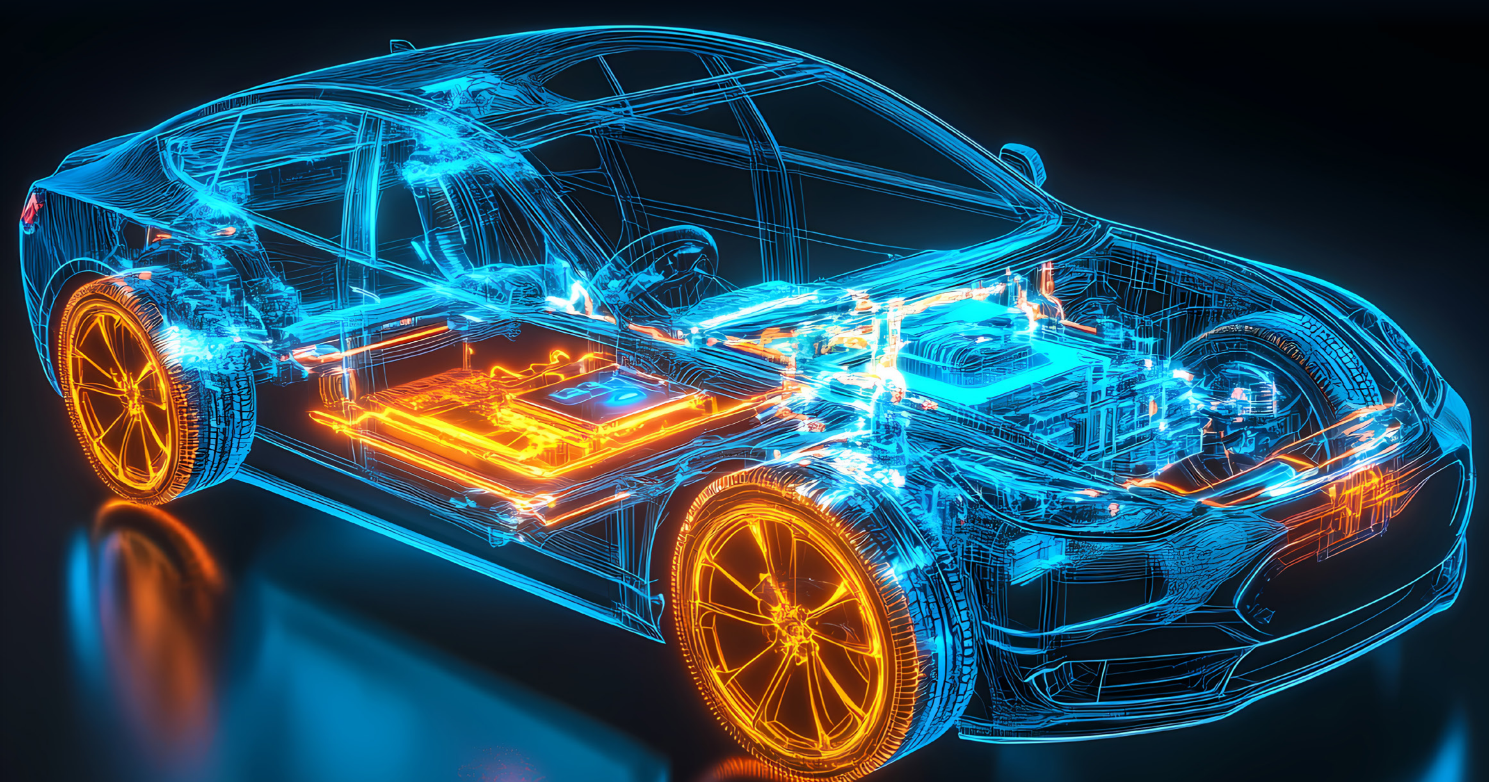
VOLTCAR: reinventing the electric motor for a sustainable future

Electric vehicles (EVs) are often celebrated as the future of clean mobility. At the heart of every EV lies the traction motor, which is the electromechanical device that transforms electrical energy into torque and rotational motion.



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The vast majority of motors used in current EVs are based on permanent magnet synchronous motor (PMSM) technology, which relies heavily on rare earth elements such as neodymium and dysprosium. While these magnets enable a compact, efficient design, they also raise serious concerns. Mining and refining rare earths are energy-intensive and environmentally destructive, and the global supply chain is concentrated in a few regions, leaving Europe strategically vulnerable.

The EU-funded VOLTCAR project—Design, Manufacturing, and Validation of Ecocycle Electric Traction Motor—addresses these limitations through a systematic rethinking of how traction motors are designed, manufactured and recycled. By combining novel motor architectures, ecodesign principles and digitalisation tools, VOLTCAR aims to deliver a new class of motors that are lighter, more efficient, less dependent on rare materials and fully aligned with circular-economy objectives.

The primary objective of VOLTCAR is to develop the most advanced next-generation electrical traction motor prototype, capable of rapid industrialisation. The VOLTCAR motor is designed to be easily manufacturable and recyclable at the end of its first life. VOLTCAR's main aim is split into **four specific objectives**, guaranteeing all relevant topics are adequately covered with measurable and achievable targets.

1. Create highly compact and efficient VOLTCAR traction motors with a reduced amount of rare materials for passenger cars and vans (nominal power 50–120 kW).
2. Develop circular technologies for next-generation electrical traction motors.
3. Demonstrate a cost-efficient, durable, over the life cycle digitalised motor.
4. Comprehensively test and validate VOLTCAR traction motors and systems according to automotive standards with advanced and virtual testing methodologies.

Rethinking motor design

The central engineering challenge VOLTCAR addresses is producing traction motors in the 50–120 kW range that rival or exceed the performance of today's PMSMs while using minimal rare-earth content. This requires not just incremental improvements, but a holistic redesign of the motor.

The project focuses on increasing the motor's rotating speed beyond current state-of-the-art solutions. Achieving higher speeds is crucial to improving the motor's power density. To handle the resulting high electromagnetic loads, an efficient direct liquid cooling system is being developed. Other key innovations include careful structural optimisation and material selection of the rotor, while simultaneously maximising synchronous reluctance torque production to further reduce reliance on rare-earth permanent magnets.

The first 50 kW prototype demonstrates this philosophy in practice. It is being manufactured with a significantly reduced permanent magnet fraction, yet it is engineered to meet stringent automotive energy efficiency and power density requirements. In parallel, a 120-kW motor is being developed with ambitious specifications: a specific power of 7 kW/kg and a power density exceeding 23 kW per litre. These figures place the design among the most advanced globally.

To achieve such targets, the consortium employs multiphysics simulations that combine electromagnetic, thermal and mechanical modelling, and explores hundreds of design variants in silico before committing to physical prototypes. The motor prototypes incorporate a direct oil cooling system, a sophisticated method in which lubricant is circulated directly around the stator windings and core, extracting heat efficiently and allowing continuous operation at rotational speeds in the range of 12 000 rpm.

Preliminary specifications indicate that the complete motor, including the housing, weighs just 17.14 kilograms and occupies a volume of less than five litres. These values represent a significant leap forward in compactness and efficiency compared to conventional traction motors of similar rating.

Key technical highlights

- A 50 kW prototype is already in manufacture with reduced rare earth magnet content.
- The 120 kW prototype aims for record-breaking compactness and efficiency.
  - Specific power target: 7 kW/kg.
  - Power density target: 23 kW/litre.
- Advanced direct oil cooling system ensures thermal stability at a range of 0–30 000 rpm.

Designing for circularity

While performance is essential, VOLTCAR's philosophy extends beyond efficiency to embrace full circularity. Conventional EV motors are difficult to disassemble, making the recovery of valuable materials challenging. The project addresses this by embedding ecodesign considerations from the earliest stages of development.

One tangible innovation is the introduction of encapsulated magnets. This design feature enables magnets to be easily extracted at end of life, allowing them to be reused in new motors or recycled into raw materials. This approach transforms magnets from consumables into recoverable assets, directly contributing to resource efficiency.

To evaluate environmental and economic impacts, the project is applying rigorous life cycle assessment (LCA) and life cycle costing (LCC) methodologies. These analyses quantify everything from the carbon footprint of raw material extraction to energy consumption during operation and disposal costs at the end of the product's life. Already, these studies have informed design optimisations in the 120 kW prototype, showing how engineering and sustainability can reinforce one another rather than compete.

Circularity in practice

- Encapsulated magnets enable reuse and recycling.
- LCA and LCC analyses guide material selection and cost optimisation.
- Focus on second-life applications and the reduction of end-of-life waste.
- Strong alignment with EU circular economy strategies.

Digitalisation: building the motor's invisible twin

A defining innovation of VOLTCAR is its use of digitalisation as an integral part of motor development. Every prototype is paired with a digital twin, which is a high-fidelity virtual model that evolves in tandem with the physical motor.

The digital twin enables the simulation of the motor performance across its lifecycle under a wide range of operating conditions. These models can be refined with experimental data, linking design, manufacturing, testing, operation and end-of-life processes. For example, this enables the prediction of wear mechanisms, optimisation of thermal management and anticipation of failures long before they occur.

Supporting this is the implementation of digital threads. Unlike traditional approaches where design, manufacturing, testing, operation and end of life are separate silos, the digital threads connect these stages into a continuous flow of data. Through this integration, enabled by digital threads, the entire motor lifecycle becomes a connected and optimised continuum. This ensures that lessons learned during operation can feed back into future designs, creating a self-improving engineering cycle.

A benchmarking tool has also been developed to evaluate VOLTCAR's designs against existing commercial motors, ensuring they remain competitive in terms of performance, cost and sustainability. Collectively, these advances enable predictive maintenance, cost optimisation and comprehensive lifecycle monitoring.

Testing and validation

Scientific credibility requires robust validation, and VOLTCAR has established a comprehensive testing framework. This includes both virtual environments and physical testbeds, aligned with automotive standards.

Virtual testing relies on X-in-the-loop (XiL) simulations, where digital motor models interact dynamically with fundamental hardware components. Physical testing is equally rigorous. Subcomponent tests evaluate acoustic noise, thermal stability and structural integrity. Full-scale experiments include back-to-back testing, where two identical motors are mechanically coupled to measure efficiency and torque characteristics, and system-level testing, where motors are integrated with gearboxes to replicate real-world vehicle conditions.

Experimental setups have been initiated, covering subcomponent testing (e.g. structural, acoustic, thermal), back-to-back motor tests, gearbox-integrated motor tests, as well as hardware-in-the-loop (HiL) and software-in-the-loop (SiL)-based virtual testing.

A key innovation is the fusion of physical and digital domains. Data generated in the laboratory is fed directly into the digital twins, which in turn refine their predictions and guide further experiments. This feedback loop reduces development costs, accelerates optimisation and ensures a seamless transition from prototype to validated product.

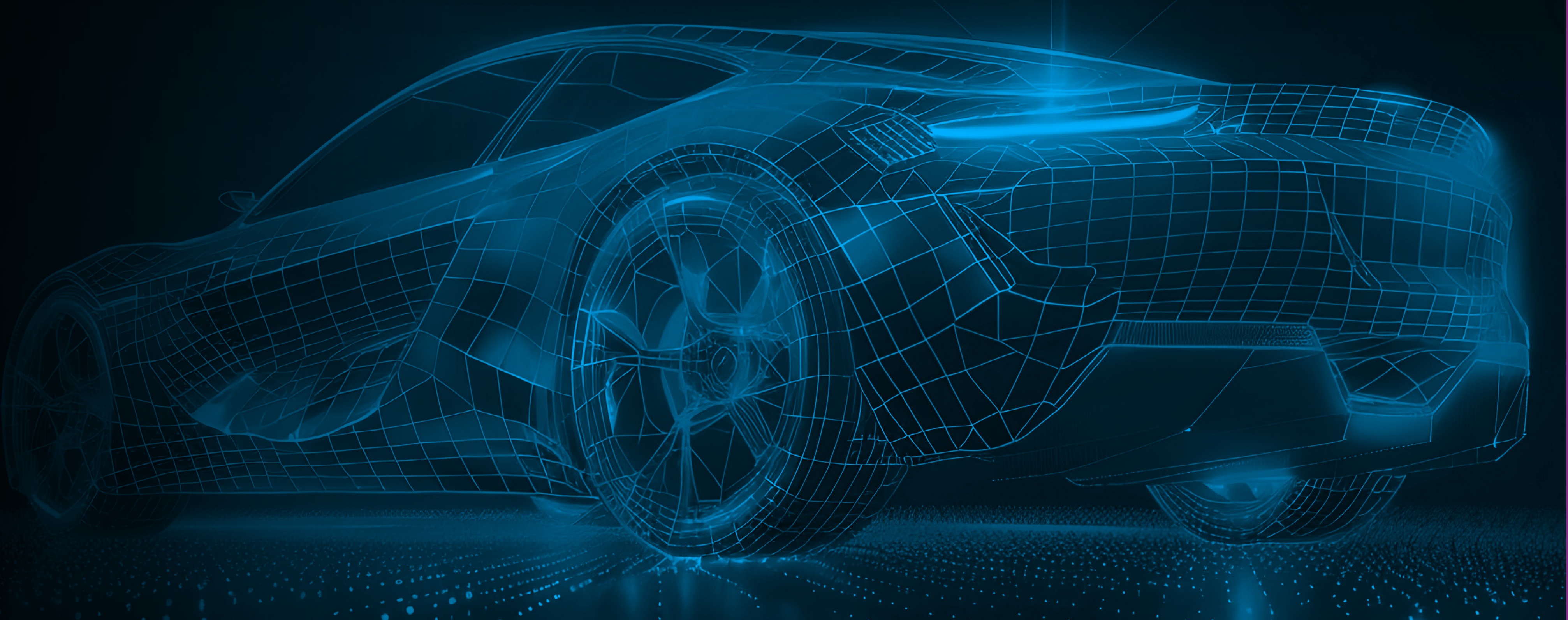
By aligning real-world testing with digital simulations, the consortium achieves accurate design validation through continuous model refinement, while also enhancing predictive modelling with empirical data. This integrated approach allows faster and more efficient optimisation, significantly reducing the need for repeated physical prototyping. At the same time, it ensures continuity of lifecycle data, which supports operational monitoring and enables more effective maintenance planning throughout the motor's service life.

Towards Europe's sustainable mobility

The VOLTCAR project represents a paradigm shift in electric motor technology. By integrating compact design, circularity and digitalisation, it demonstrates that high performance and sustainability are not mutually exclusive but mutually reinforcing.

For Europe, VOLTCAR strengthens technological sovereignty by reducing reliance on imported rare earths and promoting local innovation. For the environment, it ensures that EVs not only reduce emissions during use but also minimise resource impacts across their entire lifecycle. For society, it promises vehicles that are cleaner, more efficient and aligned with global sustainability objectives.

As VOLTCAR progresses into full-system validation, the outcomes will likely redefine benchmarks for electric traction motors worldwide. These motors will not simply power vehicles but will embody a new generation of engineering that unites performance, circularity and responsibility.



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VOLTCAR

PROJECT SUMMARY

The EU-funded VOLTCAR project develops next-generation electric traction motors with reduced rare earth dependence, high power density and improved energy efficiency. Using advanced ecodesign, life cycle analyses, digital twins and X-in-the-loop testing, VOLTCAR creates recyclable, cost-efficient 50 kW and 120 kW prototypes. The project strengthens Europe's automotive competitiveness, fosters sustainability and advances circular, low-carbon electromobility.

PROJECT PARTNERS

The VOLTCAR consortium unites 12 partners from six European countries, including leading industrial players and top research institutions. With expertise spanning motor design, materials, sustainability and digitalisation, the consortium integrates strong SME contributions and academic excellence. This multidisciplinary collaboration ensures the successful development of innovative, circular electric traction motors while enhancing Europe's competitiveness in sustainable mobility technologies.

PROJECT LEAD PROFILE

VTT Technical Research Centre of Finland is one of Europe's leading applied research institutions, owned by the Finnish state. VTT drives sustainable growth by turning scientific research into practical solutions for industry and society. As VOLTCAR's coordinator, VTT leads sustainability assessments, magnet circularity and prototype validation, building on extensive experience in EU-funded research and innovation projects.

PROJECT CONTACTS

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