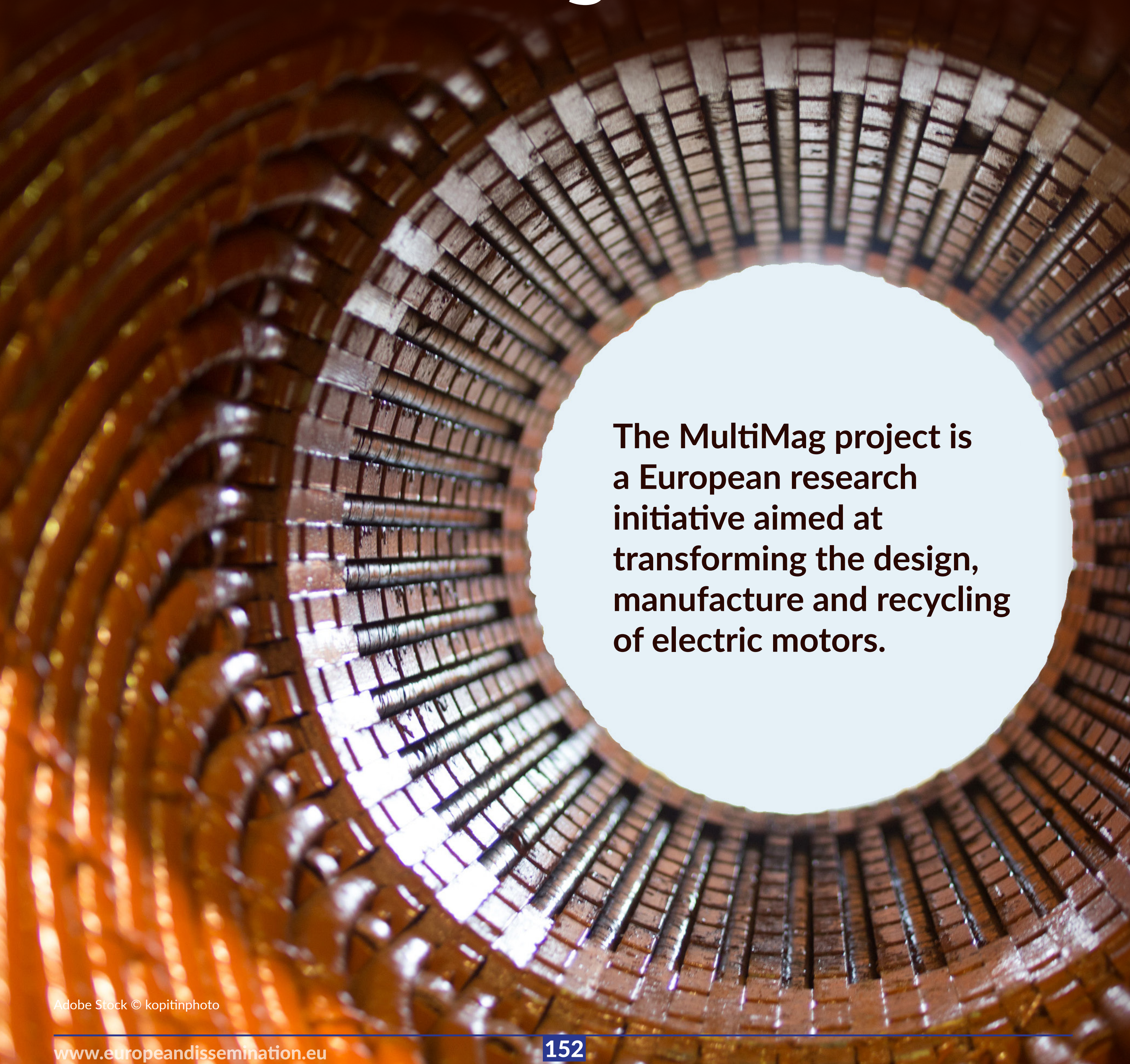
MultiMag: advancing electric motor design with multi-material additive manufacturing



The MultiMag project is a European research initiative aimed at transforming the design, manufacture and recycling of electric motors.

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At its core, the project develops multi-material additive manufacturing (MM-AM) techniques to produce high-performance, lightweight and resource-efficient motor components. By integrating new materials, advanced manufacturing processes and circular economy principles, MultiMag is addressing key challenges in electrification while reducing Europe's dependency on critical raw materials, such as rare earth elements (REEs).

Electric motors are essential to modern life, powering everything from household appliances to industrial machinery, electric vehicles and even spacecraft. However, conventional motors still face significant limitations. Their reliance on rare-earth permanent magnets poses supply chain risks, while traditional manufacturing methods limit design freedom, resulting in heavier and less efficient machines. MultiMag addresses these challenges by combining innovative material development, advanced design tools and additive manufacturing (AM) methods to deliver motors that are lighter, more efficient and easier to recycle.

Use cases

To ensure real-world relevance, the project is structured around three diverse use cases.

- **Use case 1 (UC1)** focuses on the development of a general-purpose induction motor widely used in industrial automation and energy-intensive systems such as pumps and compressors. Improvements in this motor type can have a significant impact on electricity savings on a large scale.
- **Use case 2 (UC2)** addresses synchronous permanent magnet brushless motors designed for electric mobility, where high torque density, cooling performance and reduced rare earth content are critical for the automotive sector.
- **Use case 3 (UC3)** targets aerospace applications, particularly rotary actuators for satellites and spacecraft, where lightweight construction, high precision and low production volumes are essential.

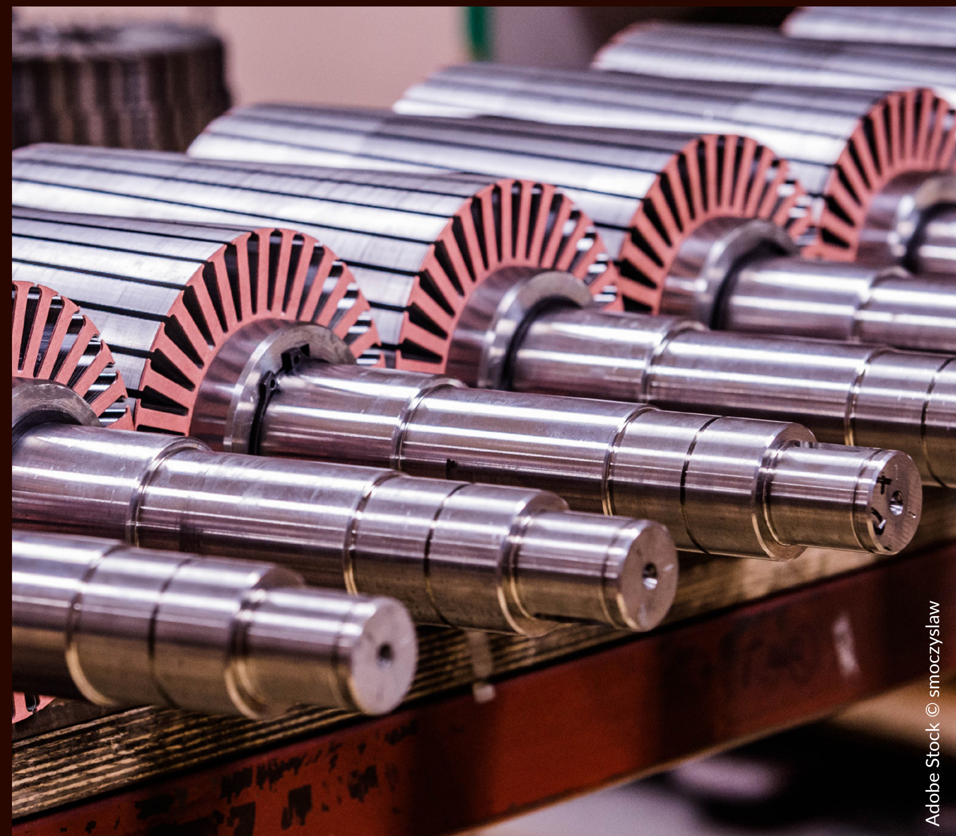
Each of these use cases represents a sector where advances in MM-AM can generate measurable benefits: energy savings in industry, higher performance and sustainability in mobility, and lightweight efficiency in aerospace.

Manufacturing approaches

The technical approach of MultiMag combines three complementary AM technologies:

- **Binder jetting (BJT)** enables the cost-effective production of intricate components by binding layers of fine metal powder that are later sintered, offering high flexibility for combining different materials.
- **Powder bed fusion – laser beam (PBF-LB)** enables the creation of complex three-dimensional geometries through selective laser melting of powders, making it ideal for integrating flux-guiding structures and reducing motor weight.
- **Sheet lamination (SHL)** applies alternating layers of magnetic and insulating materials, resulting in laminated stacks with exceptionally low iron losses and induction motor efficiencies of up to 93%.

Together, these technologies enable new levels of design freedom, allowing for both macro- and microscale optimisation of motor structures that cannot be



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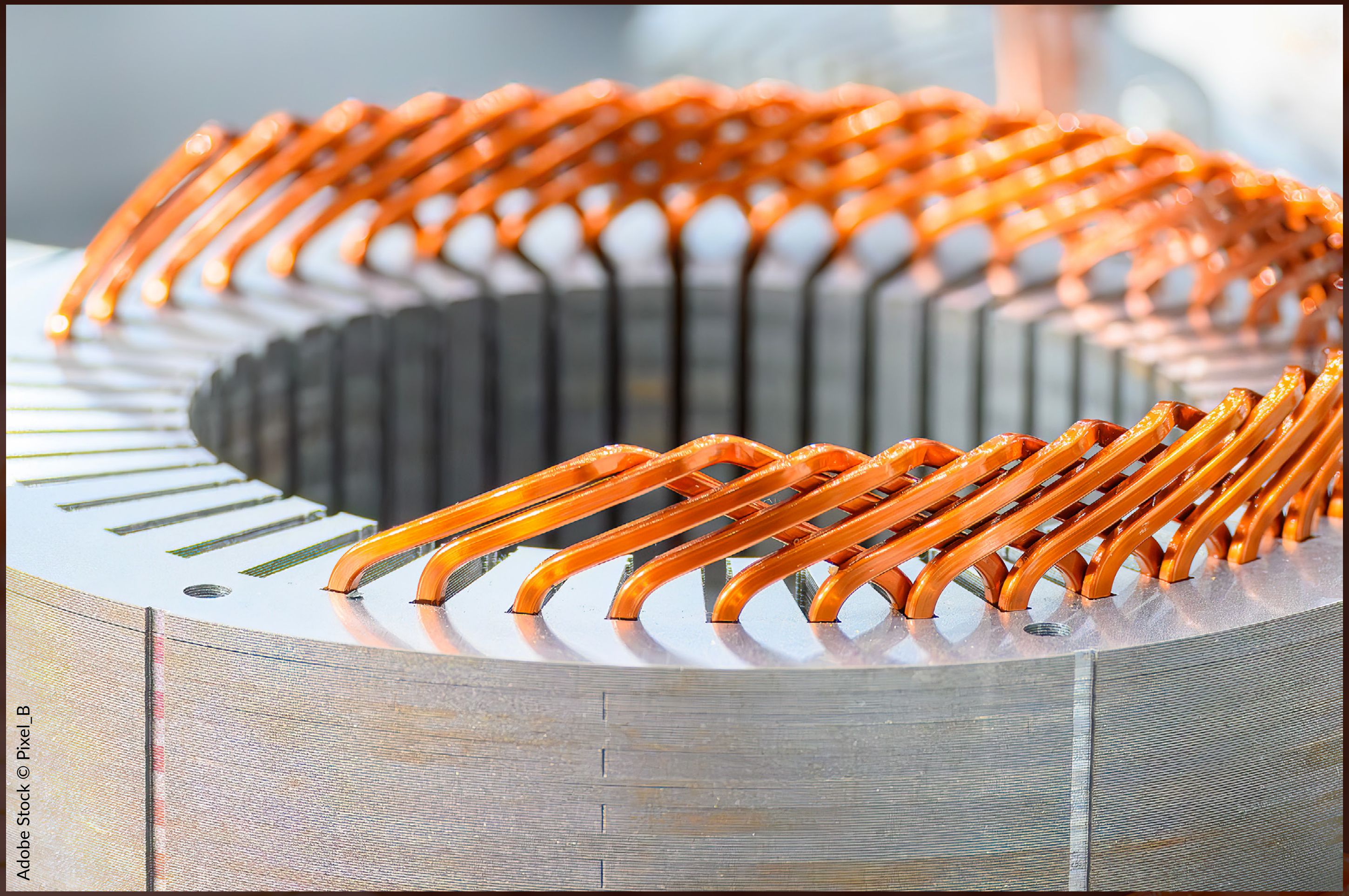

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achieved through conventional lamination or machining processes.

Technical progress and achievements

MultiMag has made significant strides in material development, design optimisation and manufacturing, demonstrating the feasibility of applying multi-material AM to electric motors. These achievements showcase how advances in powders, interfaces, simulations and prototypes are converging to deliver lighter, more efficient and sustainable motor components.

On the materials side, specialised powders for hard magnets, soft magnetic alloys, ceramic insulators and lightweight structural materials have been developed and tested. Hard magnets produced via AM demonstrated improved coercivity after annealing. Remanence is still below the current state-of-the-art, compared to other sintered magnets; however, the consortium is researching efforts to enhance the current remanence displayed. At the same time, soft magnetic alloys showed higher permeability and lower coercivity compared to conventional electrical steels after heat treatment. Insulating mid-layer materials, based on ceramics and oxides, have been validated for their electrical resistivity, and new aluminium alloys have been developed with promising structural and thermal properties.

In parallel, work on multi-material interfaces has shown that strong and defect-free joints can be achieved between dissimilar materials. Intermixing zones of 10–30 micrometres have been produced, with interface strengths exceeding those of bulk neodymium-iron-boron (NdFeB) magnets in some tests. This demonstrates the feasibility of combining functional magnetic, insulating and structural materials in a single manufacturing process.

Smarter motor design

On the design and modelling side, a comprehensive simulation framework has been created to optimise motor components across electromagnetic, thermal and mechanical domains. This integrated approach enables performance improvements to be identified early in the design process while accounting for the unique constraints of AM. The framework has been applied across all three use cases with notable achievements:

- **UC1** – A synchronous reluctance motor (SynRM) featuring an additively manufactured rotor has been designed and modelled. Advanced simulations demonstrated a significant efficiency improvement, increasing from **88% to 94%**, while also delivering higher torque compared to conventional designs.
- **UC2** – Electromagnetic and thermal simulations guided the design of innovative components, including hybrid stator poles and optimised solid poles. These models achieved a **29% reduction in active part weight**, a **50% reduction in magnet weight**, and efficiencies ranging from 95% to **96%**, fully meeting key project performance indicators for electric vehicle applications.
- **UC3** – Genetic algorithm-based optimisation has been employed to explore new rotor geometries tailored to aerospace requirements. The simulations validated that the defined KPIs—particularly weight reduction and improved power density—can be met, confirming the feasibility of AM-enabled designs for lightweight, high-performance aerospace motors.

Demonstrator development and prototyping

Significant progress has also been made in manufacturing demonstrators, which represent a key milestone of the MultiMag project. These prototypes serve as proof-of-concept components, where newly developed materials and advanced AM techniques converge to create functional motor parts. By integrating innovative powders, optimised material pairings and hybrid manufacturing methods, the demonstrators highlight the project's ability to translate laboratory advances into industrially relevant applications. Each use case targets specific performance improvements and sustainability benefits in different sectors:

- **UC1** – Ceramic-insulated rotor stacks have been designed and manufactured, combining AM and lamination to reduce losses and improve efficiency.
- **UC2** – Hybrid stator poles integrating SHL with additive pole shoes, as well as topologically optimised solid poles, have been produced to enhance performance and reduce magnet use.
- **UC3** – Lightweight rotors with complex AM-optimised geometries have been developed, aiming to deliver higher power density and significant weight reduction for aerospace applications.

These demonstrators will undergo industrial validation in the upcoming project phase.

Sustainability and recycling

Sustainability is embedded throughout the MultiMag project. A comprehensive life cycle assessment (LCA) methodology has been established for all three use cases, supported by the new Circularity by Design Indicator (ICbD), which guides material and design choices by balancing supply risk, availability and environmental impacts.

In parallel, significant progress has been made in recycling trials, including an 86% recovery rate for NdFeB magnets, a 96.8% iron removal efficiency, improvements in the purity of recovered materials, and successful reprocessing of recycled praseodymium (Pr^{59}) and neodymium (Nd^{60}) into new alloy feedstock.

These steps strengthen Europe's resource resilience and demonstrate pathways towards a circular economy for electric motor production.

Outlook

The MultiMag project is proving how advances in materials science, AM and sustainability can converge to redefine the future of electric motors. Through the development of novel powders, optimised design frameworks and functional demonstrators across three distinct use cases, the project has demonstrated the transformative potential of multi-material AM to deliver motors that are lighter, more efficient and designed with recyclability in mind.

As these demonstrators transition into industrial validation, MultiMag is set to provide concrete evidence that high-performance electric machines can be produced with reduced reliance on critical raw materials and significantly improved environmental performance. These achievements not only accelerate the pathway to industrial adoption but also strengthen Europe's strategic autonomy, support circular economy goals and contribute to the broader transition towards a greener, electrified future.

MultiMag

PROJECT SUMMARY

MultiMag is an EU-funded project which leverages multi-material additive manufacturing to develop advanced rotor and stator structures, optimising performance and reducing material use. Through innovations in design, materials, production, and lifecycle management, the project delivers lightweight, efficient electric motor components with minimised reliance on rare earth elements.

PROJECT PARTNERS

The MultiMag consortium has partners from nine different countries with a wide geographical distribution within the European continent. It is bringing together raw material suppliers, end-users and RTOs for joint development of novel solutions in the field of magnetic applications and electric machines.

PROJECT LEAD PROFILE

VTT is one of the leading RTOs in Europe, owned by the Finnish state, with an 80-year track record in solving global challenges with science and technology, and turning them into opportunities for the betterment of society and companies. They advance the utilisation and commercialisation of research and technology in commerce and society.

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