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AVL

>94 % Cycle Efficiency Electric Drive Unit

Dr. Wieselhuber & Partner GmbH

From Stress to Strength: Restructuring for Financial Resilience of Automotive Suppliers

Joe Tolkacz, Stellantis

If you have Vehicle-to-Home, Vehicle-to-Grid is an Easy Add-on

Image source: Stellantis

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From Stress to Strength: Restructuring for Financial Resilience of Automotive Suppliers

How automotive suppliers turn crisis pressure into liquidity, innovation and long-term competitiveness.

Matthias Müller, Partner Restructuring and Finance, Dr. Wieselhuber & Partner GmbH

Dr. Dirk Artelt, Managing Partner Industrial Goods and Automotive, Dr. Wieselhuber & Partner GmbH

1. When Transformation Meets Pressure

The automotive supply industry is under historic pressure. Electrification, digitalization and sustainability requirements are reshaping value chains, while inflation, volatile call-offs and financing constraints are compressing margins and liquidity. Many suppliers are struggling to balance transformation investments with short-term financial stability.

At the same time, traditional commercial banks are increasingly withdrawing from the sector, reducing credit exposure and tightening risk criteria. This structural shift in financing markets further limits access to liquidity precisely when suppliers need it most – to stabilize operations, fund innovation and manage volatility.

However, crisis and transformation are not opposites. If managed systematically, short-term stress can become a catalyst for structural improvement, turning liquidity pressure into financial resilience and innovative strength.

2. Creating Transparency: Assessing Position and Potential

Every restructuring and transformation process begins with a clear understanding of the current position. The foundation is a pragmatic and well-founded assessment of the status quo: Where does the company stand today in terms of its business model and financing structure?

Two analytical dimensions form the core of this assessment:

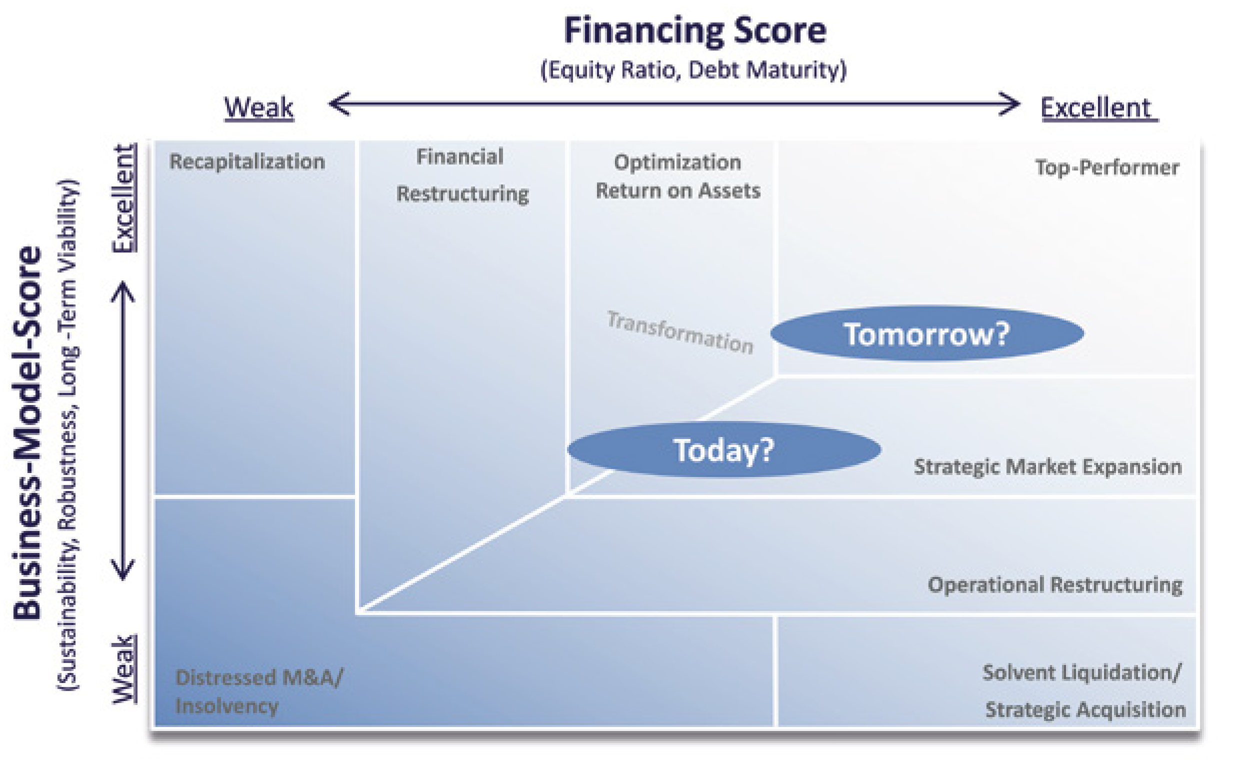
- Business Model Score: evaluation of the robustness, cash generation capacity and future viability of the business model.
- Financing Score: analysis of equity strength and debt maturity as key indicators of stability and crisis sensitivity.

Together, these dimensions provide a concise view of both the company's operational performance and its financial resilience. They answer the essential question: How robust is the business model – and how stable is the financing architecture that supports it?

Once this position is defined, ongoing and planned transformation projects are mapped into the model. This reveals how each initiative contributes to strengthening either the business model or the financing structure, and where gaps or additional fields of action remain.

Based on this analysis, a target scenario is developed that quantifies the impact of the transformation on the income statement, balance sheet and cash flow. This target scenario becomes the anchor for strategic alignment, prioritization of further measures and structured communication with key stakeholders.

By linking transparency with strategic direction, the company turns diagnosis into dialogue – and establishes a measurable path from short-term stabilization to long-term financial resilience.



3. When Financial Covenants Are at Risk

In times of stress, financial covenants such as leverage, equity ratio or interest coverage are often the first early-warning indicators of structural imbalance. A potential breach does not necessarily mean failure, but it must be managed with precision and foresight.

From recent restructuring cases several practical lessons can be drawn:

- Understand the implications. Especially in bilateral financing structures, one covenant breach may trigger cross-default effects in other contracts, including factoring, leasing or supplier-financing agreements. Every interdependence must be understood before entering discussions.
- Communicate early. Transparency towards financing partners should begin as soon as a breach becomes likely, not after it has occurred. Delayed communication undermines trust; proactive dialogue maintains credibility and optionality.
- Be transparent. Clearly explain the reasons behind deviations and present realistic countermeasures. Transparency builds confidence and shows that management remains in control.
- Adopt a forward-looking stance. Update the financial plan and scenario analyses early. Bankers rarely ask, "What happened?" – they ask, "What will happen next quarter?" Demonstrating foresight is the single most important trust factor.
- Safeguard liquidity. Regardless of the covenant concerned, liquidity must be ensured under all scenarios. "Cash is king" remains the guiding principle in every restructuring.
- Keep the long-term perspective. Covenant discussions are not only about short-term waivers. They are part of a broader dialogue about the company's transformation path and future viability.

Experience shows that most banks do not terminate financing merely due to a covenant breach. Their intent is to bring management to the table and jointly evaluate options. Calm analysis, disciplined communication and a clear liquidity plan are far more effective than defensive reactions.

4. From Transparency to Action: Turning Stress into Structure

Once the initial position is clear, the focus shifts from analysis to implementation. Typical stress patterns in the automotive supplier industry include liquidity bottlenecks caused by uneven OEM call-offs and high working capital, margin pressure from rising material costs and price rigidity, investment strain due to electrification or automation, as well as tightened financing terms and covenant restrictions.

Addressing these challenges requires an integrated, interdisciplinary process that combines financial, operational and strategic measures. Key elements include:

- Liquidity planning: rolling 13-week cash forecasts to ensure solvency and negotiation capability.
- Integrated business planning: linking P&L, balance sheet and cash flow to ensure funding adequacy.
- Restructuring concepts: developing financial turnaround roadmaps with measurable milestones.
- Comparative analyses: quantifying continuation versus liquidation scenarios for stakeholder alignment.
- Operational implementation: translating financial targets into performance and footprint measures.
- Financial advisory and M&A: structuring refinancing, asset-based lending or selective divestments to restore flexibility.

This systematic approach transforms reactive crisis management into structured, data-driven decision-making.

5. Financing Transformation: The Missing Link

In many companies, restructuring and innovation are treated as separate topics, one defensive, the other offensive. In reality, however, they are mutually dependent: without innovation, restructuring remains temporary; without restructuring, innovation remains unfunded.

Automotive suppliers therefore need financing structures that support both stability and transformation. Alongside classical bank loans and syndicated facilities, alternative instruments are increasingly relevant:

- Factoring and leasing to free tied-up capital
- Asset-based lending secured by inventories or receivables
- Private debt, mezzanine or continuation funds to close equity gaps
- OEM or strategic investor participation models to stabilize critical suppliers

Integrating such elements into the financial architecture enables suppliers to fund new technologies even under pressure, thereby securing the link between liquidity, innovation and long-term competitiveness.

6. The Restructuring Advisor as a Transmission Belt for Transformation

Restructuring advisors play a crucial intermediary role between financial stabilization and strategic renewal. Their tools, from liquidity and integrated business planning to comparative analyses and operational implementation, form the transmission belt that translates financial recovery into lasting transformation.

Through structured planning, they provide a quantitative foundation for decision-making: Which product lines can be financed? Which sites are sustainable? Which investments generate the highest cash impact.

By integrating refinancing and M&A processes, advisors align short-term liquidity measures with long-term portfolio strategy. They turn transparency into traction, ensuring that every step in the restructuring process contributes to the company's future viability.

In this capacity, the restructuring advisor bridges multiple disciplines: economics, law, operations and corporate finance. The goal is not only to repair what is broken but to design a financial and operational architecture that can carry innovation. Restructuring thus becomes the operating system for transformation.

7. Continuous Transformation: Managing Change as a System

In the automotive sector, restructuring is no longer just a one-time crisis response, but a continuous management responsibility. Market volatility, technological change and supply dependencies demand permanent financial steering.

The dual perspective of business model quality and financing architecture provides a simple yet powerful framework for this purpose. It helps companies visualize where they stand, prioritize transformation projects and communicate clearly with lenders and investors. Over time, this transparency builds trust both internally and externally and becomes a key component of long-term competitiveness.

8. Conclusion: From Stress to Strength

Crisis and transformation are two sides of the same coin. Automotive suppliers that manage to quantify their financial resilience, align stakeholders and fund innovation systematically can turn pressure into progress.

Restructuring, in this sense, is not about short-term survival but about designing financial structures that enable long-term agility and competitiveness. Transparency becomes the bridge between liquidity management and innovation strategy.

Those who master this balance will not only withstand the transformation of the automotive industry but help shape its future.

Interview

"If you have Vehicle-to-Home, Vehicle-to-Grid is an Easy Add-on"

Joe Tolkacz, Chief Engineer, Stellantis

The Stellantis RAM 1500 Ramcharger is the first of its kind in the US market – a light truck with a pure serial range extender drive, a range of 690 miles, and two e-drives providing 647 hp in total. We spoke to Chief Engineer Joe Tolkacz, who presented the Ramcharger at the CTI Symposium 2025 in Novi. We were particularly interested in the additional utility value, compared to a conventionally powered light truck.

Mr Tolkacz, you could have built a 'classic' parallel plug-in hybrid. Why did you pick a serial hybrid?

When you switch from electric to serial hybrid drive, when the engine starts making torque, the start-stop capability and smoothness are very transparent to the customer. The other thing is that we are working on a battery-electric-only version, and we will be able to reuse many of the components from the range extender on the BEV. The electric drive modules and the charger work very well in both the electric range-extended vehicle and the BEV version. Basically, you could take the Ramcharger, take the engine out, and you have a BEV. Those were two big factors for us.

Some people say P2 hybrids have better load and towing capacity, because there are no thermal issues with an engine drive. How did you handle that with the serial hybrid?

The first thing we did was a lot of analysis. We have capable tools for estimating our towing capacity and other performance attributes. These tools helped us to work backwards to design the motors, the batteries, and other components. With the tools, we can do more than just typical EPA cycles. We have the capability to simulate the Davis Dam test, which includes towing on an 11.4-mile slope with a 3500-foot altitude difference, for example. We can also simulate 65 miles cross-country towing, and we can simulate the Eisenhower pass in Colorado. So we have a lot of great simulation capabilities. We broke the results down to the subsystem level. We tested the heck out of all components, put it all back together, and now we're finishing up on the vehicle side to ensure that the simulations correlate well with what we saw in the vehicle. If we find things that don't quite correlate, we can go back to the simulations and correct them. That helps us to preverify design changes. You know, we want to have a no-compromise vehicle for the customer, so that was our guiding principle from the start – from the simulation through the vehicle design and testing.

Given the traction requirements, why don't you have gears for the e-drive, or for parallel hybrid mode?

One of the things you get into when you have these additional gears, such as when you have a multi-speed gearbox or multi-speed e-drive, is where the shifts occur. It's challenging to make those shifts transparent. But the key point is, we don't need any gears for traction reasons. Another advantage of having no gearbox for the engine drive is that we have a lot of flexibility with engine positioning. We saw that multi-gears were not needed, the complexity was not needed, and the drive disturbance was certainly not desired. One of the main reasons for studying a multi-speed gearbox for the e-drive is when you are limited in your motor capabilities. Fortunately, for this vehicle, the top speed isn't crazy – it is in the region of 115 mph – so our motors were able to achieve that with a 15:1 gear ratio. You may need multispeed gearboxes for some performance cars with higher speeds, where you may have an issue with the motor speed. So we are pretty comfortable with where we ended up.

The generator has much less power than both drive motors. How do you continually ensure full power supply during serial operation?

We do have modes where the battery power plus generator power can result in the electric drive units being capable of making 500 kW. If we claimed that we had e-drives that could achieve 500 kW theoretically, but not in any practical situation, that would look awkward. As for steady-state conditions with continuous power requirements, for me it was pretty surprising that we can tow our max trailer cross-country at 65 to 75 mph, and our generator keeps up with our power requirements. We don't ever deplete the battery in these conditions. As I mentioned in my speech here at the CTI symposium, we have some special modes. For instance, if we're towing a trailer uphill, say, up Davis Dam at 120 °F (49 °C), we know we have a lot of thermal load. So when a customer anticipates such a scenario, he can push the 'tow' button, and we pick a different state-of-charge point that allows for maximum load towing in charge sustaining mode. Or we have the 'e-save' button that preserves the state-of-charge, and so forth. So there is a lot of flexibility there. We'll have to do a good job of educating drivers to make sure they take advantage of all these opportunities.

Which axle design did you choose to enable off-road capacity?

We designed the Ramcharger with independent front and rear suspension and frame-mounted drives. Ordinarily, that's not the choice for off-roaders. We did that intentionally because we didn't want to compromise the on-road experience. Many people never go off-road; they don't even tow anything. The Ramcharger is their family vehicle. They want it to be luxurious and comfortable. However, we added some features to balance that trade-off, for instance, the electronic locking differential, or active suspension, so you can raise or lower the vehicle. These features are good ways to satisfy our off-road customers.

What extra utility value does the Ramcharger offer, compared to traditional powertrains in this segment?

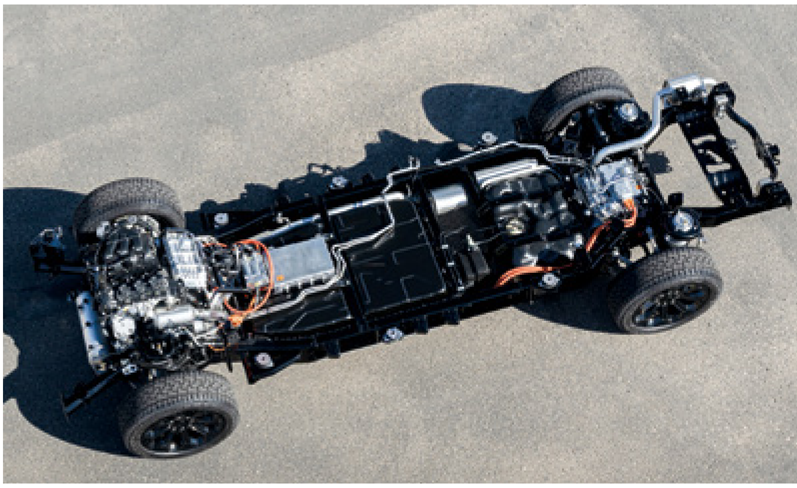
You know, 14,000 pounds is a pretty nice towing capacity! If you compare that to some of our competitors, it's close to medium-duty capability, it's really a lot for a light truck. We have 690 miles of range, which is not far off from diesel territory. I took a compass and drew a circle around Auburn Hills, to see how far I could get with those 690 miles. It covers a lot within the USA. You can get to Kansas City, St. Louis, or up to Quebec City in Canada. Then we have these V2X features that conventional drives cannot offer. That, to me, is a huge selling point for a truck. I love the idea of having a power panel to plug stuff in at my cabin in northern Michigan. You don't always have extension cords to reach from where the outlets

are. I can move the car around my property and use it for any kind of electric equipment I have. It can be useful when people are building homes before electricity reaches the site. So they can run their circular saw, their tile cutters, or whatever they need to run, off the battery of their truck. And there are also these guys on primitive campsites in a national forest area, for example, without any electric outlets. Another thing in the US, especially in college football, is tailgating. That's when people drive their trucks to the stadium and sit in a parking lot for a picnic. Sometimes you see people with television sets, electric pots with barbecue pulled pork, or other things. For that kind of adventure, there's the word glamping, which means glamorous camping. The Ramcharger supports all these activities.

What do you offer in terms of vehicle-to-home or even vehicle-to-grid, and how much of a future will this technology have?

Currently, we can do what's called vehicle-to-home or V2Home. If you assume 30 kW, which is quite a lot, you can power a house from the gasoline and the battery for about 11 days. And if you cut that down to 15 kW, it's about 22 days. The next thing that is coming in the future is vehicle-to-grid. The requirements haven't stabilized yet, so we decided not to chase that. But technically, it's quite easy to do with our baseline. Once you have V2Home, vehicle-to-grid is an easy add-on.

Interview: Gernot Goppelt



The front and rear e-drives, engine-generator unit, and the battery of the Ramcharger are mounted in a frame structure with independent front and rear suspension. (© Stellantis)

Interview

“We Believe Polymer is the Sweet Spot for Solid-state Batteries“

Adrian Tylim, Head of Business Development, Blue Solutions

Blue Solutions makes solid-state batteries in France and Canada. Series production is scheduled to begin in 2029, with significant advantages in energy density, cost, and safety, says Adrian Tylim, Head of Business Development. On the CTI Symposium Novi in May 2025, we discussed the prospects for solid-state batteries, and the company’s polymer-based technical approach.

Mr. Tylim, what are the functional challenges when developing solid-state vehicle batteries?

There are several. It’s a very competitive industry that attracts money, specifically for advanced and solid-state batteries. Many companies say they have solid-state batteries, but some may just produce small samples in a lab. When you start putting them into an application, it’s tough to increase the size of the cell and maintain or improve the performance. In the lab, the cell is usually the size of a coin, and increasing the size, voltage, etc., is a challenge. The second challenge is that you want to produce quickly, and on a large scale. For that, you need to develop a perfect process, which requires a lot of innovation. Then you have requirements in terms of safety and performance, and issues with decoupling from risky material supply chains. And of course, you want to produce the best product. Not many companies can meet those requirements in line with customer expectations.

In terms of production, what advantages do you have compared to 'conventional' Li-Ion batteries?

Lithium-ion batteries are easy to produce and have become very cost-competitive on a large scale. They are made all over the world, they have been manufactured and deployed for decades, and the technology is still improving. So anything we design to replace Lithium-ion must have specific advantages. One main focus is safety. Lithium-ion batteries have a liquid electrolyte. When a cell is defective, you get thermal runaway: the cell ignites, and the fire propagates from cell to cell. Our solid-state batteries have a solid electrolyte that doesn't catch fire as with lithium-ion cells. We chose an electrolyte that surpasses the melting point of the lithium anode, which is the key variable in terms of thermal stability. The second main focus is manufacturing at cost and integrating the technology into the vehicle. Other solid-state advantages are longevity, more charging cycles, and higher energy density.

What kind of electrolyte material do you use?

Our material is a solid-state polymer. In the battery world, we talk about solid-state materials and semi-solid-state materials, which contain a little liquid. For strictly solid-state, you have either ceramics or polymers. And within ceramics, you have oxides and sulfides. We chose a polymer material for several reasons. One is that Blue Solutions has a legacy of making films and ultra-thin films. We have developed a very simple process with a small manufacturing footprint. We make everything from raw materials. We extrude the lithium metal anode, the polymer electrolyte, and cathode. In the case of the anode, we start with a lithium metal cylinder. We extrude it at high speed, make it very thin, wide, and consistent, and then roll it. We do similarly with the polymer electrolyte. For the cathode, we have different dry coating or extrusion processes. And then we slit them and stack them to form our cell.

Speaking of so-called semi-solid-state technology, how do you rate its prospects?

Automotive batteries often have 100 layers, or 50 double layers. Whenever you charge and discharge the batteries, the stack basically expands and contracts. It's a process we call 'breathing'. So let's say a vehicle is going to be out there for ten years. To ensure longevity, you must ensure all the interfacial contact between those layers stays intact. With ceramic materials, you need a lot of pressure to maintain that contact – between 5 to 20 bar. For that, you need a lot of mechanical components such as springs. But the more mechanical components you use, the less space volume is available to put energy storage inside the car, and the more complex and expensive it becomes. So we opted for a polymer material, which is elastic, so the interfacial contact remains intact with very little pressure and minimal components needed. Semi-solid attempts to do the same thing as we're doing with our polymer, only using a ceramic material with a porous structure that contains some liquid. So while polymer may not be the best ionic conductor, when we look at all other beneficial aspects, we believe polymer is the sweet spot.

What are the USPs of your Gen 4 technology and Blue Solution's capacities?

So far, we've made more than three million cells. Most of them fitted to commercial vehicles starting in 2011. Since then, there have been many improvements and lessons learned, which we have integrated in line with the requirements of our automotive customers. For example, the ability for the electrolyte to work at room temperature, even as the battery functions in temperatures from -20 to 60 °C. Additionally, our cells have been performing over 3,000 cycles, far exceeding the typical OEM benchmark of 1,000. This allows us to use an even thinner anode. The thickness is now <20 µm, compared to 60 µm in the third generation. Also, we can now service different vehicle market segments by using different cathode materials, like NMC or LMFP, and varying energy densities of up to 450 Wh/kg. After all, a Ferrari and a Fiat have different requirements. And by varying the cathode materials, we can scale the costs and performance of our cells. We are currently working with three automakers: BMW, and two others in the Top Five. We're also cooperating with a Taiwanese electronics company, and we're looking at two-wheelers and other areas. Right now, we are at a point where we're tweaking the chemistry and the form factor, for example, prismatic or pouch cells, etc. We are in the validation phase and expect to start series production around 2029.

How is the supply situation for the raw materials in your cells?

Sustainability is a core development goal for us. At the end of life, we can reuse all critical materials to produce new cells. We have also filed a new patent to extract lithium metal from the cells. The good thing is that we never use materials like copper. For our cathode current collector, for example, we only use aluminium. And for the anode, the collector is the lithium-metal foil itself. Also, polymer materials are not rare, so we have several suppliers – not just China. I don't see any problems with the supply chain. And we have 20 years of experience in locating and sourcing materials for iron phosphate, lithium, and so forth.

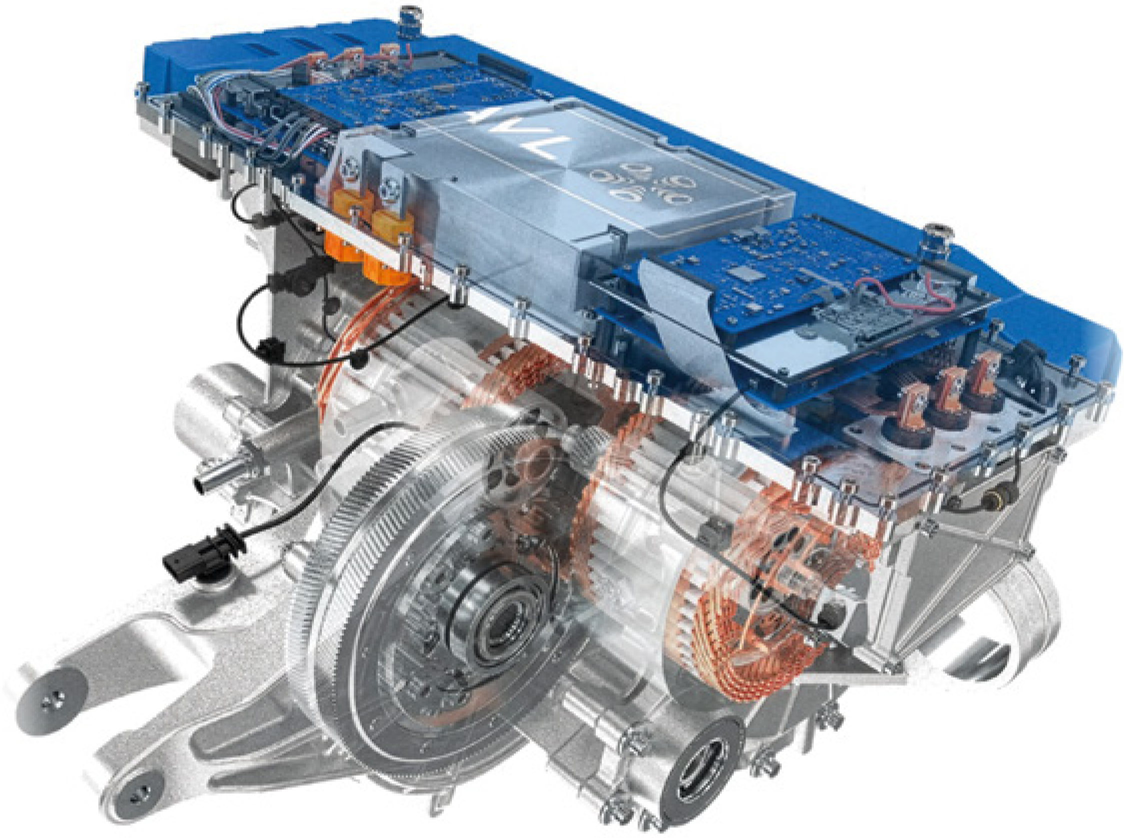
How do energy density and costs compare to current state-of-the-art batteries?

That's one of the most critical questions for customers! I could give you today's figures, but it wouldn't help much because our goals for series production in 2029 are 20 to 40 % higher density than the best lithium-ion battery, at unit costs of 20 to 40 % less. That's the target we think we can achieve. When visitors tour our manufacturing plant, they are amazed at how simple our manufacturing is, with such a small footprint. For example, there's no need for the calendering process used by lithium-ion battery manufacturers . And there is no need for an electrolyte filling process. So we save money on equipment, around 20 or 30 % of the CAPEX which should impact the price of the final product. And finally, another benefit is that there are fewer environmental requirements due to our simpler, which again lowers the costs.

When will we see your technology on the streets, and what market penetration do you expect?

As I said earlier, our goal is to start production in 2029. It's hard to predict, but we think solid-state batteries can reach a market penetration of 5 % in 2030 and about 8 % in 2035. Based on what we see, and on analyses from some of the best sources, that seems realistic.

Interview: Gernot Goppelt



>94 % Cycle Efficiency Electric Drive Unit: From Ambitious Targets to Validated Reality

DI (FH) Wilhelm Vallant, Product and Business Development Manager Transmission & E-axle, AVL List GmbH

The automotive sector is experiencing a profound transformation towards electrification, motivated by the dual objectives of mitigating greenhouse gas emissions and ensuring uncompromised vehicle performance. Original Equipment Manufacturers (OEMs) are increasingly challenged to meet rigorous sustainability and cost-efficiency benchmarks. In response, AVL introduces a forward thinking and validated solution that establishes new standards in electric drive unit (EDU) efficiency, lifecycle CO_2 emissions reduction, and system integration.

This article details the development and empirical validation of a high-efficiency EDU system that achieves an average cycle efficiency exceeding 94 % under the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) as well as the China Light-Duty Vehicle Test Cycle (CLTC) and maintains vehicle energy consumption below 10 kWh per 100 km. The discussion further encompasses the technological advancements and sustainability frameworks that underpin these accomplishments.

EDU Architecture and Operational Strategy

At the core of a demonstrator vehicle developed by AVL as part of an R&D project lies a dual-motor EDU configuration consisting of:

- Two Permanent Magnet Synchronous Machines (PMSMs)
- A compact, single-stage spur-gear transmission with double helical gears
- Compact final drive with integrated planetary gear differential
- A dual Silicon Carbide (SiC) inverter system
- Oil catch tank to decrease the oil level during operation

To meet the ambitious energy consumption and efficiency goals, an innovation-driven development process was implemented, enabling the early-stage comparison of a wide range of technologies. By applying advanced simulation methods, numerous potential solutions can be evaluated early on in terms of their alignment with the project objectives. Key measures include component technology selection, architectural studies to balance performance and losses and system simulation using AVL's proprietary development toolchain, the Powertrain System Optimizer (PSO). Step by step, the number of possible variants is reduced by selecting the most promising solutions, while the level of simulation detail is progressively increased. Once only a few options remain, detailed component optimization and initial control strategy refinement are carried out in the final development phase. FIGURE 1 illustrates the AVL PSO methodology.

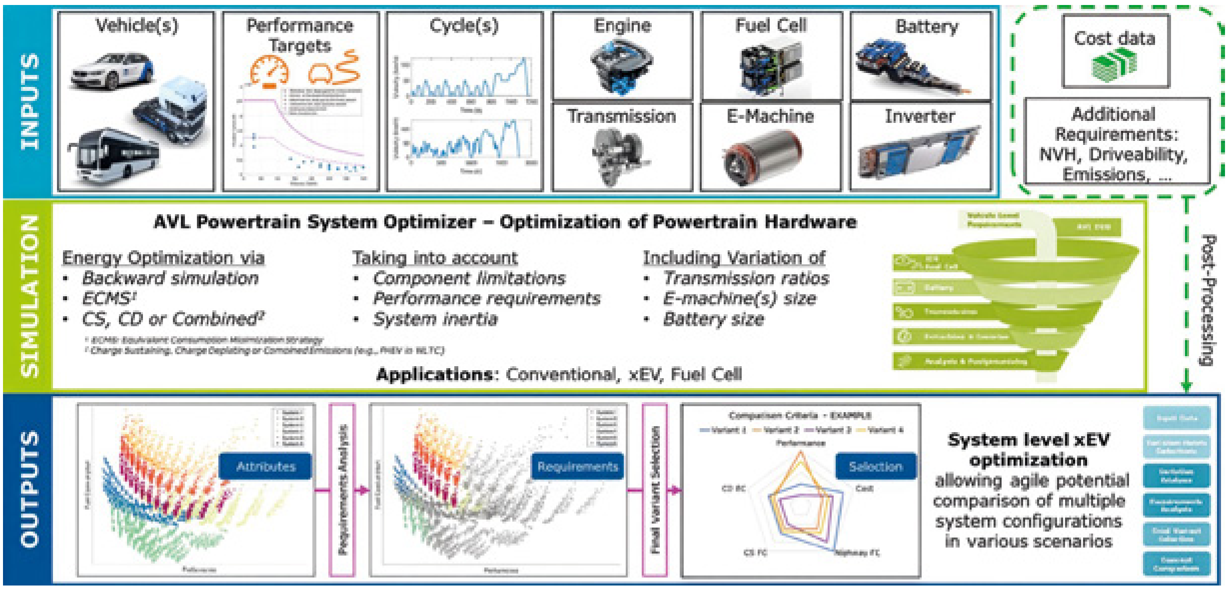


Figure 1: AVL Powertrain System Optimizer Workflow

The selection of transmission, electric motor and inverter technologies was guided by cost reduction and sustainability, with a focus on intelligent integration, minimizing drag losses and using efficient materials. Achieving maximum efficiency in the EDU architecture was essential to reaching a WLTP cycle efficiency of more than 94 %, and a dual-motor concept proved to be the most effective solution. The main motor was designed for efficient continuous operation, while the secondary motor supports boosting and recuperation. This secondary motor, which can be decoupled via a dog clutch, was specifically optimized for its intended use and the load points defined by the operating strategy.

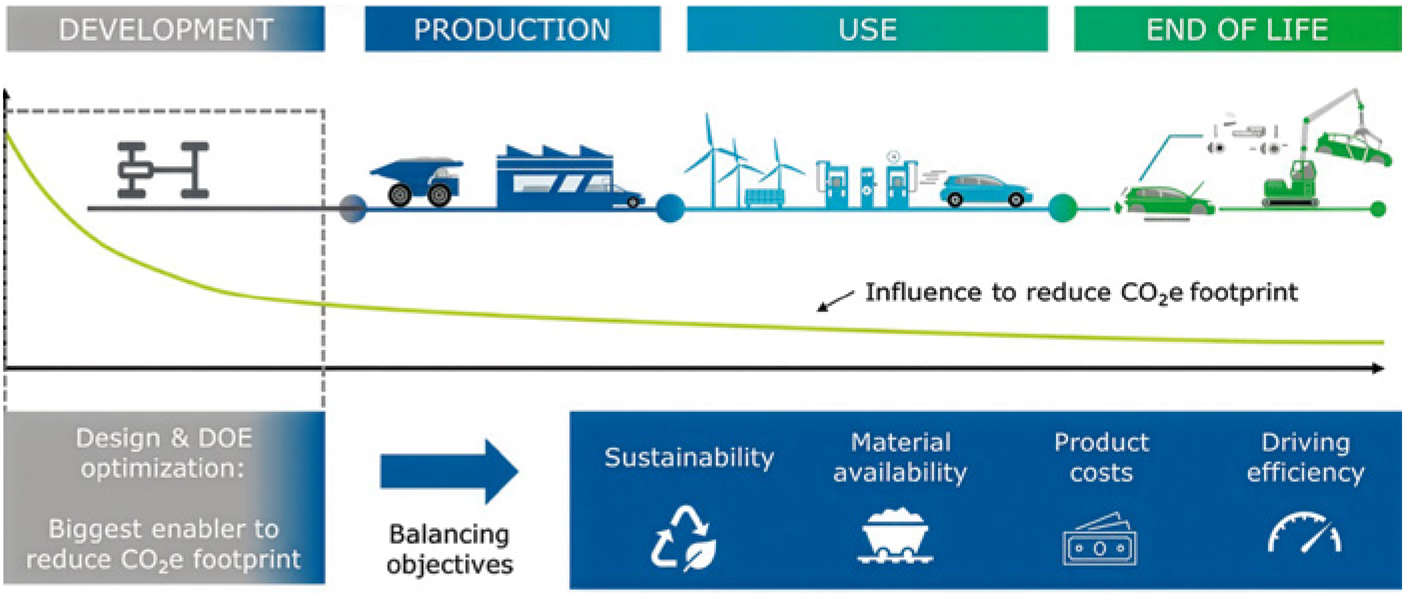


Figure 2: Sustainability in the Drivetrain – Impact of Development Phase on Lifecycle GHG Emissions

The AVL PSO development methodology was used to optimize the EDU's dimensions, simulating numerous variants to evaluate efficiency and performance under varying parameters. The basic design specification was derived from system simulations, with components and operating strategies already optimized during the early concept phase.

Outcome of this design evolution process is a unique system featuring key elements to support the lowest possible energy consumption in the vehicle. The gear-set features a single stage transmission with double helix gears, reducing mechanical losses in high torque and speed operating conditions by -16 % compared to conventional designs. In moderate torque and speed losses are reduced by 11 %. To enable compact packaging of the two e-Motors a planetary differential is used which could be packaged inside the double helix final drive gear with an axial length of less than 80 mm. The lightweight design reduces weight by -15 % to -20 % compared to conventional solutions.

An oil catch tank is positioned at the differential gear to collect oil effectively. This collected oil is then distributed to various components, including gears, bearings, and the dog clutch. Besides securing proper lubrication of the system the oil catch tank also lowers the oil level in the transmission sump, thus reducing splash-losses while the vehicle is running. The key element for enabling the operation of the boost electric motor is an electromechanically actuated disconnect clutch located on the e-Motor shaft. When it is not engaged, it is ensuring operational efficiency.

To ensure safe operation of the dog clutch a special simulation experiment was set up to analyze the impact of the stator windings magnetic field on the dog clutch's actuation force. Based on this investigation, using the advanced in-house simulation capabilities, it was possible in a virtual stage to evaluate a safe operation of the dog clutch under all operating conditions.

With introduction of the disconnect clutch enabled the implementation of an operating strategy, further contributing to highest possible system efficiency hence contributing to lowest possible energy consumption.

Design-to-CO_2 Methodology

Considering the complete life cycle as a system with certain limits is essential for a valid analysis. Automotive manufacturers can influence most scope 1 and 2 emissions according to the Greenhouse Gas (GHG) Protocol Corporate Standard (2) and have certain but not full control of the upstream scope 3 emissions of the supply chain, as well as the scope 3 emissions downstream in the usage and recycling phases (3).

In product life cycle modelling, it is important to know the qualitative patterns for CO_2e influenceability, determination and the actual occurrence to define appropriate optimization measures at the right times.

FIGURE 2 shows an ideal-typical pattern for the product life cycle of a Battery Electric Vehicle (BEV) assuming a European 2023 electricity mix in the production and in-use phase (1). It is shown that the CO_2e influenceability decreases significantly during the later phases described. Although the majority of CO_2e emissions occur during the production phase and typically need to be offset during the in-use phase when compared to other powertrain technologies, the development phase has the most significant impact on the CO_2e footprint.

By integrating life cycle assessment (LCA) methodologies and sustainability criteria from the outset, developers can evaluate and compare the environmental impacts of various powertrain technologies. This proactive approach enables the identification of technologies that not only meet performance and cost requirements but also minimize CO_2e emissions throughout the product's life cycle. Consequently, making informed decisions early in the development process ensures that the chosen technology aligns with sustainability goals, leading to a more environmentally friendly product.

Through the integration of these cutting-edge technologies, AVL enables OEMs to deliver electric powertrains that excel in performance, efficiency, and sustainability. This advancement constitutes a significant milestone toward fulfilling the automotive industry's climate objectives while preserving competitive product offerings.

Real Life Demonstrator

From the outset, the goal was to transfer the resulting technology into customer applications, aiming for comparable efficiency and consumption values in the target vehicle. When the EDU was integrated into a customer vehicle based on the original design, a slight efficiency loss was initially observed due to different driving conditions and load points. However, the efficiency still significantly improved the customer's baseline EDU. To meet the original efficiency targets, goal-oriented adjustments were necessary.

Subsequently, the electric motor topologies and gear ratios were optimized. The adaptation process included detailed investigations to improve efficiency under the boundary of materials usage comparable to benchmark solutions. All modifications were made with the updated customer load profile and the geometric constraints of the target vehicle in mind, ensuring seamless integration. Vehicle simulations confirmed the effectiveness of these measures, achieving an average customer cycle efficiency of more than 94 %.

The EDU was tested both on a test bench and in the vehicle to validate system efficiency. While the test bench results did not exceed the 94 % cycle efficiency target, further optimization of the operating strategy for in-vehicle use led to an average efficiency of 94.4 % during real-world testing, confirming the achievement of the project goals.

Conclusion

AVL has developed a high-efficiency electric drive unit (EDU) achieving over 94 % cycle efficiency under WLTP and CLTC standards, with vehicle energy consumption below 10 kWh/100 km. The EDU features a dual-motor configuration with permanent magnet synchronous machines, a single-stage double helical gears transmission, and a dual SiC inverter system, optimized through AVL's Powertrain System Optimizer. Innovations include a lightweight, compact design with reduced mechanical losses and an electromechanically actuated disconnect clutch to enhance efficiency. The development incorporated lifecycle CO_2 assessments to align with sustainability goals, emphasizing early-stage optimization to minimize emissions. Real-world vehicle integration confirmed the system's efficiency, reaching 94.4 % in testing, demonstrating a significant advancement in electric powertrain performance and environmental impact reduction enabled thorough AVL technology and engineering methodology.

Validated Outcomes:

- Achieved an average EDU efficiency of more than 94 % in real-world testing scenarios
- Recorded 94.4 % efficiency in customer-specific driving cycles

Quotes:

- „>94 % EDU efficiency and <10 kWh/100 km energy demand – validated on the road, not just in simulation.“
- „Design-to-CO_2e turns sustainability into an engineering parameter, not a marketing claim.“

See the Unseen from NVH Performance of E-powertrain – the Un-audible High Voltage Ripple and Transients that Affects EVs

Xiao Cai, Chairman & CTO, Stropower Technologies Co., Ltd.

- The correlation factors between the NVH performance of e-drive vehicles and its inner high-voltage power network
- Extensive impact of underlying electrical fluctuations and transients on electric drive vehicles
- Development of industry testing standards and testing environment

A key difference in NVH performance between e-drive vehicles and internal combustion engine (ICE) vehicles lies in the electromagnetic excitation vibration caused by the vehicle's electric drive, such as the humming of the battery pack and the characteristic noise of the motor's electrical speed in the high dynamic region. This is the NVH characteristic of the high-voltage system of e-drive vehicles that can be perceived when exposed. However, through a deeper understanding of its mechanism, we will see more widespread high-voltage electronic and electrical fluctuations and transients, which more often and silently affect the control performance – functional status – driving experience – safety and durability of the electric drive. Effective high-voltage testing can help us better predict these potential hazards.

The correlation factors between the NVH performance of e-drive vehicles and its inner high-voltage powernet.

The mechanical structure design and power transmission design of the vehicle body form the self-foundation of the vehicle's NVH performance. With the assistance of good chassis suspension, noise-absorbing layers, and wind noise isolation, luxurious and quiet models can achieve better NVH performance in terms of mechanical quality. This is a very important design field in the automotive industry. These measures and means are effective and primary for mechanical vibrations below 100 Hertz. However, in electric vehicle models, there are typical noises in the kilohertz frequency band. These comparably high-frequency noises cannot be effectively suppressed by the absorbing materials and traditionally designed body structures, nor can they be masked by other low-frequency noises due to the difference in timbre. And it suddenly brings about new problems in NVH engineering for e-drive vehicles.

The difference in noise sources is the cause of different timbres. The main noise sources existing inside e-drive vehicles are the electrical fluctuations and transients of the high-voltage system caused by the operations of various power semiconductor switches.

A typical phenomenon can illustrate this issue: when charging your laptop with a charger in a quiet room, in most cases, you can clearly hear the humming sound of the charger. This is a common acoustic noise in daily life caused by electromagnetic fluctuations. The reason is that the power transmission control of switching power supplies relies on the switching actions of power devices. During the use of electric vehicles, similar causes of noise can also often be found: a faint humming sound that can be heard even when the vehicle is not in motion after just being powered on, and the special tonality variation in accordance with your pedal position.

During the power fluctuation of several hundred kilowatts (x kW) in an electric vehicle, the voltage and current of the internal high-voltage system will be subjected to electrical fluctuation impacts of varying speeds, ranging from 1V/ms to 1V/ns, for example. In terms of the composition of the high-voltage system, different electronic and electrical units inside are connected in parallel to the DC bus supported by lithium battery packs and DC link capacitors, and they will experience varying degrees of interference.

By conducting ripple injection tests on the lithium battery packs of e-drive vehicles ranging from 10Hz to 150kHz – that is, by simulating the ripple amplitude of the DC bus voltage and applying it to the power battery pack, the acoustic noise spectrum generated by the power battery pack was tested.

From the test results: due to the high-voltage battery pack characteristics of power batteries, there are several uH components in their internal impedance characteristics in the equivalent model at the circuit level. This enables its response to fluctuations in AC voltage to generate an AC current with a sufficiently high phase difference – **that is, the AC current intensity of the power battery pack varies with frequency according to its own impedance-frequency characteristics (D-EIS or in-situ EIS).** This also leads to the NVH noise tones produced by the fluctuations of bus voltages of different frequencies on the battery pack being quite distinct. Based on the current test results, the corresponding relationship between the magnetic field stress of the current and the structural vibration (such as copper bars and metal covers) also confirms the causal relationship of frequency correspondence.

Effective control of electromagnetic interference fluctuations that may generate NVH excitation is currently an important research topic in high-voltage electronic and electrical testing. However, due to the very wide differences in the „excitation – transmission – response" path among different vehicle models, the applicability of general models is limited. More prediction and verification methods still require appropriate test platforms for verification.

Take the electric drive power unit as an example. Under different power density design requirements, the controlled performance of the motor and the electrical shocks, such as ripple and surge, caused by the high-voltage system during the power output process, are related to the designer's optimization level of the control process, as well as appropriate peripheral filtering and anti-interference measures. The final production vehicle's torque ripple wave and NVH characteristics are the result of design efforts coming from multiple aspects.

Extensive impact of underlying electrical fluctuations and transients on electric drive vehicles

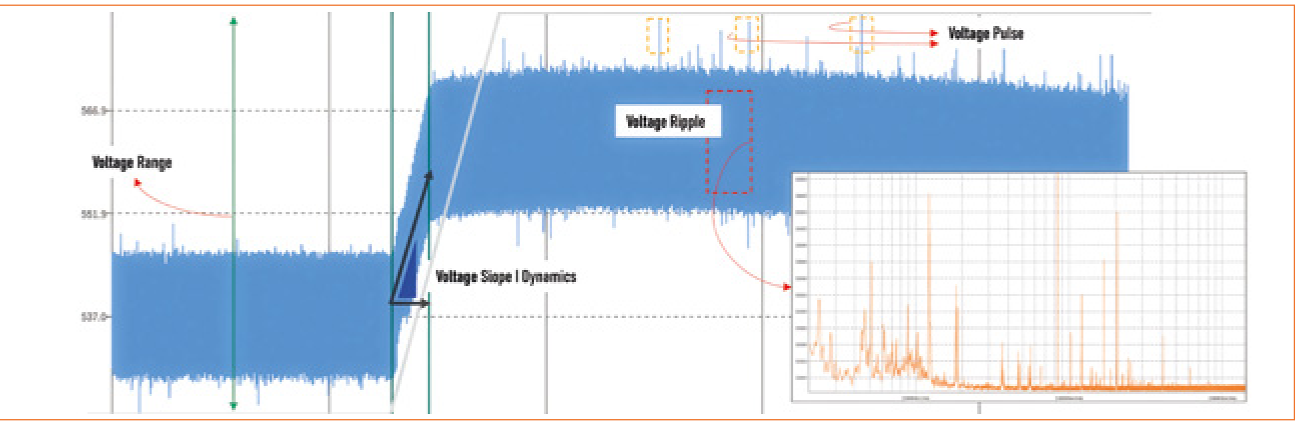
The above description of the explicit NVH performance of vehicles has revealed the impact of electrical fluctuations and transients within the high-voltage system of e-drive vehicles on them, a problem that has not been encountered in ICE models.

In fact, since the large-scale commercial use of electric vehicles began, vehicle problems caused by the dynamic stress of high-voltage electrical systems have been very frequent, and most of these problems do not occur in a way that drivers can perceive.

For. example: due to the excessive AC current at the impedance resonance point formed by the high-voltage wiring loop, the relay disengages and the BMS protection signal is mistakenly triggered; the overvoltage warning shutdown of the TMS is triggered by the voltage fluctuation of the DC bus caused by the operation of the MCU; the overvoltage of the DC bus which caused by the energy regnerated during heavy braking, which breaks down the components, etc.

From the various electrical dynamics of high-voltage systems that have been mentioned, the major types of threat factors that mainly emerged can be classified in terms of waveform as:

1. Ripple during steady status
2. Transients during dynamic motion



Among them, the steady-state ripple mainly refers to the regular fluctuations in the bus voltage caused by the controller during the process of stabilizing the power output.

Under normal circumstances, since the on-off control of the switching elements by the controller is implemented by the software, if the load current fluctuates within a defined tolerance range, the command response for a stable output is completed. This process is usually achieved at a steady state through „feedback-control", such as typical PID control or complex PID control with algorithm update functions. The timing pulses of the switch nodes formed by the on-off control constitute the AC excitation of the entire in-vehicle high-voltage system, and through the impedance network of the system, the bus current is ultimately formed – this is a typical controlled response. **Therefore, the level of ripple is directly related to the excitation composition, which is also the key way to usually increase performance or avoid the frequency of feature problems through control and regulation.**

Transients during dynamic motion often occur in an „uncontrolled" state, such as in a typical load-dump situation: the energy shock and high-voltage pulses generated by the drastic changes in current are natural responses without any controller management, and the survivability of the component unit solely depends on the stress margin at the time of design.

Another type of transient occurs with a higher probability. It also appears at the semiconductor nodes of the power bridge; that is, during the instantaneous process of the bridge arm switching, the voltage or current pulse is commonly seen at the rising and falling edges of the switching waveform. Although these transients cannot be regarded as truly „uncontrolled", in fact, once a piece of hardware design is completed, it is very difficult to make changes to the ramping rates.

So, it is not difficult to see that the main difference between ripple and transient lies in the rate of voltage change, that is: V/s. Inside e-drive vehicles, with the development of the design trend towards functional integration, more and more functional units are gradually integrated into the same high-voltage system. For instance, several inverters are added to achieve an outdoor power supply, a step-up and step-down voltage module is added to be compatible with high and low voltage charging piles, and a 48V module is added for functionality and comfort, etc. Different units operate at different frequencies, which will apply more voltage variability on the DC bus. As a result, the generation of interference and the verification of anti-interference become important.

Development of industry testing standards and testing environment

At present, the industry is still in the research and early standard establishment stage for the design control and suppression countermeasures of ripple and transient pulses in EVs.

Conducting electronic and electrical tests on the high-voltage system of electric vehicles can simulate the extremely large electrical stress that occurs, thereby verifying the safety design margin and functional anti-interference capability of each component unit inside the vehicle. Avoid situations that threaten driving safety and affect the driver's experience.

Starting from the early LV123 standard, mainstream European car manufacturers have made many early efforts in the high-voltage electronic and electrical testing standards of vehicles, such as VW80300.

Today, the main general standards referred to in the industry are ISO 21498-1, -2. Since 2023, Vehicle manufacturers and testing institutions in China have gradually begun to pay attention to the corresponding testing standards and have already made preparations for the release of the corresponding Chinese standards as the testing progresses, and it is expected that the corresponding standards will be released within the next one or two years. In the future, based on the relevant test results and the accumulation of more new test cases, there will also be updated standards to gradually improve the current test standards, enabling them to provide more valuable references for detecting potential design issues of vehicles.

Stropower Technologies has always been dedicated to the development of green energy and the research and development of zero-emission vehicles R&D. As a major equipment supplier for lithium battery testing and a leading enterprise in the electronic and electrical testing of high-voltage systems for electric vehicles.

Since 2018, based on the VW80300-2016 standard, the world's first vehicle ripple spectrum response analyzer that fully meets the standard requirements has been developed by Stropower Technologies.

Subsequently, it became the first supplier to offer a complete set of test equipment, including different voltage ramping rates and transient pulses.

Stropower Technologies officially released the third-generation vehicle high-voltage electronic and electrical complete test solution in October 2024, which includes a wide-frequency ripple disturbance emulator, a program-controlled test power supply system up to 1200V-1000A, a high-voltage artificial network that fully meets the impedance spectrum characteristics, and other auxiliary test equipment modules. It is a leading test solution provider in the industry that fully complies with test requirements and can comprehensively cover the main power dynamic ranges.

Thanks to the vigorous development of the electric vehicle market in China and the long-term trust and support of major vehicle manufacturers and testing institutions for Stropower Technologies, through the accumulation of hundreds of test cases, the company can not only provide customers with a one-stop complete set of test equipment assembly solutions, moreover, it can provide customers with professional and predictive test environment setup based on their testing purposes and the characteristics of the objects under test, avoiding time waste caused by the lack of understanding of tests and interferences from related variable factors. It also offers professional suggestions and technical support for the correct conduct of tests and the accuracy of test results.

Effective Solutions for Bearing Insulation to Prevent Electrical Corrosion in E-Drive Systems

Philippe Pauchard, Application Engineers at DuPont (Switzerland)

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Ruth Jackowiak Application Engineers at DuPont (Switzerland)

The automotive industry is progressing toward high-voltage systems for electric vehicles (EVs) with enhanced efficiency. Reliable and durable components are increasingly critical, particularly bearings in electric motors, which can suffer from electrical erosion due to parasitic currents, causing significant damage and premature failure. This challenge is addressed by using insulation provided by DuPont™ Vespel® polyimide parts.

Electric erosion in bearings

In traction motors, parasitic current can move through the roller bearings and cause damage. The bearing failure mechanism is called electrical erosion. An electrical discharge between the rolling element and a bearing raceway creates spot welds between the surfaces. With the ongoing rolling motion, those spot welds break apart and small particles are generated, causing additional wear of the surfaces.

Electrical erosion occurs in modern high-speed electric motors, in regenerative braking systems of electric vehicles, or wherever Variable Frequency Drive (VFD) are used to control a motor. The worst-case scenario of electrical erosion in bearings is the premature failure of the electric motor, which can lead to safety hazards, and significant costs associated with repairs.

Risk Reduction methods

Preventing parasitic currents through system design would be the ideal solution, but this remains a significant challenge. While future inverter technologies may eventually mitigate the risk of voltage spikes, the cost-effectiveness for high-volume applications is still questionable. Alternative solutions, such as Insulated-Gate Bipolar Transistors (IGBTs) or gallium nitride-based switches, offer potential benefits but seem to be either limited in efficiency or still too expensive for widespread use. Moreover, their effectiveness in preventing electrical erosion can only be assured when the entire system is designed and manufactured by a single supplier. Once subsystems from different sources are integrated, predicting the system's behavior becomes increasingly complex.

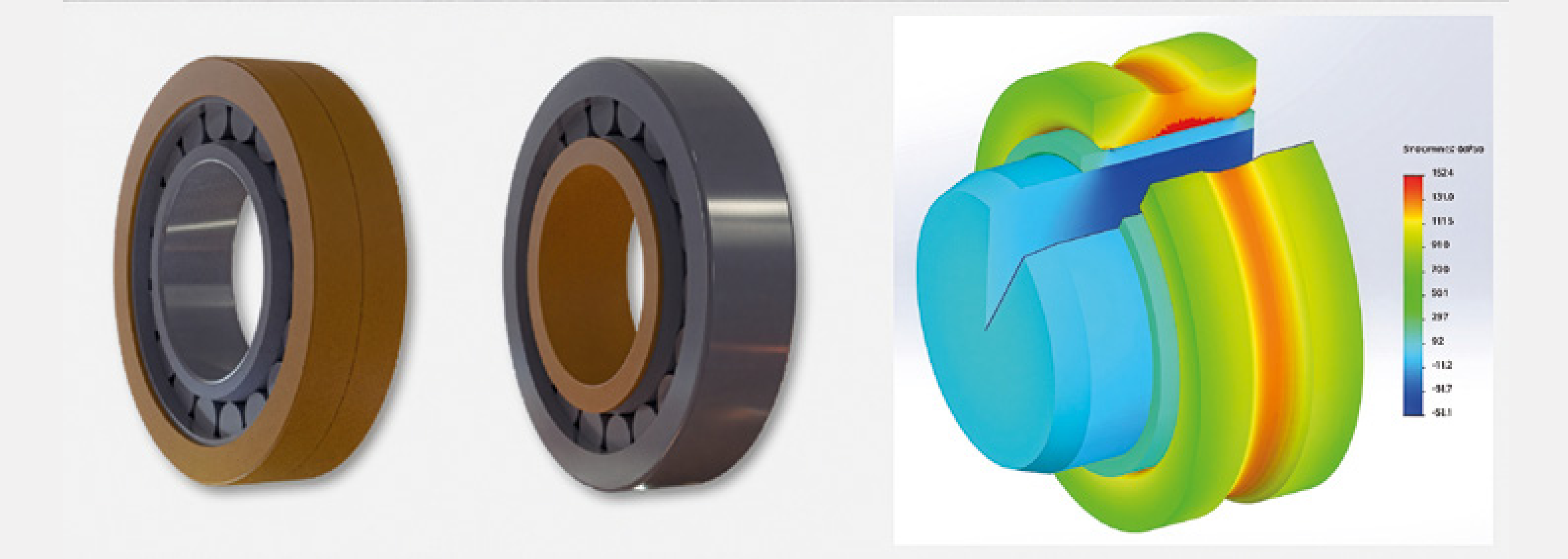


Figure 1: Vespel® bearing insulation sleeves (left) and Stress analysis of the Vespel® sleeve press-fitted over the shaft and assembled on the inside diameter of the bearing (right).

Vespel® polyimide insulating bearing sleeves

Vespel® S is a sintered polyimide which has no observable glass transition temperature or melting point. Its high-temperature resistance allows it to be used as an insert in die-cast aluminum parts. Its unique property is key for applications where high loads and elevated temperatures can occur, as may be the case in traction motors in critical drive modes or in the case of malfunction.

Vespel® polyimide insulating bearing sleeves, can be used to electrically insulate the rotor from the housing and suppress discharge currents. They offer a versatile and cost-effective solution for mitigating electrical corrosion in e-motor bearings. These sleeves can be installed during final assembly by press-fitting onto either the rotor shaft or one of the bearing rings (Figure 1). In all cases, standard steel ball bearings can be utilized with Vespel® sleeve, eliminating the need for expensive ceramic rolling elements such as hybrid bearings.

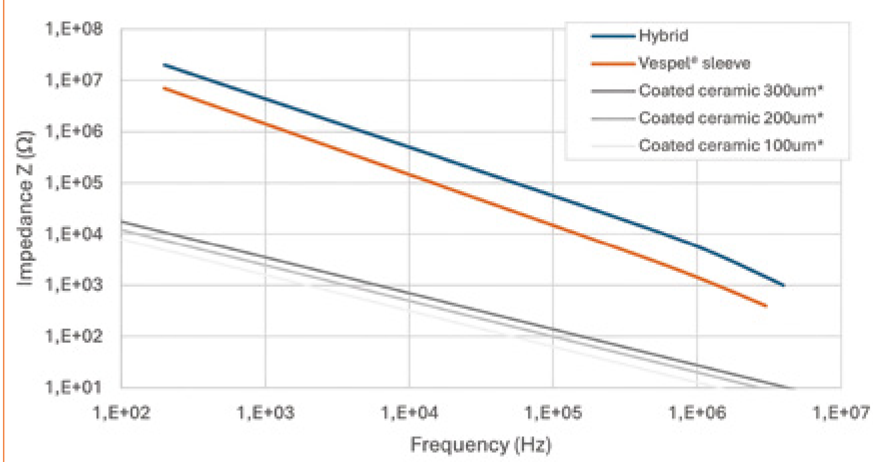
Vespel® polyimide insulating layer between 1 and 2 mm offers robust insulation by significantly increasing electrical impedance. This effectively attenuates high-frequency currents traversing the bearing, thereby reducing the risk of electrical erosion. Vespel® polyimide also exhibits mechanical damping properties that may help reduce noise, vibration, and harshness (NVH) in electric motor systems.

Existing solutions, such as ceramic and polymeric coatings provide adequate insulation in DC environments, they often fail to prevent electrical discharge under AC conditions, particularly at higher frequencies, and may suffer from mechanical fragility.

Electrical insulation performance

Various tests have been conducted to support the use of Vespel® sleeves in addressing electrical corrosion issues. The electrical impedance has been measured by IMKT (Institut für Maschinen-konstruktion und Tribologie at Leibniz Universität Hannover). Results indicate that the electrical insulation performance of Vespel® SP-1, although slightly lower than that of the hybrid bearing, remains in the same order of magnitude and significantly higher than the ceramic-coated bearing solution [8], even when compared to the thickest layer of ceramic coating (Figure 2).

Figure 2: Comparison of Electrical Impedance Across Various Insulated Bearing Solutions



Designing Vespel® polyimide Insulating sleeve

The design of the Vespel® polyimide sleeve requires studying the different press-fitting scenarios and checking that the loads resulting from the press-fitting of the various parts, combined with thermal expansion, are acceptable (Figure 1). Bearing manufacturers typically provide maximum hoop stress and radial stress; this information is used to properly dimension the Vespel® polyimide sleeve. Although proper testing needs to be conducted on the final system to ensure the parts behave appropriately, simulations are used to build confidence and quickly design a working prototype (Figure 1).

Other polymeric solutions could be used, but they need to be reinforced with fibers to enhance mechanical strength. The fibers are abrasive and easily cause wear issues when they are in contact with aluminum. In EV cars, this phenomenon is amplified with the vibration generated by electrical motors causing fretting wear issues on aluminum housing.

Unlike standard polymers, Vespel® polyimide, with extreme temperature capabilities, does not require fiber reinforcement to maintain its mechanical performance and withstand the maximum temperature of 150°C, observed at the bearing position for traction motors. Tests conducted at the DuPont Tribological Laboratory under similar conditions revealed that fiber-reinforced thermoplastics caused significant wear on aluminum components, whereas Vespel® polyimide resulted in no measurable wear (Figure 3).

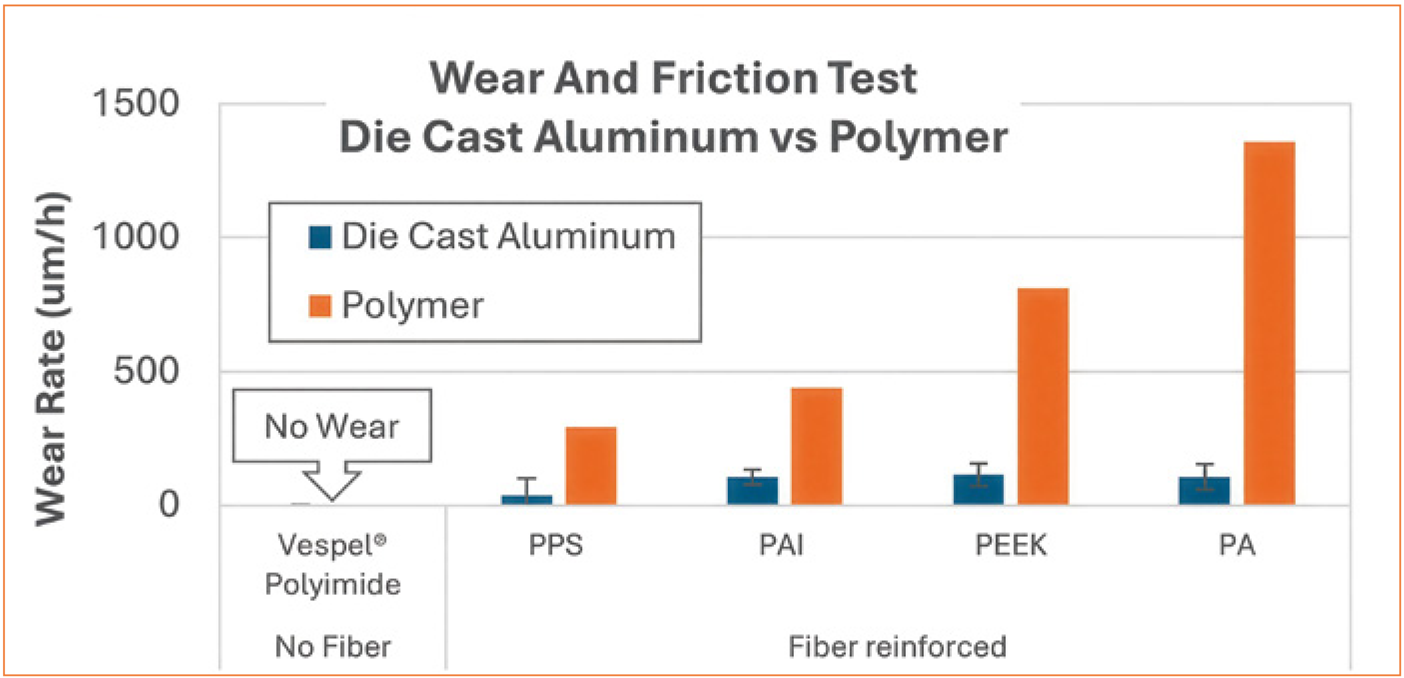


Figure 3: Wear performance of Vespel® polyimide vs polymeric solution against die cast aluminum

Aluminum die-casting insert

Another innovative solution involves the use of Vespel® polyimide as an insert in aluminum die-casting, leveraging its exceptional high-temperature resistance and lack of a melting point, which enables it to withstand aluminum processing temperatures up to 680 °C. By integrating a Vespel® insert directly into the mold, an electrically insulating barrier is formed between the traction motor housing and the bearing. Following the die-casting process, the insert can be machined to achieve precise tolerances – a standard step prior to bearing assembly.

In collaboration with Swiss aluminum die caster Aluwag AG, the feasibility of this concept was successfully demonstrated through the production of aluminum housings incorporating a 90 mm diameter Vespel® insert (Figure 4). Notably, the interface exhibited no structural or dimensional changes after multiple thermal cycles ranging from −40 °C to 150 °C, underscoring its suitability for long-term use in demanding application environments.

Figure 4: Cross section of bearing seat with Vespel® insert (© DuPont)

Recyclability of aluminum components with Vespel® polyimide inserts

Die cast aluminum housings containing Vespel® polyimide inserts are currently being evaluated by companies for use in electric vehicle driveline components. In addition to performance testing, there is a need to recycle aluminum housings that exhibit defects. During the casting process, a skimming operation is typically performed to eliminate impurities such as oxides, slag, and other contaminants that form at the surface of the molten aluminum. Preliminary tests have shown that Vespel® polyimide components float on the surface of the molten aluminum, which could simplify their removal during the skimming operation.

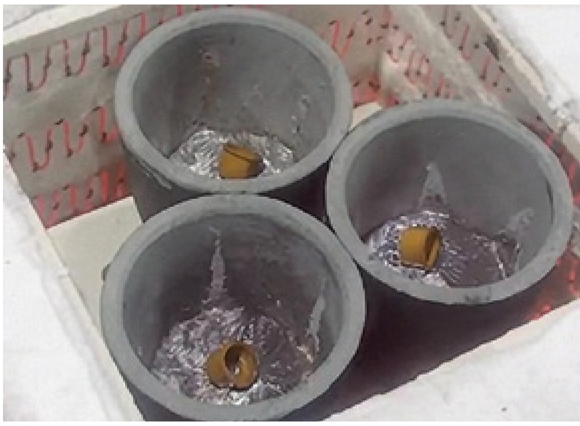


Figure 5: Vespel® Inserts Floating on the Surface of Melted Aluminum

Most electric motor housings use steel sleeves to protect aluminum from bearing-induced fretting wear. However, these inserts complicate recycling due to material separation. Vespel® polyimide could offer a more sustainable alternative, replacing steel sleeves used with ceramic bearings while maintaining electrical insulation and simplifying recycling.

Summary

As electric vehicles evolve, the need for reliable and durable components, particularly bearings, is paramount due to their susceptibility to electrical erosion in high-voltage systems. DuPont™ Vespel® polyimide offers a groundbreaking solution with its insulating bearing sleeves, which can enable the use of standard roller bearings instead of costly ceramic alternatives, thereby helping to reduce material costs significantly.

Additionally, Vespel® polyimide inserts can be integrated within aluminum die-casting processes, providing effective electrical insulation and enhanced performance in demanding environments. The combination of these innovative solutions positions Vespel® polyimide as an essential material for the future of electric vehicle technology, promoting safer, more efficient, and sustainable electrified drivetrains.

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Safe and Sustainable-by-Design: Setting New Standards for EV Coolants

Dr. Sander Clerick, Development Chemist, Arteco

The automotive industry is rapidly shifting to low- and zero-emission solutions. Electrification, including hybrid, battery, and fuel cell electric vehicles (EVs), is driving innovation in powertrain and thermal management systems. Moving away from internal combustion engines is crucial to reducing greenhouse gases, air pollution, and their impact on the climate. With transportation accounting for ~28% of global emissions, reducing its impact is essential to achieving global decarbonisation.

Effective thermal management plays a key role in maximising performance and durability. Arteco develops high-performance engine and electric vehicle coolants designed to meet strict safety and environmental standards, with a focus on long-term durability. These formulations are specifically engineered for modern vehicle systems where thermal control is essential.

By applying safe and sustainable-by-design (SSbD) principles during R&D, Arteco ensures its solutions are aligned with future environmental and regulatory standards. This approach balances technical expertise with human and environmental safety, supporting the industry's shift towards sustainability. The introduction of specialised product ranges marks a significant step forward, setting a new benchmark for minimising environmental impact by embedding safety and sustainability at the heart of product design.

Safe-by-Design

Water–glycol-based engine coolants are widely used in electric vehicles for indirect liquid cooling. Their excellent heat transfer properties, proven automotive performance, compatibility, and ease of handling make them a commercially preferred solution for thermal management. In EV systems, the coolant is physically separated from electrical components, often by using a battery bottom cooling plate, to ensure safe and reliable operation.

For demanding scenarios such as fast charging, the industry is trending towards increased battery-to-coolant integration. Closer contact between the fluid and battery, with higher heat exchange surface, enhances thermal management by improving heat transfer efficiency. As a result, the coolant's electrical properties become increasingly critical. Traditional engine coolants, while robust and corrosion-resistant, typically have electrical conductivities between 2.000 and 10.000 µS/cm. If leakage occurs within the battery pack, this level of conductivity can pose a serious electrical safety risk. Effects can range from external short circuits triggering rapid battery discharge to internal cell damage and even thermal runaway if the situation is not properly managed.

To address this challenge, there is a growing focus on dedicated EV coolants that not only deliver thermal performance and material compatibility, but also fulfil a safety-critical function throughout the product's lifecycle.

Recognising this need early, Arteco's pioneering work led to the development of Freecor® EV Milli coolants with low electrical conductivity, specifically designed to enhance the safety of battery systems.

To demonstrate the effect of coolant leakage into battery cells, Arteco collaborated with leading academic research institutions and independent specialised testing institutes to conduct controlled abuse testing. The experimental setup (Figure 1) featured a 57 Ah Li NMC prismatic cell at 100% state of charge (SoC), partially submerged in water-glycol coolants of varying electrical conductivity. A 1 cm gap was maintained between the battery's negative terminal and a copper busbar, across which a 400 V potential was applied, simulating a worst-case short-circuit event at the pack level.

When exposed to a conventional engine coolant (pink, 5.000 µS/cm), the system immediately exhibited short-circuit behaviour. The coolant boiled locally at the electrode, and electrical arcing was observed. Battery surface temperature rose rapidly, to levels potentially initiating thermal runaway. The combined effects of hydrogen generation via coolant hydrolysis and electrical arcing created a severely hazardous scenario within a very short timeframe.

In contrast, testing with a low-conductivity coolant (blue, 100 µS/cm) demonstrated substantially improved safety characteristics. Electrical arcing was entirely suppressed, and the battery surface temperature increased only gradually under identical abuse conditions. While hydrogen evolution could not be fully prevented due to the high applied voltage, the overall risk profile was significantly reduced. This delay in escalation provides critical time for users to evacuate and for emergency responders to intervene.

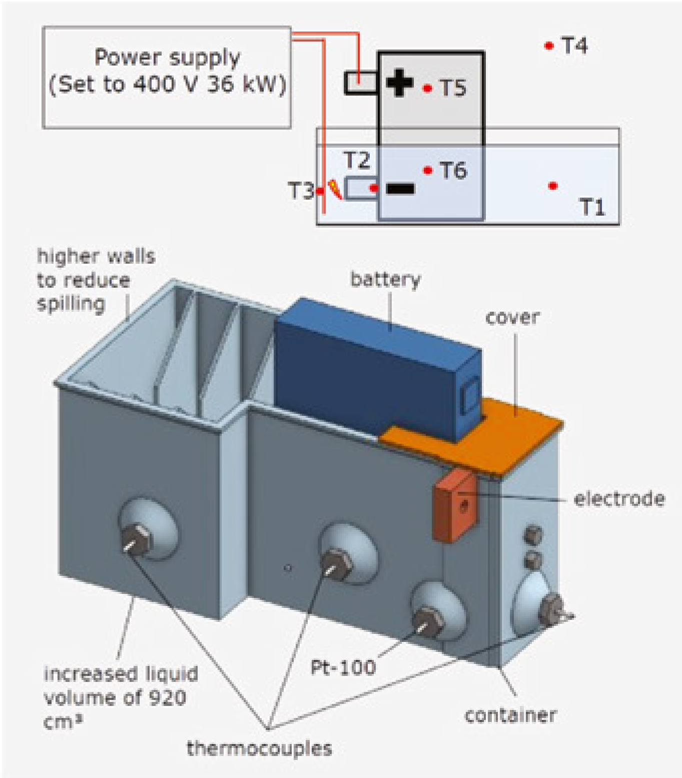


Figure 1: Controlled battery abuse testing at 400 V using water-glycol coolants of varying electrical conductivities.

In light of these findings, industry standards have begun to impose stricter limits on electrical conductivity. For example, ASTM D8566 specifies a maximum electrical conductivity of 100 µS/cm for fresh coolants used in battery electric vehicle applications. A significant regulatory step was taken with the implementation of China's GB29743.2 standard in October 2025. This regulation mandates that as-supplied coolants used in newly developed vehicle platforms in the People's Republic of China must not exceed 100 µS/cm, particularly for systems using water-glycol battery cooling.

Maintaining low levels of electrical conductivity, a parameter often overlooked or insufficiently emphasised in existing specifications, is essential to ensure system robustness. During controlled atmosphere brazing of aluminium components, such as radiators, cold plates, and other battery cooling structures, brazing aids and fluxes leave behind ionic residues on internal surfaces. Once the cooling system is assembled and filled, these residues dissolve into the coolant as residual salts, leading to a sharp increase in electrical conductivity. If the coolant is not specifically formulated to counteract this effect, the resulting conductivity spike may compromise the intended safety improvements (see Figure 2, 300 µS/cm).

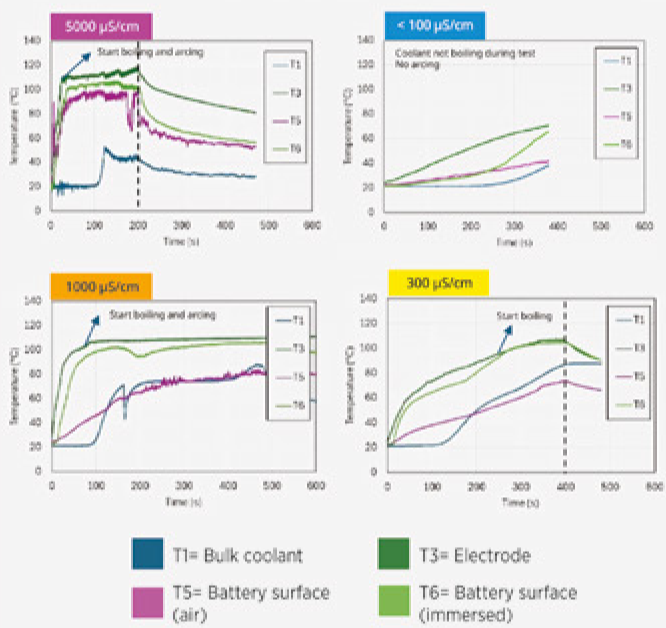


Figure 2: Temperature evolution during battery abuse testing using water-glycol coolants of varying electrical conductivities, ranging from 5.000 µS/cm (ICE) to 100 µS/cm (BEV). Conductivities of 300 µS/cm and 1.000 µS/cm are illustrative of degraded, unstable, or contaminated BEV coolants.

Freecor® EV Milli technology resists such electrical conductivity spikes upon contact with brazed aluminium surfaces (Figure 3). Its formulation helps maintain the initial safety benefits by stabilising conductivity levels, ensuring continued electrical insulation throughout the vehicle's operational life.

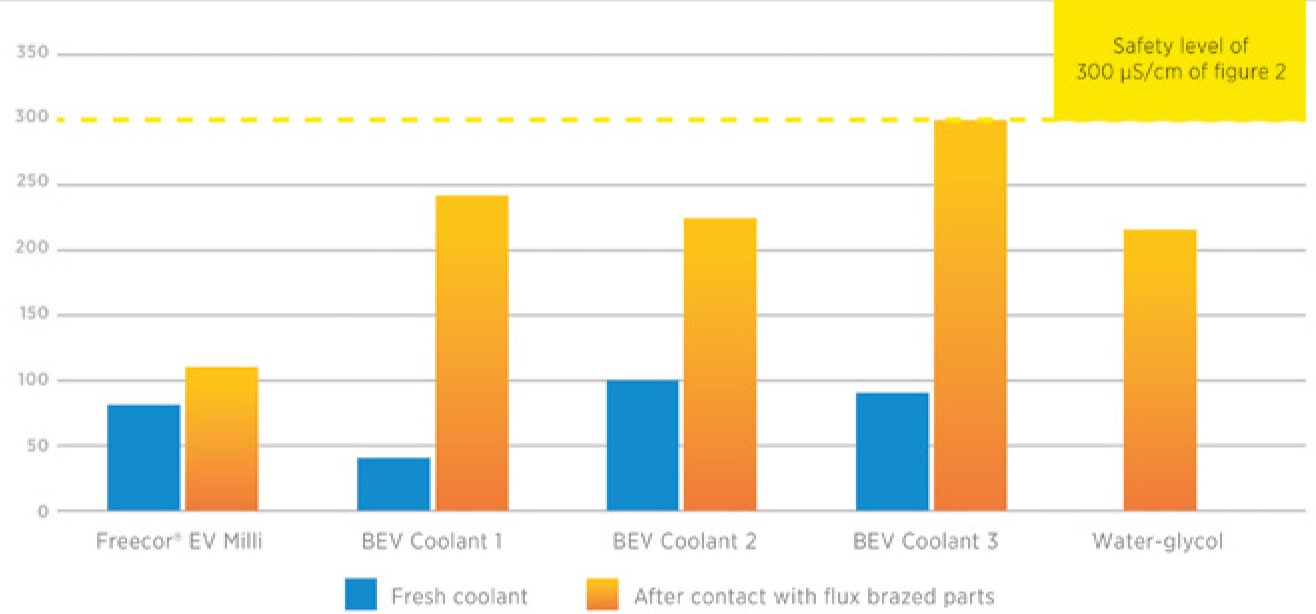


Figure 3: Stress test of coolants (90 °C, 7 days), simulating system filling and operation with flux-brazed parts. Demonstrates electrical conductivity control using Freecor® EV Milli technology.

Sustainable-by-Design

While EV-specific coolants are developed to meet safety and performance requirements, Arteco has gone further by addressing their climate impact. Recent life cycle assessment (LCA) studies show that the most significant climate impacts associated with coolants are largely attributable to raw material extraction and end-of-life treatment. In response, Arteco has prioritised resource efficiency in its development strategy, leading to the creation of the Freecor® EV ECO coolant range.

Freecor® EV ECO coolants incorporate base fluids linked to bio-based or recycled feedstocks, allocated via a certified mass balance approach. This method enables the integration of alternative raw materials into existing production systems, while ensuring full traceability and third-party certification across the supply chain. The base fluids used, Monoethylene Glycol (MEG) or Monopropylene Glycol (MPG), are traditionally virgin-grade materials linked to fossil resources. The Freecor® EV ECO product line helps reduce reliance on virgin fossil resources. To confirm the traceability and reliability of this process, Arteco has received the International Sustainability and Carbon Certification (ISCC) PLUS certification for its mass balance approach towards bioeconomy and circular economy.

The benefits of the ECO coolants are reflected in their significantly reduced Product Carbon Footprint (PCF) compared to their traditional virgin fossil-based equivalents.

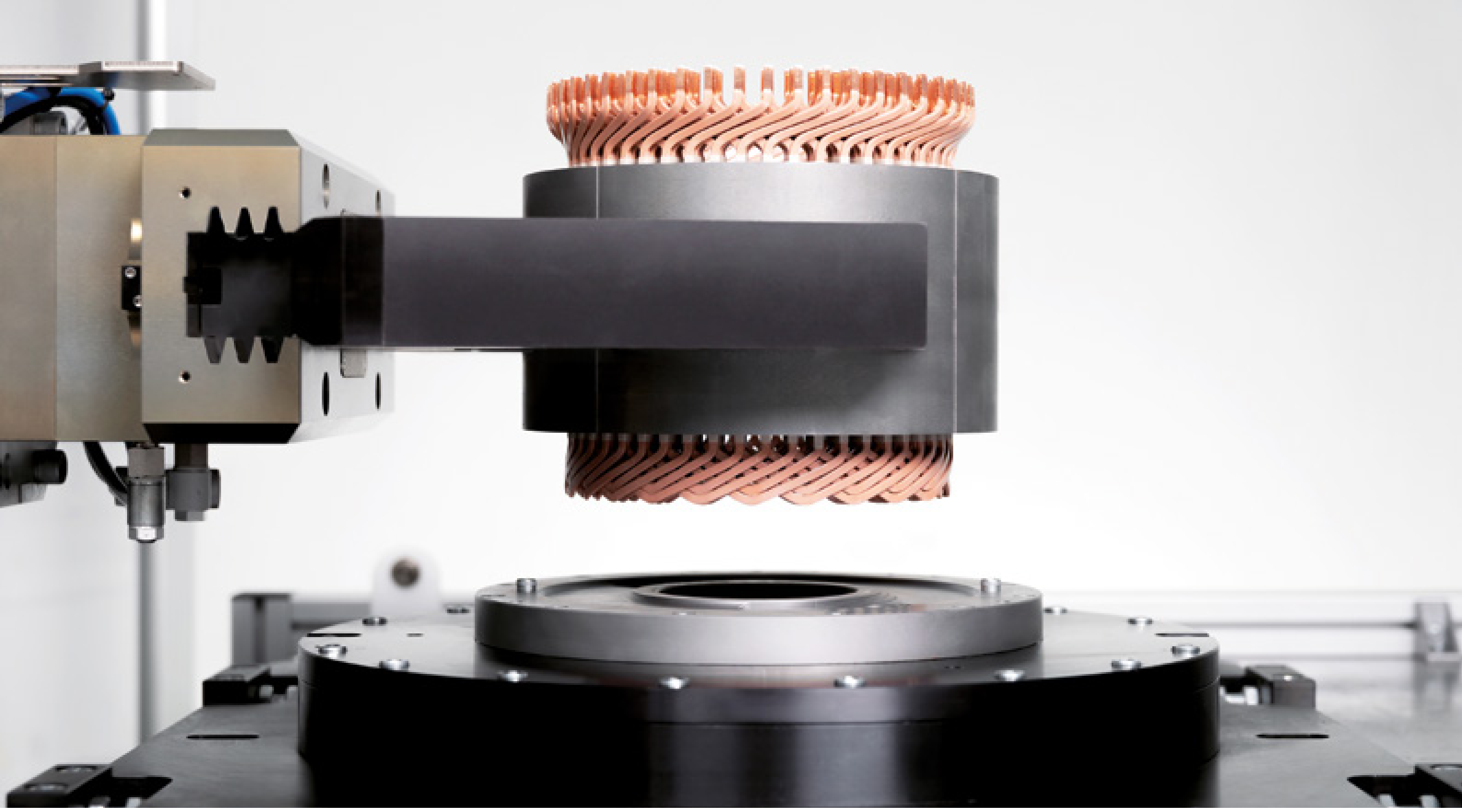
Arteco's strategy involves identifying a strong supplier network capable of meeting stringent sustainability and quality standards. Sustainable sourcing plays a central role in this strategy, supported by thorough evaluation of all input materials to ensure coolant performance and reliability are never compromised.

Interpreting environmental data remains inherently complex, particularly in quantifying carbon savings. Variables such as feedstock origin and methodological assumptions can substantially influence the outcome of impact assessment. To strengthen data quality and transparency, Arteco collaborates with accredited external partners to develop a scientifically grounded, reliable database of product environmental information.

Developing sustainable coolants is a shared responsibility across the value chain. A proactive strategy focused on climate action, responsible resource use, and stakeholder collaboration is essential to achieve meaningful progress.

Arteco's advancements in EV coolant technology contribute to the evolution of safe, sustainable mobility. Its solutions specifically designed for indirect liquid cooling in EVs, address the industry's increasingly stringent safety and performance requirements. With the introduction of ECO coolants, Arteco is raising the bar for decarbonisation efforts across the entire value chain.

Disclaimer: Statements regarding environmental benefits, CO_2 reductions and other sustainability-related performance characteristics of the product(s) referenced herein are based on recognised scientific evidence and internal and/or external data available to us at the time of publication. Actual environmental performance may vary depending on use, conditions, and context. Supporting data and methodology are available on request (info@arteco-coolants.com). This information is provided for transparency purposes and does not constitute a guarantee of performance in all circumstances.



A Long Journey from the First Hair-pin Stator Line to Continuous Flow Winding

Edoardo Freschi, EV-Traction Sales Director, IMA EV-TECH

It was early in 2009 when ATOP started developing the first fully automatic line to produce hair-pin stators. Being a medium-sized company and not having, at that time, the capacity to support such a wide range of solutions, it was necessary to make a choice between the well-known, state-of-the-art coil insertion technology or exploring the brand-new copper bar technology with a pioneering approach. With a focus on the future, the choice was to explore this new territory and today we can say the decision was the right one.

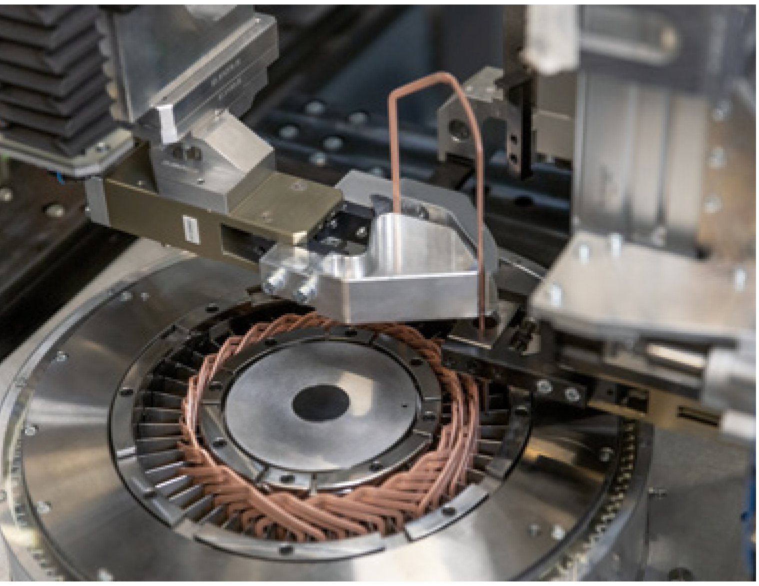
As has always been the case in over 30 years of **IMA EV-TECH – ATOP** history, process equipment must preserve some of the **unique characteristics** that have always distinguished our machines: they must be **innovative, flexible** and **compact** in design.

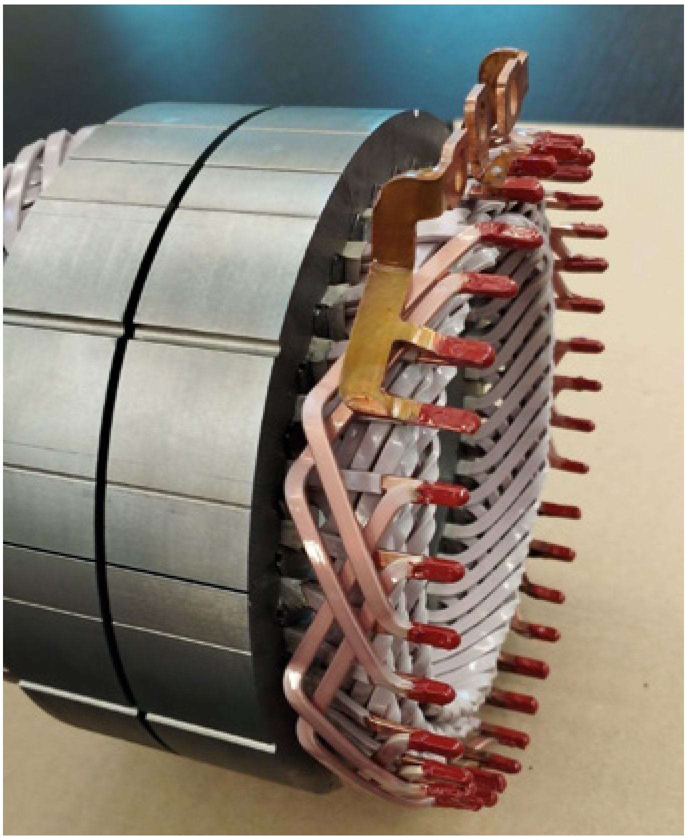
The main focus was on hair-pin forming process, considered the true key to the success of this new solution. The innovation requirement was met through the introduction of a CO_2 laser for enamel removal on the wire combined with a fully programmable 3D forming robot used to bend copper wire. This solution perfectly matched the second prerequisite of flexibility. In fact, like for the pin forming, all machines in the line had to be suitable for different products with varying dimensions, slot geometries, and conductors per slot.

The application of **QCO (Quick Change Over) technology** to the new machines in stage of development, appears as a perfect combination. New machines are born with the natural predisposition to receive different sets of tooling for different products. The idea was to have a complete tool installed in the machine with fixed references, requiring no fine-tuning or adjustments to start production. Given the high value of EV motor components, it was defined that, after all quality checks, the first part produced must be a good part. The presence of electric axes to control all process functions definitively helped engineers in their work.

With the experience gained in the electric motor manufacturing field, it was considered an added value to approach the third pre-requisite: compact design. We integrated the electrical and pneumatic cabinets inside the machine frame. Further on, we had chance to learn how automotive industry standards were different in this field. While Tier 1 and Tier 2 customers accepted this solution, OEMs required a more conventional external electrical cabinet. To satisfy both philosophies, today both configurations are available.

In over 15 years of experience with copper bar stators for e-Mobility applications, we have grown our experience thanks to the scientific approach always applied even through **a close cooperation of our R&D** with universities. Nonetheless, events and reaction of the





copper that initially appeared to be inexplicable, have gradually found their explanation. Experience taught us to define the copper "the alive material" because, like a chameleon is capable to change his characteristics so quickly and sometime without any apparent reasons.

Welding is keen while producing the hair-pin technology. From the very beginning the idea to use a mask to align the couple of wires was developed and applied. This solution was later abandoned in all those cases of high slot numbers and small diameters. Where it was preferred clamping by gripper. Today, the alignment by mask is made using a three-effect mask that allows to make tangential and radial wires alignment while providing axial containment.

The new mask, thanks to its reduced thickness, perfectly meets the needs of extremely short wire leads, those known in Asia as **"minipins"**. This is not a novelty, since we already have high-capacity lines in serial production with wire terminals below 6 mm in straight path.

The current state of the art is the ATOP machines generation that represent the **fourth generation of machines developed for hair-pin stator technology.** Maintaining the original pre-requisites, achievements of this latest generation, are the condensation of all experiences matured in those year, with higher process speed and productivity.

What about the future of e-mobility motor design? It is a widely shared opinion that hair-pin stators may represent a transitional solution toward a simpler and more cost-effective process.

Here at IMA EV-TECH, we continue to monitor developments and, just as we did 15 years ago, try to explore possible alternatives.

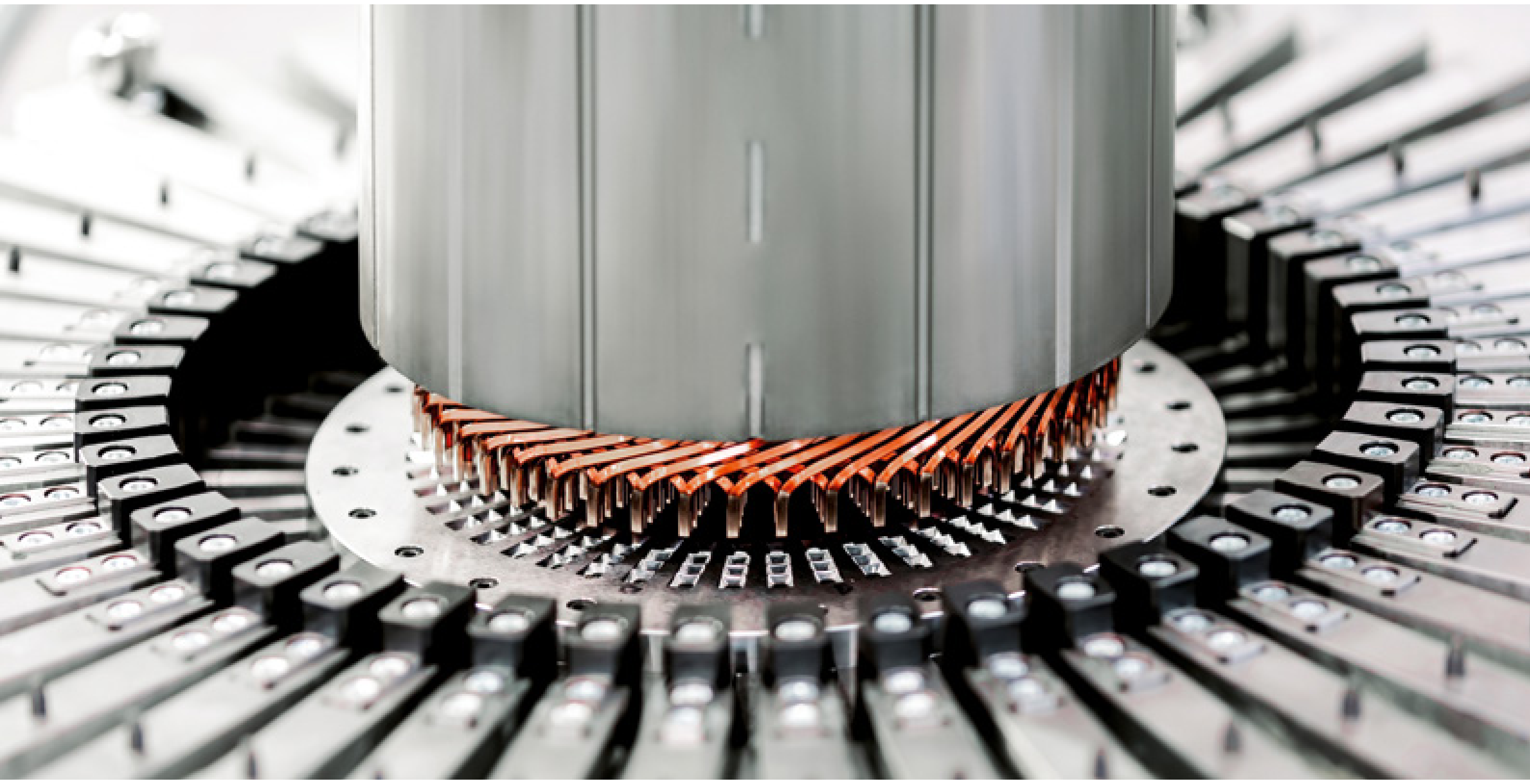
Wave winding, as it stands today, presents clear limitations in terms of motor design constraints, lack of process control, cost, floor space occupation of the production lines and difficulties in achieving a fully automated process.

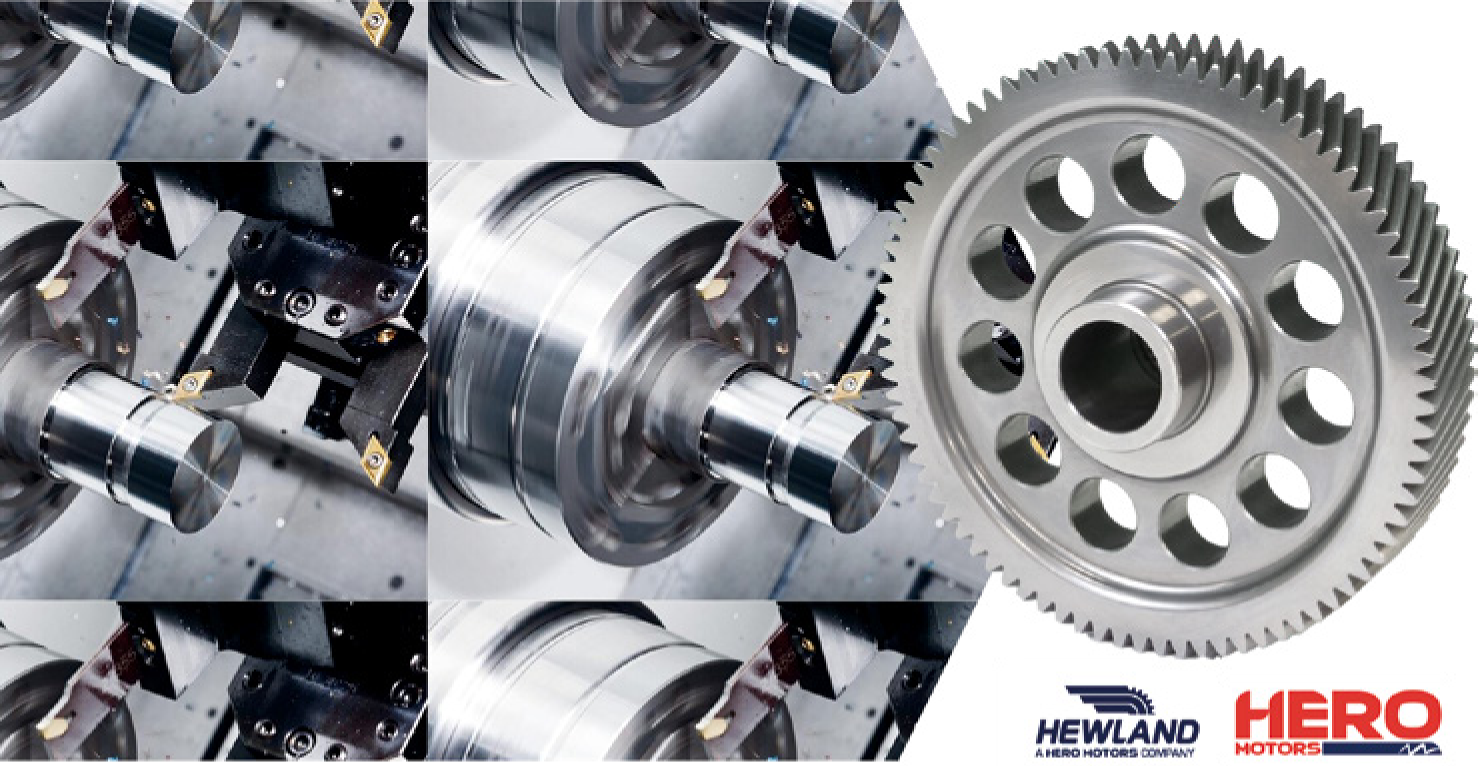
An interesting alternative to traditional wave winding is the **CFW** solution, acronym for **Continuous Flow Winding**. This technology was developed to meet the requirement of the motor from MAVEL. This already solved most of the criticality typical of a wave winding:

- Closed-gap inner diameter, because the insertion is made from outside
- Helicoidal slot profile, offering a well-distributed magnetic flow distribution and helps tremendously on having in a smooth wire insertion process
- Small waves development, that leads to compact footprint equipment. A complete line having the floor space occupation similar to an hair-pin stator line
- Low-height copper headers outside the slots, with crown height contained below 24 mm thanks to outer-slot insertion

Applications with Litz-wire have been developed in recent years, with flexible conductor used to wind single poles stators as well as rigid bars for hair-pin production.

It is hard to define what the future will bring, but one thing is sure: **IMA EV-TECH will be there supporting the growth of our customers.**





UK testbed for sustainable gear manufacturing: scaling to Indian volume production

Dr Agnes Ragondet, Group Sustainability Director, Hewland/Hero Motors.

This paper presents a sustainability-driven manufacturing initiative that leverages a UK-based pilot facility to develop, test, and optimise sustainable technologies in gear manufacturing with the objective to enable scalable implementation in Indian high-volume production facilities.

UK gear manufacturing market benefits from a strong industrial heritage and highly skilled workforce [1]. A focus on high quality products and high end applications are key drivers of the UK sector [2].

The UK gear manufacturing market is part of a broader £1.3bn bearing and gear manufacturing industry. The precision gearbox market itself generated $30.3 million in 2023 and is projected to grow at 3.4 % CAGR through 2030 [3].

However, high operational costs, wastes, labour expenses and pressure from raw material price inflation limits the overall advantages of UK manufacturing [4, 5, 6].

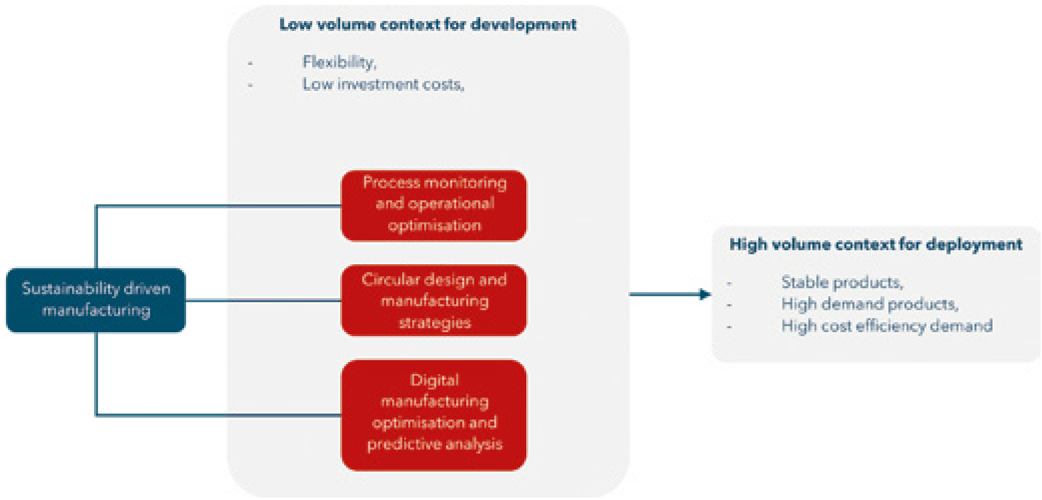


Figure 1. The drivers of sustainable manufacturing

In addition, the nature of low volume and custom-designed market leads to higher operational costs, highlighting the demand for greater efficiency and optimisation in both design & manufacturing processes.

The global gear manufacturing market is projected to increase by USD 137.8 billion at 8.1 % CAGR over the 2024 – 2029 period [7]. The market growth is fuelled notably by industrial expansion and increasing demand for high-performance transmission solutions across various sectors [8].

In India, price competitiveness is a major challenge for gear manufacturing, due to strong competition from low-cost producers abroad. Balancing competitive pricing with quality and profitability in high-volume production remains an ongoing challenge [9].

This paper demonstrates how a sustainability-driven approach to gear manufacturing can address these challenges and enhance efficiency using IoT and smart manufacturing technologies.

The initiative illustrates how implementing these practices within a controlled, low-volume manufacturing environment in the UK can facilitate the technology transfer to high-volume gear manufacturing industry in India.

Process monitoring and operational optimisation

Gear manufacturing is an energy-intensive process that generates significant amount of bi-product material waste.

On average at Hewland, a low volume manufacturing organisation, energy costs associated with gear and transmission production can account for up to 65 % of total factory energy costs, which includes heat treatment capability, while 40 % of the raw materials used in machining operations are lost as waste. In general, manufacturing sector is energy intensive and can consume up to 20 – 25 % of world's total energy [10].

Additionally, frequent tooling changes, small batch sizes, and customized new designs greatly affect operational efficiency, with up to 35 % of cycle time attributed to indirect production activities such as tooling setup, programming adjustments, and part inspections.

Finally, historical operational standards can lead to a significant increase in downtime, accounting for up to 50 % of an asset's total energy usage.

All these factors together contribute to a significant increase in the product's carbon footprint.

Figure 1 shows the drivers of sustainable manufacturing study.

Firstly, the case study involved integrating IoT and smart factory tools into each individual manufacturing asset to monitor and analyse productivity and efficiency through energy data combined with manufacturing operation management data.

It involved a physical energy monitoring and data collection device paired with a custom-developed intelligent tool for data processing and analysis.

The combined analysis of energy consumption data and manufacturing operations management software offered valuable insights into operational efficiency, revealing opportunities for both energy savings and performance improvement.

First key outcomes included:
- 20 % average asset downtime reduction
- 260,000 kWh reduction (16 % of annual consumption)
- 52tCO_2e reduction
- Greater process standardisation
- Optimised operational cost prediction

The in-house developed smart factory tool delivered precise data on the status of each manufacturing operation, enabling its use as a powerful digital twin to correlate asset and operational costs, and facilitating easy transfer to high-volume manufacturing cost predictions.

Circular manufacturing strategies

The next phase of the study focused on exploring circularity opportunities in manufacturing. Given the large volume of swarf waste generated during operations, it was crucial to identify ways to minimize waste while creating opportunities for material reuse.

The case study focused on components requiring a central hole to be machined in the steel bar. Two turning operation methods were assessed:

- A conventional process where the entire hole was produced by cutting through the material, converting all removed material into swarf.
- A more sustainable process using an optimised tool path that cut around the hole's perimeter, enabling the recovery of a solid steel piece that could be reused to manufacture another component.

The study revealed that cycle times could be reduced by 60 % to 90 %, depending on the hole size, cutting energy cost per operation by similar proportions, while waste generated per part decreased by up to 60 %.

Such simple but yet effective approach enables substantial material savings, particularly in high volume production. For instance, machining a 400cm^3 piece of steel using the perimeter tool path would save 15tons of steel and 29tCO_2e in a 5,000-part batch, allowing the recovered material to be reused for producing other components.

Sustainable design optimisation

The final phase of the study focussed on sustainable design opportunities, examining how design choices impact overall manufacturing costs, cycle times, material usage and product carbon footprint.

The component selected was a shaft with a primary wheel, originally manufactured as two separate parts welded together. This two-part design was compared with a redesigned single-part solution.

As shown in Table 1 the single-part design solution achieved a 51 % reduction in energy consumption, in-house cycle time and CO_2e emissions, while material wastage during production decreased by 11 %.

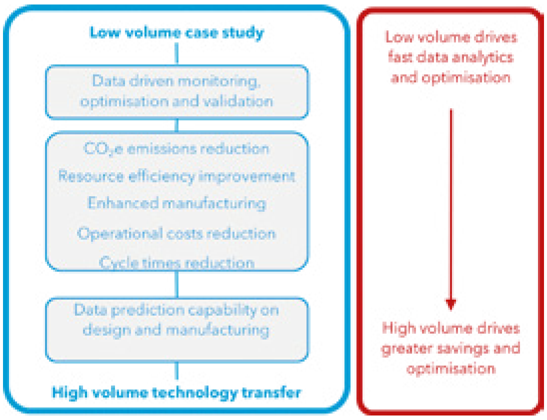
Note: the overall cycle time and cost of the two-part solution was greatly increased due to an additional welding operation that also sub-contracted.

The single-part design solution needed revision to account for a greater gap between the gears to allow for grinding operation. Although this process would not be necessary for motorsport application, it is essential for EV application in order to reach NVH requirements. High volume machining operations such as power skiving and gear honing are also considered to reduce the gap to a minimum while the choice of gear type, spur vs helical, can also impact the required distance between the gears.

All data are per part		Two part design		One part design	
Manufacturing operations	Energy cost (£)	£	291.84	£	143.66
Material	Waste generated (kg)		5.94		5.35
Carbon footprint from manufacturing operations	tCO2e		0.18		0.09
Carbon footprint of wasted material	tCO2e		0.01		0.01

Table 1. Comparison of energy cost, material wastage and carbon footprint between 1 part and 2 part design solutions

Overall, this case study demonstrates various opportunities for a more efficient and sustainable gear manufacturing approach that can be easily transferred from low volume to high volume manufacturing context as summarised in Figure 2. While low volume context allows for quick and flexible development, the high volume implementation allows for greater savings and optimisation benefits.



Manufacturing and design decisions can be influenced by a sustainability approach to be more energy efficient, more cost effective and generating a lower carbon footprint of the product.

Figure 2. Process and benefits of low volume case study to high volume technology transfer

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The automotive world has entered an era of unprecedented challenges and opportunities. The challenges have multiplied – from electrification and digitalization to sustainability and global supply dynamics. But with every challenge comes the chance to rethink, reinvent, and lead.

The CTI SYMPOSIUM is more than a conference – it's a catalyst for transformation. Our Start-up Area is where bold ideas take center stage, where pioneers share their visions to shape the future of mobility.

Meet the innovators who are redefining what's possible. Engage with the founders, explore disruptive technologies, and discover new pathways to success in a rapidly evolving landscape.

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Axialis
Axialis is a Croatian technology startup developing a next-generation axial flux electric motor featuring an innovative, patent-protected cooling system that outperforms existing technologies on the market. Our motor delivers higher power density, a more compact design, and reduced material consumption, while significantly improving efficiency and reliability. We have developed a fully functional prototype, and a European patent application confirms the originality and commercial potential of our solution. Axialis is laying the foundation for a new generation of electric motors designed for e-mobility, industrial applications, and energy-intensive systems of the future.
https://axialis.hr/

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Founded in 2019, Brudeli is at the forefront of developing multi-mode plug-in hybrid transmissions for commercial vehicles. Based in Hokksund, Norway, the team is demonstrating 50–80% fuel-saving potential and unique functionalities with its prototype 4×2 tractor truck. Leveraging extensive AMT development experience, Brudeli works closely with OEMs and major fleet operators to accelerate real-world adoption and integration. Strategic partnerships include Hexagon Composites, a global leader in clean fuel solutions, and LEAX Group, a key supplier of advanced transmission components. Serial production of the patented Brudeli Powerhybrid™ is scheduled to begin in 2029
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COAT-IT

COAT-IT is a technology company dedicated to developing advanced technologies for producing protective coatings tailored to the specific needs of our clients. We combine innovative research with practical applications to deliver solutions that enhance durability, performance, and environmental sustainability. In addition, we produce nanomaterial-based additives that improve the properties of surface treatments, addressing challenges related to resource efficiency and ecological responsibility. By integrating cutting-edge coating technologies with high-quality additives, COAT-IT provides comprehensive, client-focused solutions across multiple industries, including automotive, construction, and energy, supporting both product longevity and reduced environmental impact.

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Founded as a spin-off from TU Darmstadt, COMPREDICT combines academic excellence with industrial application. Its mission is to make vehicles more intelligent and sustainable by extracting maximum value from existing data, reducing hardware complexity and enabling the next generation of software-defined mobility.

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DiploAI is an AI-powered regulatory intelligence platform built for the automotive industry. It continuously monitors 10,000+ global, national, and local sources across 125+ jurisdictions, turning raw regulatory updates into translated, summarized, and product-mapped alerts. DiploAI explains what changed, why it matters, and which products and teams are impacted, and creates traceable tasks to drive action. Trusted by leading OEMs and suppliers, DiploAI helps teams avoid missed regulatory change, accelerate product launches, and cut compliance workload by 10x.

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Drive13

Drive13 is a Flemish technology company based in Belgium dedicated to accelerating E-motor innovation. Originating as a spin-off from Ghent University, Drive13 (formerly USP3D) specializes in pioneering winding systems, smart use of 3D printed aluminum, and advanced thermal management components for high-performance and sustainable electrical machines, with key applications in racing motors, aerospace, and other high-speed drive systems.

https://www.drive13.tech

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Hyperdrives

Hyperdrives is a pioneering deep-tech engineering company revolutionizing how we design and build electric motors. Hollow-conductor-enabled super-efficient, extremely power-dense, and exceptionally cost-effective electric motors without rare-earth elements increase range and reduce cost by up to 50 %. Hyperdrives' proprietary motor design is based on industry-standard materials and components only, and their patented manufacturing technology can seamlessly be integrated into the existing automotive hairpin production lines. With this, Hyperdrives aims to establish a new global gold standard for electric motors in cars, trucks, eVTOLs, and boats within the next 5-7 years.

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https://go.tugraz.at/oped

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Theissl Systems
THEISSL Systems ist ein Hightech-Messtechnikunternehmen für Automobilanwendungen. Die Kernkompetenz unseres Unternehmens liegt in der Forschung, Entwicklung und Produktion von minimal-invasiven drahtlosen und kabelgebundenen Sensorsystemen zur Temperatur-, Durchfluss- und Flüssigkeitsverteilungsmessung für die Automobilindustrie.
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Vaionic Technologies
Vaionic specializes in the design and development of high-efficiency E-Drive systems based on the unique stator-ironless axial flux motor technology. The ironless stator design eliminates electrical steel, resulting in a lighter, more efficient, and recyclable drive with a lower CO_2 footprint. This design approach delivers exceptional performance where size, weight, efficiency, and cost matter most. While the current focus is on E-Mobility, the technology is suitable for diverse applications – from land to air and wind generation.
http://www.vaionic.de

Yeesma
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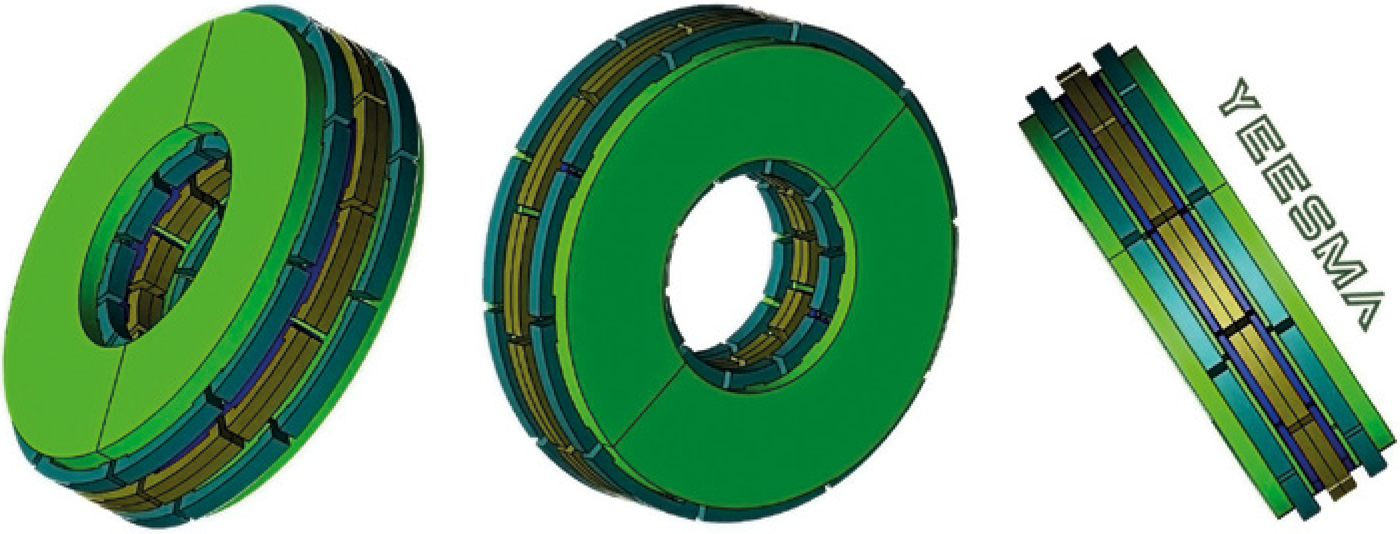
Besides our Motors having no rare-earth magnets eliminate the Supply chain risk and Sustainability issues due the Rare-Earth, being Heavy like Dysprosium or Light like Neodymium.
YEESMA can provide significant Cost reduction from 30 to 70 % Bill Of Material while Providing 50% to 70 % CO_2 reduction, index of high Sustainability index. This is obtained in combination of ~20 to 30 % Volume reduction which makes such Machine an eMobility DREAM: Cost, CO_2 and Packaging.
https://yeesma.com/index.html#/



Boosted Sustainable Electrically Excited Synchronous Motors

Dr-Ing. Philippe Farah, CEO – Founder YEESMA SARL

Dr-Ing. Shafigh Nategh, CTO – Founder, YEESMA SARL

Yu-Chi Tsai, Business Development & Marketing, YEESMA SARL

Electrically Excited Synchronous Machines (EESM) is one of the strong candidates to solve the supply chain risks, costs and sustainability issues due to the Rare-Earth magnets presently used in almost 90 % of the Traction Motors. However, for long, EESM presented lower Performances, especially in terms of Torque density: approximately 10 to 20 % bigger volume required combined with Lower Efficiency (down to 3 %) compared to Radial Flux Interior Permanent Magnets solutions considered as today's Benchmark.

Introduction and Objectives:

YEESMA combined 2 major concepts into what's called YEESMA that stands for Yokeless (Yoked) Electrically Excited Synchronous Machines. This Proprietary solution consists of an Axial Flux AND Electrically Excited Topology. Preferred topology is a Dual Rotor, Single Stator that helps solving the Packaging and Performances challenges: up to 20 % Torque volumetric density, with more than 60 % Bill Of Material (BOM) cost reduction AND 60 % Higher Sustainability Index.

	Radial Flux IPM	Radial Flux EESM	Axial Flux IPM	YEESMA
Description	IPM rotors contain powerful, usually rare earth (REE) permanent magnets	EESMs have rotors with wound copper coils instead of magnets	Axial Flux instead of Radial Flux, → improves Compactness	Best of Radial Flux EESM and Axial Flux worlds
Sustainability	High amount of REE Permanent Magnets High amount of Copper High amount of Lamination Steel **→ Less sustainable**	No REE permanent magnets Higher amount of Copper High amount of Lamination Steel **→ Sustainable**	Higher amount of REE Permanent Magnets High amount of Copper Use of SMC instead of steel laminations **→ Least sustainable**	No REE Permanent Magnets Reduced amount of copper Use of SMC instead of steel laminations **→ More sustainable**
Efficiency	Superior low-speed efficiency have propelled it to dominance in EV mobility	Low-speed efficiency are mostly offset with superior high- speed efficiency	Same than Radial Flux IPM	Low-speed efficiency are mostly offset with superior high- speed efficiency
Compactness	High power density	High power density	Highest power density	Higher power density
Cost	IPMs are expensive due to the REE materials required to provide high-power density and temperature resistance	Large net savings from magnet elimination are only partially offset by rotor winding costs	Expensive due to the increased REE magnets & Manufacturing costs (Axial Force, PM Losses, etc ...	Large net savings + High volume production design → Lower Costs

Figure 1: Topologies Comparison

Inverter Phase current is also significantly reduced thank to a Unity Power Factor and participates to the 60 % Cost reduction mentioned above.

YEESMA Technology

YEESMA solution is an Axial Flux based topology. Preferred solution is typical Single Wound-Stator sandwiched between 2 Wound-Field Rotors. Note that intrinsic to Axial Flux, inner diameter areas being "empty", YEESMA can incorporate there both Position Sensor and Rotor Power Supply (being Brush type, or Brushless Inductive Transformer).

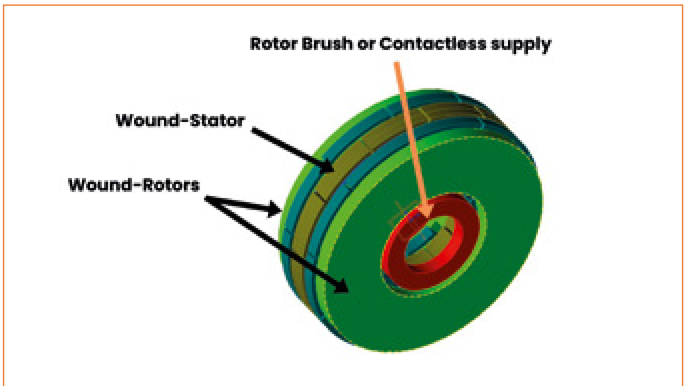


Figure 2: YEESMA Technology

Development Methodology

YEESMA developed their own FEA & Optimization models to reduce development time while still keeping "Digital-Twin" approach: Define at best all requirements' details, from Performances outputs through Environment Specifications, like e.g. Air Cooling requirements for a 2-Wheelers or Oil-cooling specifications for a Truck Application. Our Approach heavily relies on conducting thorough Simulation Analysis before building Hardware parts. Such optimization process through a 3D-FEA Electromagnetic analysis is shown hereafter:

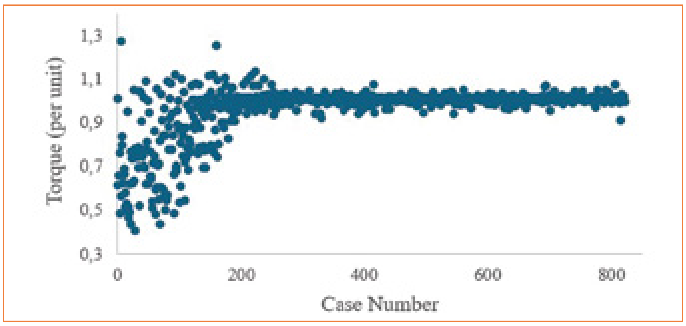


Figure 3: Optimization Process

The genetic algorithm progressively concentrates the population of candidate designs in the performance-optimal region of the search space.

Case Studies Results

Several Case Studies were conducted following same “Digital Twin” process. For simplicity and confidentiality reasons, only 4 cases studies are presented here.

For each case, we used CO_2 footprint as a Sustainably Quantifier. This is done through summing up for each design material amount (active parts only), mostly Steel, Copper or Aluminum, and rare-earth permanent magnets for Benchmarks solutions.

Figure 4: YEESMA Case Studies Results

Proof Of Concept Experimental Results

To further validate all our design tools, YEESMA designed, built and tested its own Proof Of Concept Hardware [1] – [2]. This has been done through the Department of Engineering “Enzo Ferrari”, University of Modena and Reggio Emilia (Italy).

Picture hereafter shows (manually) wound rotor.

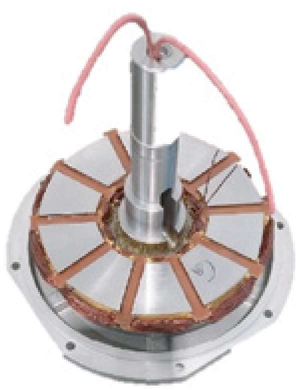


Figure 5: YEESMA Wound-Rotor

Whole tests were conducted on a dynamometer setup, with an external drive capable to provide both Stator Armature AC currents and Rotor field DC current.

Thorough analysis was done at first at no-load comparing theoretical BACK-EMF and measured voltages at various excitations levels. Exceptional confirmation was obtained through the whole excitation current range. Figure below measured data at 2000 rpm and 6.0A (considered as nominal excitation current)

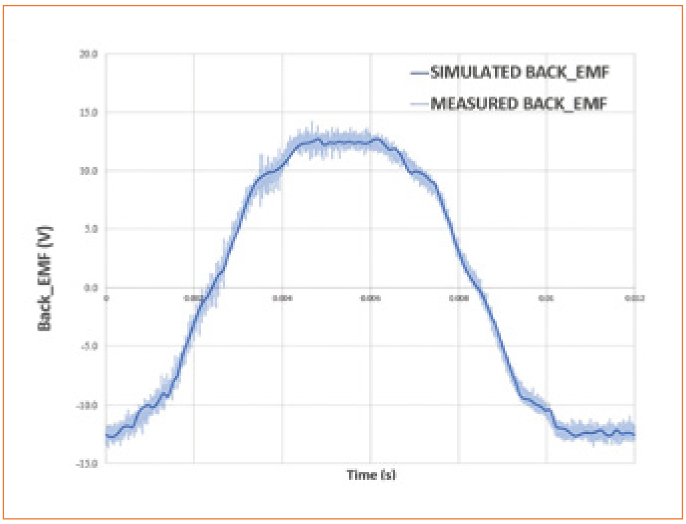


Figure 6: Comparison between Measured and Simulated Back-EMF

Load-tests focused first in the Continuous Torque/Speed area and shows as well very good fit between FEA Simulation and Experimental Results. Less than 5 % difference can be reported up to 1.6 times Maximum Continuous Torque

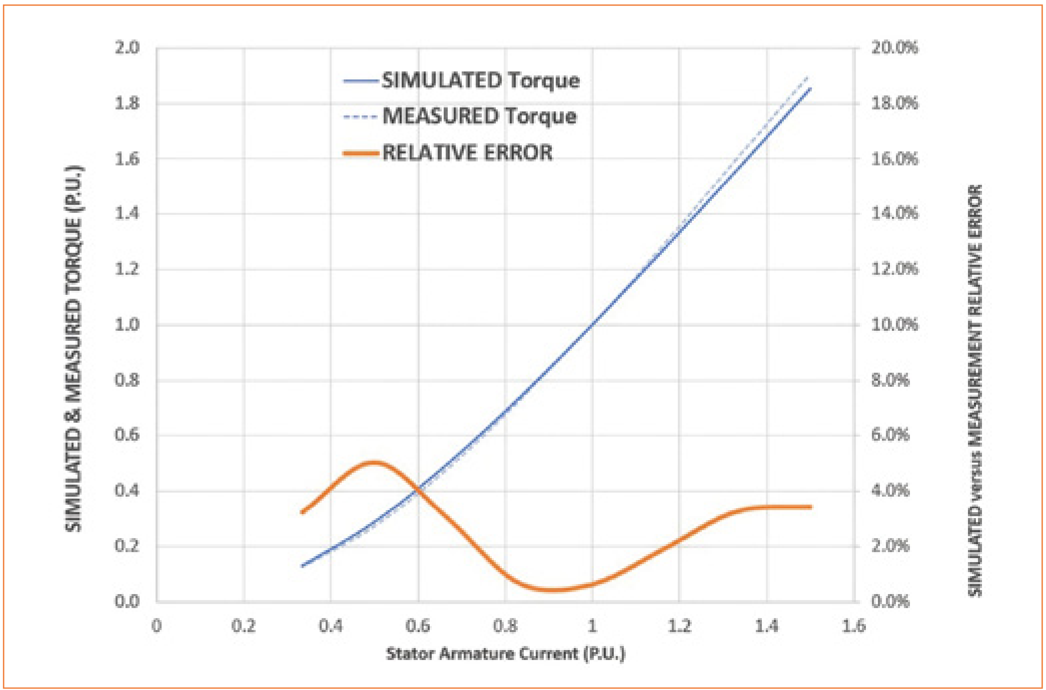


Figure 7: Comparison between Measured and Simulated Torque

Conclusion

This study has presented the Yokeless Electrically Excited Synchronous Machine (YEESMA) as a viable, high-performance, and sustainable alternative to conventional rare-earth permanent magnet machines. By eliminating the need for rare-earth materials and transitioning from a radial flux to an axial flux configuration, the YEESMA topology achieves significant reductions in copper usage, weight, and raw material demand, while maintaining competitive torque and power density. In addition, the proposed design achieved close to unity-power factor, it significantly reduces Inverter current demands and participates to the Overall Cost reduction.

Further development work will focus on the Manufacturing axis with Production-intend designs developed with an Industrial Partner.

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[1] V. Mangeruga, A. Piergiacomi, S. Nategh, P. Farah and S. Nuzzo, „Structural Investigations on Yokeless Electrically-Excited Segmented Armature Axial Flux Motor," 2025 IEEE Workshop on Electrical Machines Design, Control and Diagnosis (WEMDCD), Valletta, Malta, 2025, pp. 1-6

[2] Design Optimization and Experimental Validation of an Innovative and Sustainable Electric Machine Topology," in IEEE Transactions on Transportation Electrification, Oct. 2025. (Submitted)

Proposal of Next-generation HEV System

Kazuyoshi Hiraiwa, President, FINEMECH

Shinji Morihiro, Representative, M Powerlabo

Background of the proposal

In recent years, the problem of BEV has become apparent, and the value of HEVs has been reevaluated. Under these circumstances, we would like to propose a next-generation HEV system.

Purpose of the proposal

This proposal is based on the THS (Toyota Hybrid System). This is because the THS is superior to the series model in terms of power transmission efficiency as an E-CVT. The THS used in the Prius is simple system but it is generally said to have problems with starting acceleration performance and high-speed fuel economy. Looking at the specifications of the Prius, in order to ensure starting acceleration performance, the capacity of the MG2 (Motor Generator 2) for driving in recent models is larger than that of the initial model. However, the increased capacity of the MG2 makes to a deterioration in high-speed fuel economy. On the other hand, Toyota has added a four-speed automatic transmission planetary gear mechanism to the THS for LEXUS to improve both fuel efficiency and acceleration performance. However, this can only be applied to FR cars due to the axle length.

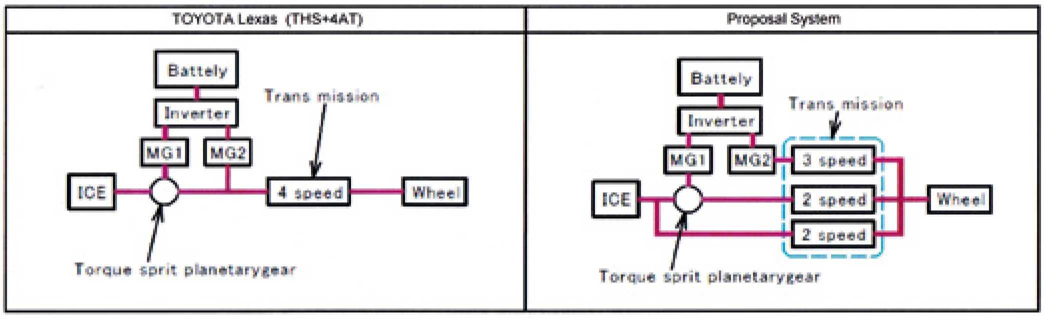

Figure 1 : Comparison THS+4AT and Proposal System

This proposal aims to improve fuel efficiency and acceleration performance by applying a dog-clutch parallel-shaft transmission mechanism to the THS, while also realizing a configuration that can be installed in FF vehicles. (see Figure 1)

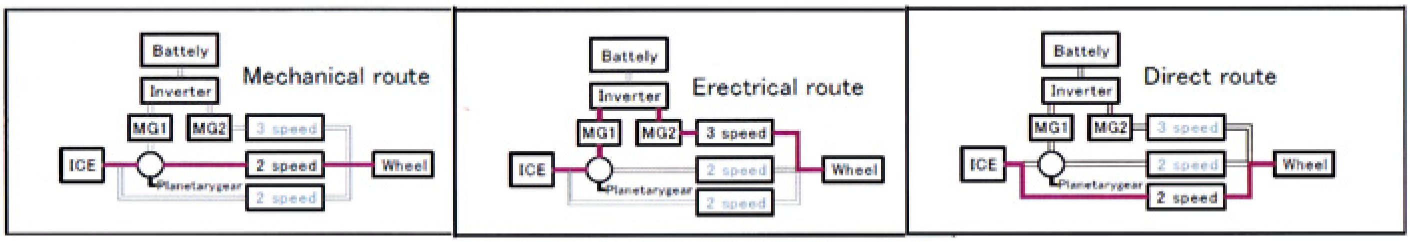

Figure 2 : Explanation of Mechanocal route, Erectrical route and Direct route

Proposal Overview

The power transmission route between the ring gear and the output shaft of the planetary gear for torque division is the „mechanical route“ (M route), and the route that transmits power from the sun gear to the output shaft via MG1 and MG2 is the „electric route (E route)". If the route between the input shaft and the output shaft is a „direct connection route (D route)", a dog clutch type transmission mechanism is provided for each route (see Fig. 2). That is, there are only three sleeves. Normally, both the M route and the E route are transmitted as an E-CVT, but when switching from H-1 to H-4, which will be described later, the gear is shifted through the D route to avoid loss of output shaft torque when driving on one route while driving on the other route, and when shifting under high load.

Main specifications (examples)

M-route gear ratio
(ring gear – output shaft)
Lm: 2.590
Hm: 0.867

E-route gear ratio
(MG2 drive shaft – output shaft)
The: 2.590
Me: 1.593
He: 0.867

D-route Gear Ratio
(Input Shaft – Output Shaft)
Ld: 1.593
Hd: 1.138

MG capacity (at ICE power 1) is assumed as follows: This takes into account that if the input shaft is fixed and used as a PHEV, the driving force equivalent to that of an ICE can be obtained. Also, the specs of the early PRIUS were almost this ratio.

MG1 0.4
MG2 0.6

Basic rule of Sleeve switching (Dog clutch)

Torque is set to 0 and the engagement is related, and the engagement is carried out with a speed difference of 50rpm or less.

Operation

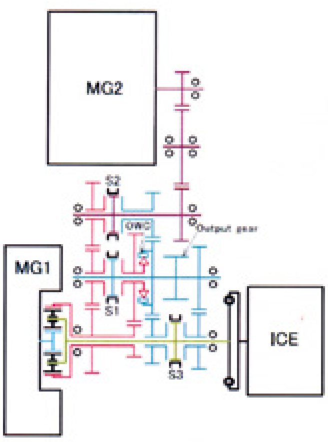

Figure 3 : Skelton Diagram

2+2 and 3M-3 FF 251018

Drive mode		S1	S2	S3	OWC	MG1	MG2	M,D ratio	M-Point	MG2 ratio
EV mode	E-1	--->	<---		#		D/G			2.590
	E-2		--->				D/G			1.593
	E-3	<---	<---				D/G			0.867
HV mode	H-1	--->	<---		#	G	D	2.590		2.590
	H-2	--->	--->			G	D	2.590	1.850	1.593
	D-1		--->	<---				1.593		(1.593)
	H-3	<---	--->			G	D	0.867		1.593
	D-2		<---	--->				1.138		(0.867)
	H-4	<---	<---			G	D	0.867	0.619	0.867

: Possible Engage

M-route ratio : Ring gear-Output
D-route ratio : Input-Output
MG2 ratio : MG2 drive shaft - Output

High Efficiency drive	Ratio	Step
H-2(M)	1.850	1.161
D-1	1.593	1.400
D-2	1.138	1.837
H-4(M)	0.619	

Figure 4 : Operation Table

First, we will explain the shifting operation of the E-CVT in HV mode. If the sleeves are S1, S2, and S3, then the H-1 is a combination of the M route (S1) and the E route (S2) with Lm and Le. Switching from H-1 to H-2 is done as follows: When driving on Lm on the M route, the MG2 torque is reduced to zero at the mechanical point (when MG1 stops), making it easier to switch the E route from Le to Me, and the output torque can be shifted without change. That is, the switching from H-1 to H-2 is carried out with gear ratios near the mechanical point of H-1.

Also, switching between H-2 and H-3 is done through the D-route Ld (D-1). In other words, if the gear ratio is equal to the value of Ld while driving in H-2, the speed of the S3 and the opponent's gear matches, so it is easy to shift S3 and switch to D-1 at this point. S1 and S2 can be freely operated while driving in D-1, so if you revive the power generation of MG1 and the drive of MG2 by connecting H-3 in the operation chart, it will switch to H-3. This can also be done without any change in output torque.

Similarly, it is easy to switch from H-2 to H-4 via D-3. You can switch in the same way in these reverse orders.

In addition, the above switching is done with a fixed gear ratio, but especially in low to medium load driving, it is possible to switch without the drive of the D-route in any gear ratio. This means that you can drive on one route, M route and E route, while switching between the other. In this way, in low- to medium-load driving, it is possible to switch between any gear ratio without little change in output torque..

Kickdown

If you press the throttle pedal sharply while cruising on the H-3, follow these steps:
When the ICE power is increased and the gear ratio is equal to the value of D-1, switch S3 to Ld (D-1) and operate S1 and S2 to switch to the desired drive mode while driving with D-1.

If you press the throttle pedal sharply while cruising on the H-4, follow these steps:
When the ICE power is increased and the gear ratio is equal to the value of D-2, switch the S3 to Hd (D-2), and operate the S1 and S2 to switch to the desired drive mode while driving with D-2.

Of course, if the amount of throttle pedal depression is not very large, you can switch at any gear ratio by switching while driving on either the M route or the E route mentioned above.

MG1 & MG2 Stops

It is widely known that power loss due to dragging torque of MG1 and MG2 occurs when the ICE stops at medium or high speeds, or when MG2 is driven at low load at high speeds. The system allows MG1 and MG2 to be stopped as needed. (See Figure 5)

This means that if the ICE stops while driving at medium to high speeds, you can stop MG1 by putting S1 in neutral. If you want to revive the connection of MG1, rotate MG1 to synchronize and shift S1 again. In addition, the gear ratio near the mechanical point of the H-4 and the low-load high-speed driving on the D-1 and D-2 can keep the MG2 at a standstill if the S2 is neutral. This avoids loss of drag torque and improves fuel economy.

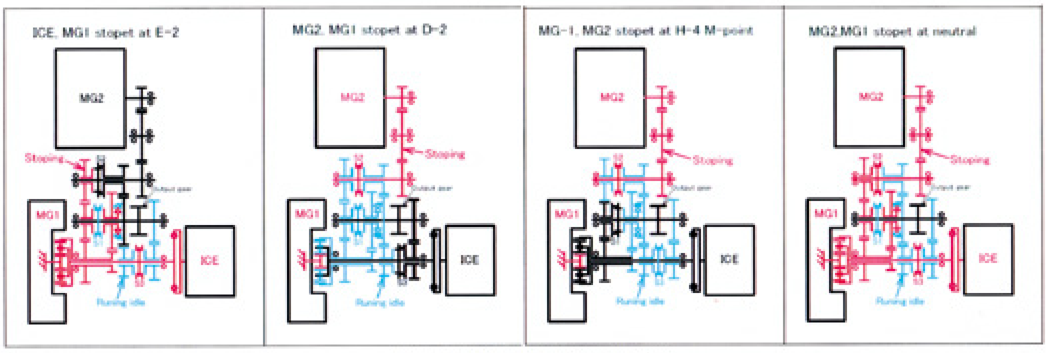

Figure 5 : MG1,MG2 stopping situation

Application to PHEV

As is well known, PHEV is established by increasing the battery capacity and providing a means to fix the input axis, allowing MG1 to participate in driving in addition to MG2 in EV mode. In this case, by driving one of the M routes and the E route while switching between the other using the same method as above, you can switch between EV mode while preventing loss of output torque. This means that it is possible to smoothly switch between the MG2's three-stage drive and the MG1's two-stage drive without losing drive torque. Of course, this is when switching, not to mention that after the switch is complete, you can drive both MG2 and MG1, or even one of them. It can also be driven by stopping one side, allowing for a variety of drives.

Advantages of this system

- The multi-stage THS reduces the capacity of the MG2 while ensuring acceleration performance in the low speed range and driving torque during reverse driving.
- In HV mode, the drive mode can be switched without changing the output torque. Moreover, in medium and low load driving, it can be switched with any gear ratio.
- No oil pump or friction clutch required.
- MG2 and MG1 can be stopped when it is not needed.
- By reducing the size and stopping of the MG2, fuel efficiency can be improved by about 6 ~ 8 % during high-speed cruising.
- When applied to a PHEV, it makes EV mode driving in multiple modes to achieve smooth shifting.
- While having the above functions, it fits into a size that can be installed on an FF car.

		Proposal system	Renault e-Hybrid	THS+4AT
1	Multi steps（HV mode)	4+2 mode	4+2 mode	4 mode
2	CVT driving at engine full power	○	△	○
3	Smoothness of shifting	○	○	△
4	Need of oil pomp and clutch	○	○	×
5	Driving on MG2 stop	△	○	×
6	Application for FF vshicle	○	○	×

Figure 6 : Comparison (Proposal vs Renault vs THS+4AT

When compared to the THS+4AT and Renault systems, we can see that this system has many advantages. (See Figure 6).

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- TOYOTA Hybrid System, Development of Multi Stage Hybrid Transmission , K. Okuda, Y. Yasuda, M. Adachi, A. Tabata, H., Suzuki, K. Takagi(Toyota), T. Atarashi, R. Horie (Aisin AW), 2017 SAE World Congress, No.2017-01-1156 (2017/4/4-6)
- Renault HEV System, The new DHT from Alliance Renault/Nissan, Antoine Vignon (Renault FRANCE), CTI Symposium 2017 Berlin

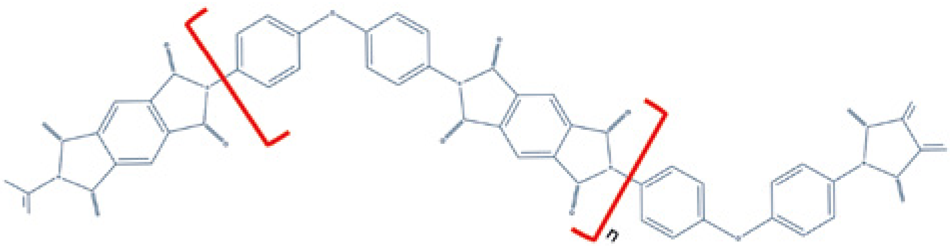
A New Material Solution for Low Wear, Low Friction, and Electrical Insulation in Automotive Transmissions

Geoff Lewis, Technical Director, Duvelco

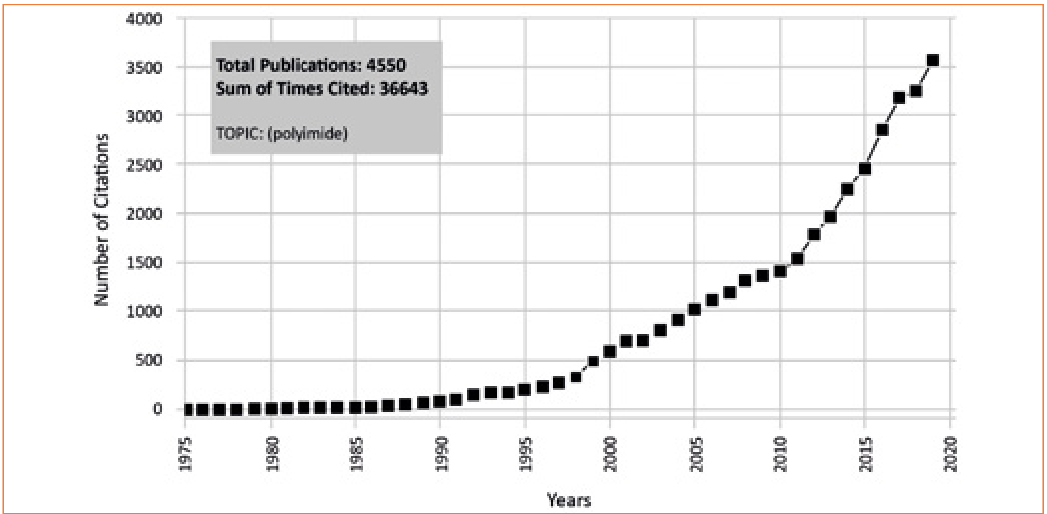
What is a New Material?

Being ‘new’ is claimed with some regularity in the world of polymers; however, step changes in performance are less frequent. Here, I am going to look at an innovation that may pass the test and rightfully be called a new material. The polymer in question has the trade name Ducoya.

In terms of chemical type, it is a semicrystalline thermoplastic block copolymer bearing the unfamiliar name PMDA-ODA or, in long form, PyroMellitic DiAnhydride – 4,4‘-OxyDiAniline. The repeat unit is shown below:



This is a polyimide with an ‘I’; not a polyamide. Polyimides are a vast and rapidly growing class of polymers. The number of polyimide papers written annually has exploded in recent years. Polyimides include thermosets, thermoplastics, amorphous, semicrystalline, and photo-imageable materials.



The above graph shows the number of papers regarding polyimide. Source: Researchgate – Number of citations per year from 1975 to 2019, Web of Science.

Some may recognise this molecule as being from the 1960s; however, that is not the new part. This molecule, initially developed for NASA's space programme, has long seemed too difficult to source and too expensive for many automotive applications.

This is especially the case as the industry moves into an era of cost-competitive BEVs, and, from a European and North American perspective, an era of low-cost, possibly subsidised Chinese BEV imports to compete with.

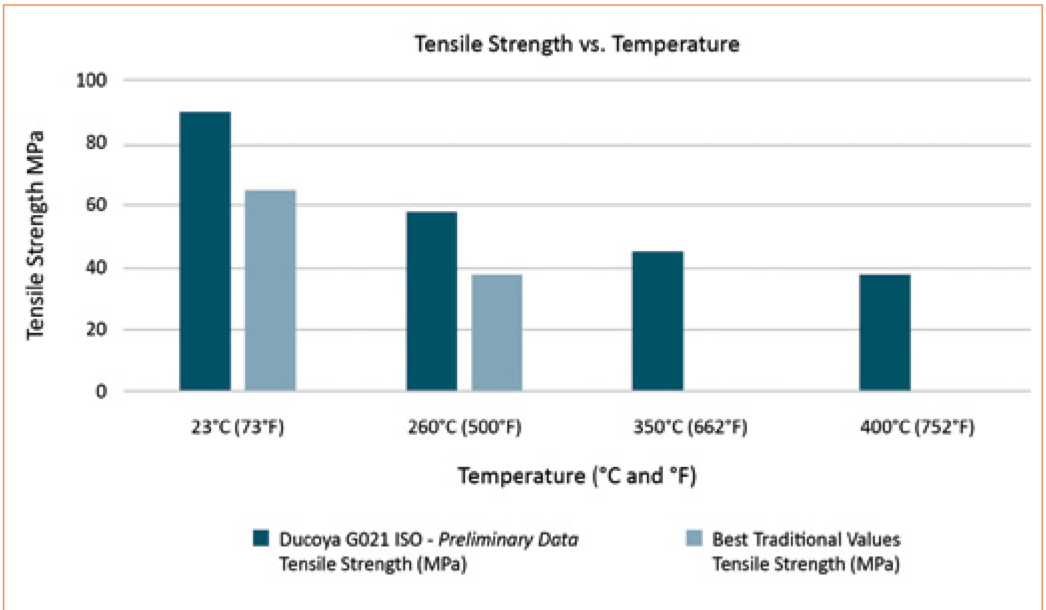
So, if it isn't the molecule, what is new?

The innovation here is a new, patented manufacturing process that also covers the resulting material. Many high-performance plastics, including those produced by the traditional PMDA-ODA Manufacturing method, utilise monomers dissolved in harmful, high-VOC solvents. The environmental and high-cost considerations of these solvents mean they must be separated, distilled, and reused, consuming a large amount of energy in the process.

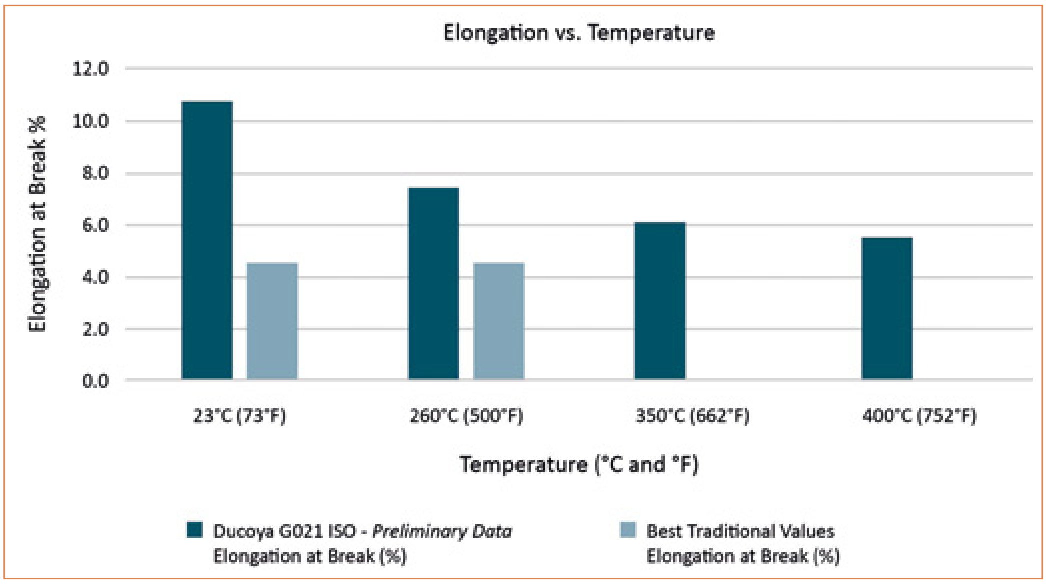
Ducoya avoids most volatile solvents used in the process and instead employs supercritical carbon dioxide and a catalyst.

Therefore, it is straightforward to separate the polymer from supercritical carbon dioxide by lowering the pressure. The carbon dioxide is repressurised and stored for reuse. This single step greatly streamlines manufacturing at scale, making the polymer considerably more accessible for automotive applications.

However, this is not the end of the story. While the original aim of the invention was to simplify manufacturing at scale, when the properties of the resulting polymer were compared with those of its traditional predecessors, something remarkable emerged – dramatically improved mechanical and tribological properties.



The above graph consists of Ducoya preliminary data – arithmetic mean of five specimens, and best traditional values taken from published datasheets, none of which reported data over 260 °C.



The above graph consists of Ducoya preliminary data – arithmetic mean of thirty specimens, and best traditional values taken from published datasheets, none of which reported data over 260 °C.

Datasheet[1]

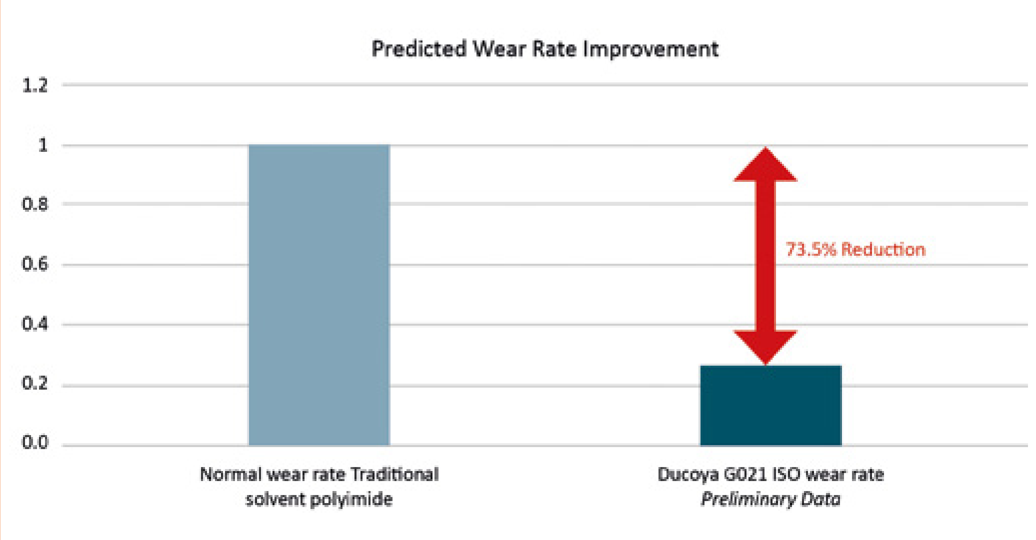
Ducoya G021 ISO is a filled version of Ducoya, containing 15 % wear- and friction-optimised graphite. Initial investigations of tribological properties in dry conditions indicate a significant improvement in wear factor compared to the best traditionally produced polyimides of this type. While much work remains to be done with this specific molecule, this result seems to confirm earlier work by Irisawa et al. on several polymers, showing that the wear rate is inversely proportional to the product of tensile strength and elongation.

Of particular importance is the continued performance of this molecule at significantly elevated temperatures. This is because, when dry friction occurs – whether by design or due to off-design operation under adverse conditions – temperatures on the wear surface can rise substantially compared to the bulk material. For instance, regular operation at 120 °C can quickly lead to temperatures exceeding 240 °C on the wear surface under harsh sliding conditions (High PV value).

	Ducoya G021 ISO	Best Traditional Values
Tensile Strength at 260 °C (MPa)	57.9	37.9
Elongation at 260 °C (%)	7.4 %	3.0 %
Product Tensile Elongation t·ε	4.28	1.14
Predicted Reduction in Wear Rate	73.46 %	

It should be noted that this general hypothesis applies only to materials of the same type (in this case, PMDA-ODA polyimides) and only when tested under identical conditions. Further work will determine whether this prediction holds for Ducoya G021 in comparison with other PMDA-ODA polyimide polymers.

[1] DuPont Vespel® SP-21 ISO Reference No. VPE-A10863-00-B0614 published 2010 and 2021.



Why would this be important to Battery Electric Vehicles?

As BEVs increase in torque, while package space and cost must decrease, this can lead to higher PV values as the available load area diminishes. This also reduces the weight of single-speed and multi-ratio transmissions. Epicyclic transmission layouts may particularly benefit from this improvement.

Furthermore, Ducoya, being wear-resistant, although still relatively soft compared to metal, allows metallic debris, such as burrs and wear particles from gears, to embed in its material and be removed as contaminants from the lubricating oil. While this embedding must be limited, removing metallics before they can interfere with the proper functioning of the electric motor – often sharing the same lubricating oil as the transmission – can only be beneficial.

Conclusion

An interesting new material that adds a new dimension to accessibility and performance in automotive applications. Here, we have focused on mechanical and tribological properties.

Future Work

Future publications will describe why this unusual and newly applied process using supercritical carbon dioxide should lead to such improved mechanical and tribological performance.

Opportunities arising from the resulting electrical performance in conjunction with the latest high-precision moulding techniques will be highlighted.

In addition, test results will be published in which the relationship between t·ε[2] and wear rates in various situations, as described above, will have been investigated.

[2] t·ε Tensile Strength vs. Elongation at break.

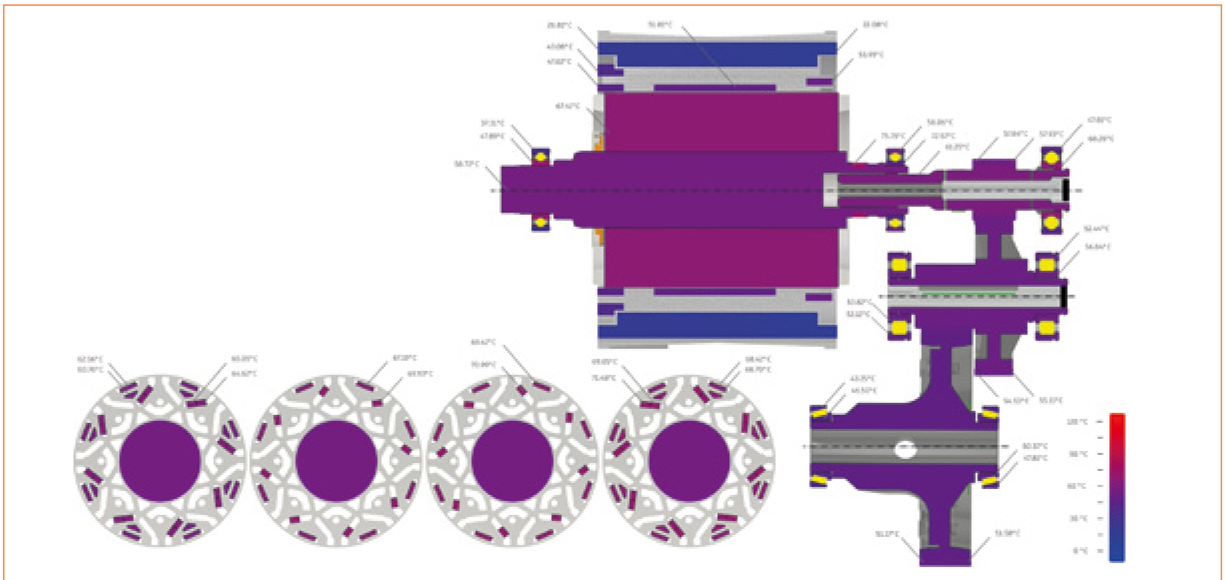
Best-in-class Thermal Assessment of Electric Powertrain

Mario Theissl, CEO, Theissl Systems GmbH

THEISSL systems enables precise measurement of temperature and torque in electric drive units with its minimally invasive sensor telemetry technology that is tailored specifically to each customer application. These systems can be seamlessly integrated into existing drive components with minimal need for system modifications, allowing for highly accurate measurements under real-world test bench and vehicle conditions.

With project-specific telemetry units for E-machine rotors gearbox shafts and clutches, the original characteristics of the DUT are inherently preserved while making optimal use of the available installation space. All systems are entirely contactless, transmitting wirelessly to the evaluation unit to ensure reliable performance on high-speed rotating components..

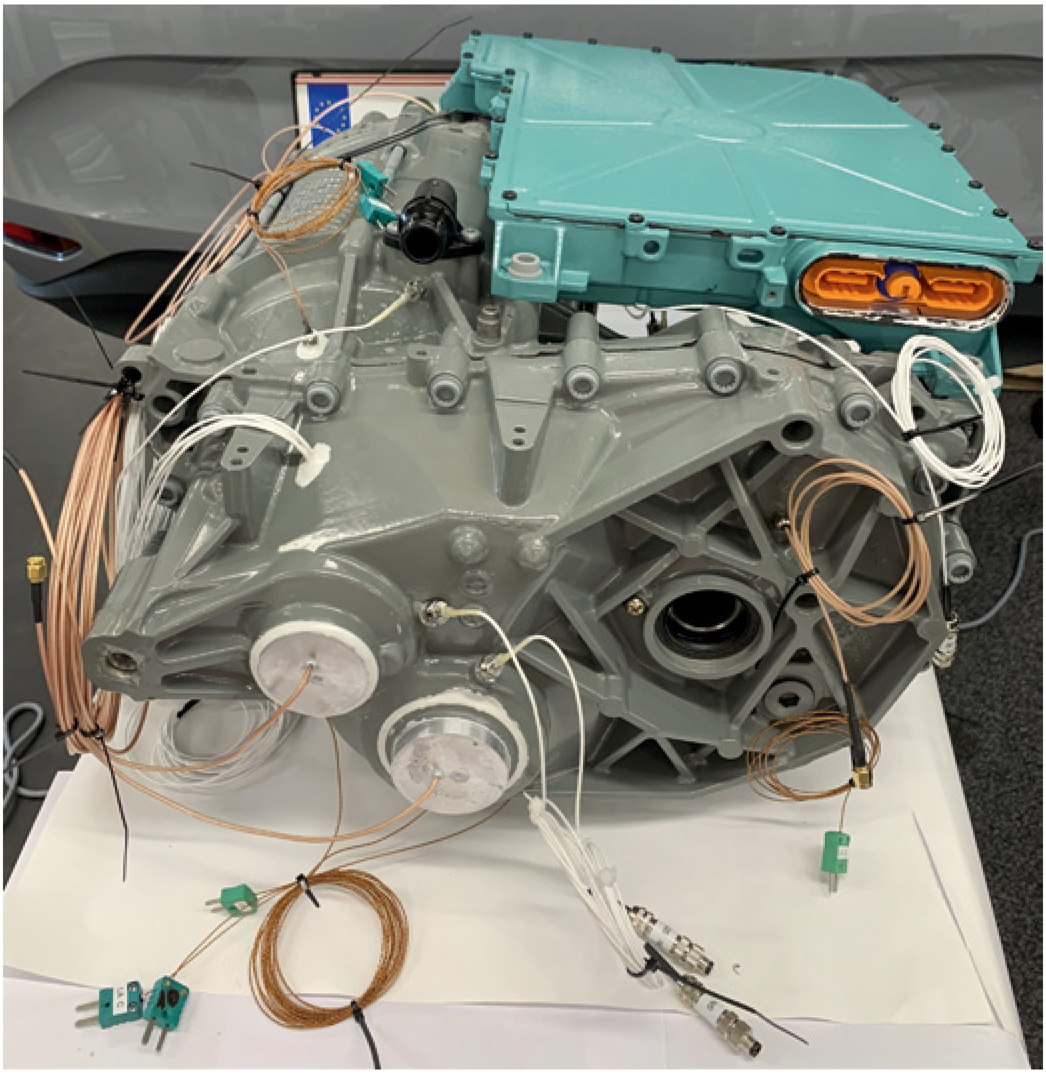
At the core of thermal EDU characterization is the choice of the right sensor elements. Therefore, as a full-service partner, THEISSL systems supports the entire measurement process starting from the definition of test points and the selection of suitable sensors all the way to data analysis after a successful test run.



Even in demanding applications, such as rotor temperature measurements in electric drives, up to 32 thermocouples can be used to gain vast knowledge of the thermal behavior of the DUT. Another variant of our telemetry boards is just 10.5 mm wide, foldable, and bendable around tight radii, which enables temperature measurements on gear teeth and bearing inner rings on transmission shafts. Furthermore, it could be mounted on the rotor shaft, for gearbox input torque measurement e.g. to determine system efficiency.

This measurement technology was implemented in a VW ID.3 demonstrator vehicle, which is showcased at CTI 2025 in Berlin. The system captures inner and outer bearing ring temperatures, gear tooth temperatures, as well as torques at the gearbox input shaft and side shafts. In the E-drive rotor temperature measurement, a telemetry system capturing 16 individual test points was complemented by four additional sensors on the stator windings, giving unprecedented insights into the thermal behavior of the vehicle's drive train.

This data, collected over more than 10,000 km of test drives then formed the basis for the training of a Thermal Neural Network (TTN) modelling the thermal behavior of the E-machine. Due to the large number of temperature measurement points, the temperature estimator for the rotor magnets achieved a highly respectable accuracy of ±1.5 K.



Application example: Thermal testing of the electric drive unit of the VW ID.3

From Lab to Exhaust: A Startup's Breakthrough in CO_2 Transformation

Alicja Stankiewicz, CTO, Coat-It

Marek Turkiewicz, CEO, Coat-It

Pollution kills more people globally each year than war, hunger, or disease. And at the heart of this crisis is carbon dioxide (CO_2) – the primary greenhouse gas driving climate change. But what if CO_2 could be split and transformed before it ever leaves a tailpipe?

That's the vision behind RainIons, a U.S.-based startup that has developed a revolutionary powder capable of reducing greenhouse gas emissions – including CO_2, NO_x, and hydrocarbons – by transforming them into safe, stable molecules. The application of technology is currently being developed further by COAT-IT, a Polish startup specializing in the engineering of high-temperature-resistant coatings tailored for practical automotive applications.

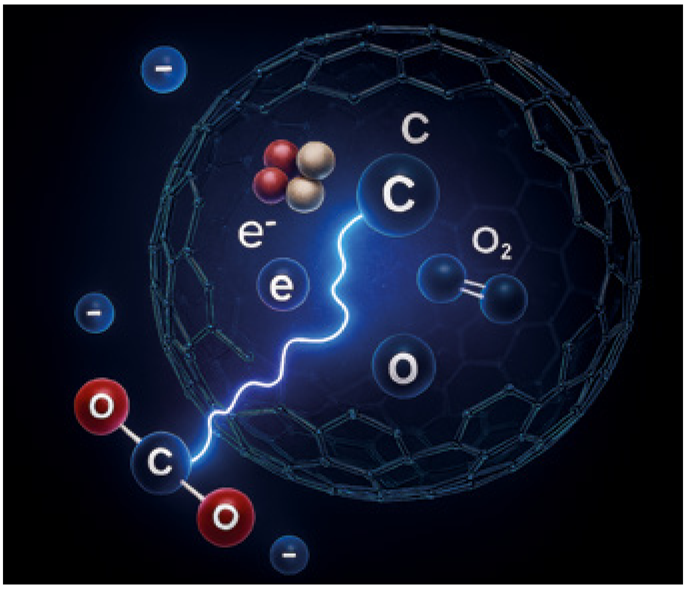
The Science Behind the Solution

The innovation combines pyroelectric and piezoelectric minerals with naturally occurring radioactive materials (NORM) in a conductive matrix. This unique blend emits alpha particles, negative ions, and electrons – without external power. These particles ionize pollutants and split strong molecular bonds, including those in CO_2.

Independent studies and internal evaluations suggest the solution can significantly reduce CO_2 emissions across a variety of conditions. At elevated temperatures (around 500 °C), reductions have been observed above of 50 %. Even in lower temperature environments (70 - 200 °C), meaningful decreases in CO_2 – typically within a 25 - 30 % range – have been noted, with no harmful byproducts identified. In moisture-rich settings, reductions of up to 50 % indicate that water may play a catalytic role in the transformation process.

From Tourmaline to Transformation

Inspired by earlier research on tourmaline-infused asphalt, the tourmaline-based "negative ion powder" was infused into a conductive coating and applied it to a diesel muffler. FTIR spectroscopy revealed that CO_2 was being split into graphite and oxygen, with water concentration directly influencing reaction efficiency.



What's Next?

COAT-IT is now developing durable, high-temperature coatings for commercial deployment. The next phase includes real-world trials using diesel engines and custom exhaust systems. The goal: to quantify transformation products and optimize substrate design for maximum pollution reduction.

If successful, this technology could redefine emissions control – turning exhaust systems into active climate solutions.

AI-Powered Engineering Software for Electric Drives: OPED

Boosting powertrain development with agility, fast time-to-market and optimal product-market fit

Dr. Martin Hofstetter, Head of E-Mobility and Alternative Drivetrains Research Group, Graz University of Technology

Dr. Dominik Lechleitner, Senior Researcher, Graz University of Technology

Designing electric powertrains is challenging: engineers must quickly find competitive designs and optimize the system for multiple key performance indicators (KPIs) at once, e.g., efficiency, cost, and package. The industry-approved engineering software OPED (Optimization of Electric Drives) can do this automatically by combining parametric system models with an AI-based optimization algorithm and exploring hundreds of thousands of design variants within 24 hours.

Development of Electric Drives

The development of electric drives (e-drives) is a highly complex and interdisciplinary process. Engineers must simultaneously design numerous electrical and mechanical subsystems (see Figure 1) that must optimally work together while meeting ambitious system targets for performance, efficiency, cost, and packaging. These objectives are often conflicting – improving one typically worsens another. Moreover, this highly challenging task must be solved under strong time pressure as it is critical for ambitious time-to-market goals. Therefore, engineering of electric drives demands digital tools capable of handling multi-criteria optimization and cross-domain interactions in an integrated way to quickly provide solid answers to complex questions.

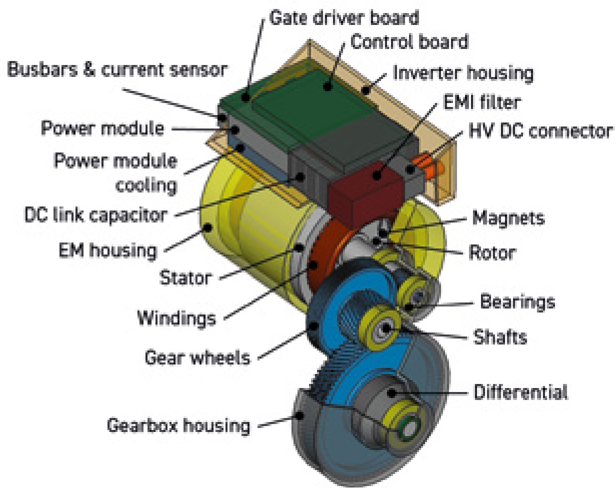


Figure 1: Typical e-drive architecture and system components

Revolutionizing the Development Process with OPED

The software OPED fundamentally changes how e-drives are developed. Instead of relying on sequential design steps and manual iterations, OPED uses parametric system models combined with an AI-powered evolutionary optimization algorithm to explore the full design space automatically. The outline of OPED is shown in Figure 2: Based on specified e-drive system requirements, the design problem is encoded as a multi-objective optimization problem. The intelligent design algorithms then generate different e-drive designs, which are evaluated by system analysis models. Based on the calculated design properties, the optimization algorithm rates the generated designs and aims at improving them based on the best found designs so far. This closed loop of design analysis and synthesis continues until no more improvements are observable and converging behavior is present. Furthermore, self-learning artificial neural networks boost the optimization performance by guiding the optimization algorithm and directing its search towards promising design regions. Within 24 hours of computation time, around 50 design parameters are varied, hundreds of thousands of possible e-drive designs are evaluated, and the most promising ones are identified based on multiple concurrent objectives such as

- performance,
- efficiency,
- cost,
- package integration,
- carbon footprint,

and any other design objective – everything that can be calculated, can be optimized. The result is a Pareto front of optimal solutions, providing engineers and decision makers with a clear overview of achievable trade-offs and design potentials. By merging simulation, optimization, and system understanding in one integrated workflow, OPED enables rapid development cycles. Agility is key: every request for quote (RFQ) or sudden project change request (PCR) is replied with fast and solid answer, tailor-fit to the specific requirements. Taking informed decisions early ultimately leads to an optimal product-market fit for the e-drive system and a fast time-to-market.

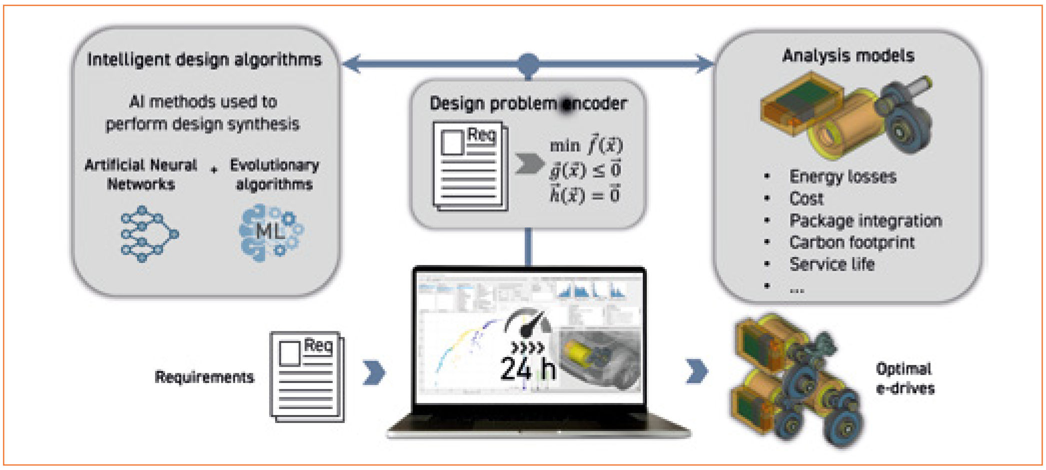


Figure 2: From e-drive system requirements to optimal e-drive solutions with OPED

Master Challenging Targets of Package, Efficiency and Cost within 24 Hours

OPED's strength lies in its versatility. The software can be applied to a wide range of design questions – from component sizing and material selection to system-level trade-offs and product family development. Moreover, as system requirements are often vague and uncertain in the early development stages, OPED can be utilized for requirements engineering. Another powerful capability lies in the full 3D package investigation: OPED not only finds designs that comply with a given 3D target installation space, it also provides possible packaging options within the available space. An example is shown in Figure 3, which depicts two possible design solutions for an e-drive: One with the smallest possible length and one with the smallest possible height (e.g., providing additional trunk space for applications at the rear vehicle axle).

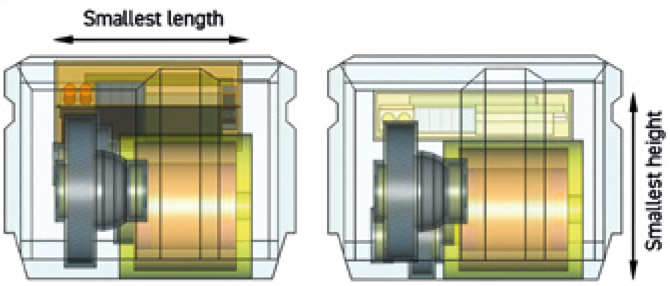


Figure 3: Example of e-drive packaging options; available installation space is shown in blue

Besides package feasibility, both energy efficiency and cost are always critical and conflicting KPIs. To select the most suitable solution, OPED provides a Pareto front of e-drive designs (Figure 4), where each point represents one optimal design solution. Accordingly, engineers and decision makers are provided with a solid foundation for selecting the most suitable system solution respecting the specific goals of each vehicle application. As each design solution from OPED contains detailed technical information – including a 3D CAD model – a seamless and smooth transition from OPED results to the A-sample development is ensured. This makes OPED a powerful enabler for fast and digital electric powertrain development.

Concluding, OPED enables engineers and decision makers to
- respond quickly to requests for quote (RFQs) and project change requests (PCRs),
- solve conflicting KPIs & do requirements engineering,
- develop competitive solutions with product-market fit,
- design optimal product families, utilizing commonality and carry-over-parts.

OPED is established in practical use at a leading global automotive tier 1 supplier – with high potential for scaling across other suppliers and OEMs.

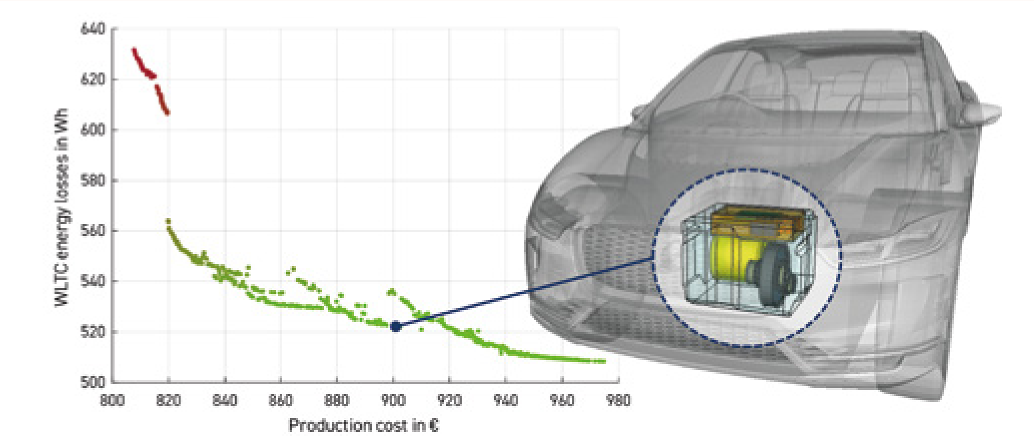


Figure 4: Select the sweet spot of energy efficiency vs. production cost (vehicle model from [1])

go.tugraz.at/oped
Video of OPED in action!

oped

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Sources:

[1] Holiday, D. (2021). Jaguar I-pace Concept. https://sketchfab.com/3d-models/jaguar-i-pace-concept-3ea106994ec9442eb4b72906026fa215. CC Attribution: https://creativecommons.org/licenses/by/4.0/, modified. [Online; accessed 13 February 2024]

How deeptech is already revolutionising EV powertrain engineering

Simon Shepherd, Head of eDrive and Chief Product Officer, Monumo

Deeptech is transforming EV powertrain engineering by introducing new levels of computational freedom, speed, and system integration, allowing companies to achieve levels of performance and cost reduction previously out of reach through existing methods.

Nature-Inspired System Design

Modern engineering increasingly draws inspiration from nature, where efficiency is achieved through adaptation and system-level harmony. EV developers are now using advanced computational tools to explore organic, highly optimised component shapes and system architectures; mirroring, for example, how a tree or a bird's wing achieves a perfect balance of forces.

Unlike natural evolution, which takes millennia, digital tools allow engineers to iterate and converge on superior solutions within weeks, critical for keeping pace with rapidly changing industry and regulatory demands.

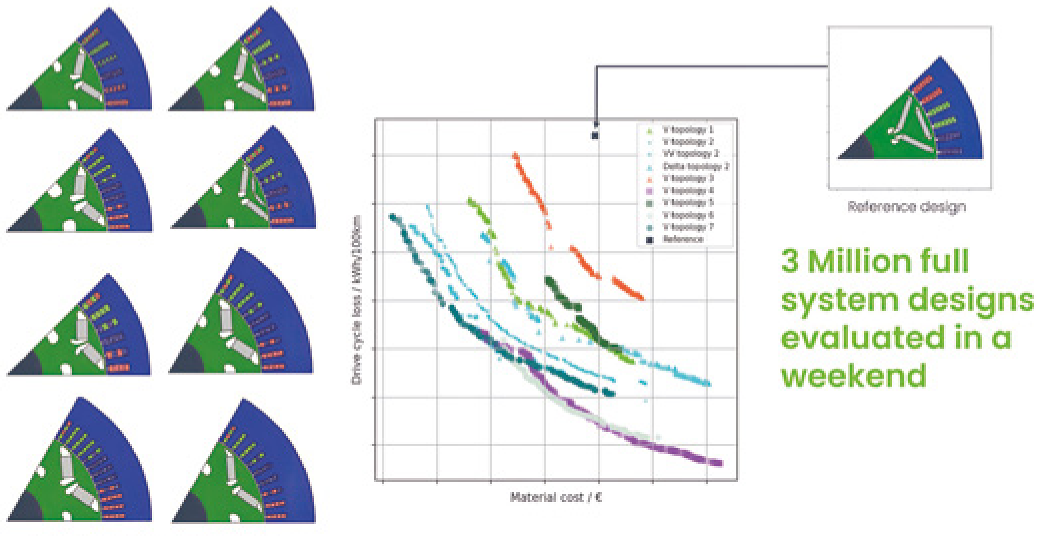
Overcoming Conventional Barriers

Classic engineering methods, which adjust just a handful of design parameters, can no longer solve today's complex powertrain optimisation challenges. Next-generation computational platforms let engineers evaluate vast combinations of component geometries and system parameters – tens of millions, in some cases -far beyond what's possible with manual approaches or simple brute-force computation. Intelligent automated routines and novel search strategies deliver the breakthroughs needed when conventional software and human time simply cannot scale.

Real-World Results at Scale

Breakthrough deeptech platforms – like Monumo's Anser® Engine – are now enabling EV makers to rapidly generate and assess hundreds of thousands of valid designs for components such as motors and gearboxes.

- In recent projects, 250,000+ viable motor designs were created in just three days, trimming magnet use by more than 8 % and cutting costs by 4 %, saving €15 per vehicle. [1]
- Expanding system optimisation to include additional variables (e.g. stator dimensions, gears, and motor length) produced over 550,000 valid solutions in five days, achieving savings as high as 11 % (€43 per unit), or reducing losses by 12.5 % at no added cost. [2][1]



The Next Frontier

The emergence of "generative design" tools – able to propose promising designs directly – suggests future engineering cycles will be radically compressed, possibly delivering optimal solutions within minutes instead of days. Monumo's technology roadmap forecasts continued gains as greater system-level freedom, parametric control, and digital intelligence are brought to bear:

- Motor-only optimisation: ~5 % cost reduction
- Whole-system integration: 10 %+
- Projected potential with full-system and freeform optimisation: 20 %+ cost reduction.

Deeptech is no longer a future prospect: it is already driving major advances in EV powertrain cost, weight, and performance, for the manufacturers prepared to fully adopt it.

Simon Shepherd is Head of eDrive and Chief Product Officer at Monumo, a deeptech startup based in Cambridge and Coventry, UK, specialising in AI-driven engineering solutions. Ready to explore how deep-tech can transform your powertrain development? Contact Simon.Shepherd@Monumo.com, see more at monumo.com listen to him speak about our latest developments at 11:15 on Wednesday 3rd December in Deep Drive Track L.

Taurus: a powerful mix of industry standard and lessons learned through experience

Automotive drivetrain engineers aim to perfect and refine electric drive lines to the point where they operate right at the edge of what is physically possible. This requires simulation models, to act as cost function in the design process or to train reduced order models. These latter models should incorporate all physical loss and performance mechanisms and should be computationally efficient at the same time. Often however, important contributions to efficiency or performance drops are hidden in empirical build factors. These factors can only be quantified too late in the design process, i.e. after testing of the first prototypes.

Based on our experience we developed Taurus, a simulation tool chain that uses industry standard tools, but adds the necessary embedded experience to capture detailed impact from component level, all the way up to the drivetrain level.

Use case: Taurus eliminates the use of build-factors for motor loss prediction

Detailed modelling in Taurus allows to calculate in a computationally efficient way the loss contributions in the motor induced by manufacturing effects and high-frequency operation. This includes degraded material properties at the cutting edges and mechanical pressure for the manufacturing effects. PWM switching induced losses in the magnets, copper, and iron are also calculated. Figure 1 illustrates the delta in amount of losses and their spatial distribution by including these effects. Prior to the calculations, additional material characterizations have been carried out.

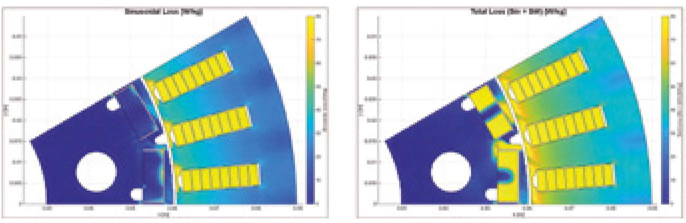


Figure 1: ignoring PWM-induced losses and manufacturing effects leads to incorrect loss distribution data.

This spatial loss information is calculated for all operating points and thus allows further detailed analysis utilizing the data in time-based simulations to identify hot spots or to calculate cycle consumption for the full driveline.

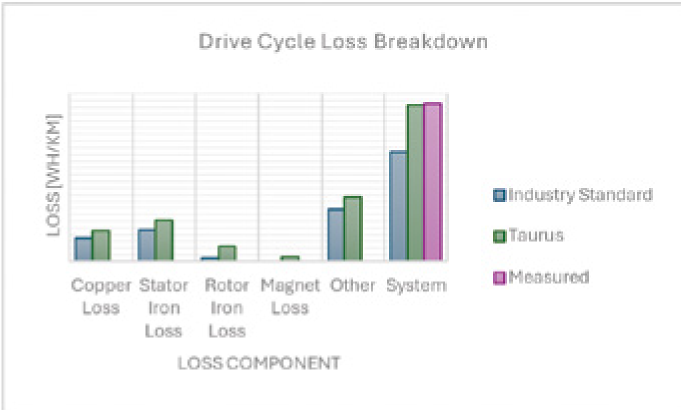


Figure 2: Cycle loss breakdown: industry standard tool (build-factors) vs. Taurus (first principles).

The net effect of this increased fidelity on a drive cycle consumption is visible in Figure 2. It compares the loss predictions from an industry standard tool (using build factors) with the first-principles approach from Taurus and shows the correlation with measurements.

Conclusion

With limited additional characterization, a detailed and computationally efficient calculation allows to optimize cycle consumption and avoid local hot spots. By adhering to two main principles: leveraging industry standard tools and including loss mechanisms on a first principles basis, Taurus enables fast driveline R&D support from concept to troubleshooting.

Introducing DRV Solutions

DRV Solutions is an engineering partner for advanced electric drivelines, supporting from concept to validation. We combine motor & power electronics design, full driveline analysis, and system integration expertise in our Taurus Toolkit. This enables us to accelerate your design and troubleshoot performance issues.

Software Increasingly Defines the Powertrain

Ten years ago, transmissions were still seen as the 'managers of the drive system'. Since then, the focus has shifted entirely. At the CTI Symposium Novi 2025, key topics included the diversity of electrified drive systems, new solutions such as Range-Extended Electric Vehicles, current challenges in electronics and battery development – and the Software-Defined Vehicle, which is also redefining drive development.

Sometimes, it can seem as though the Chinese automotive industry is inexorably outpacing Europe and North America. But in his introductory speech in Novi, CTI-USA Chairman **Patrick Lindemann** was far more upbeat. He invited his audience to see the bigger picture: Yes, over 30 million cars were sold in China in 2024, against just over 10 million in Europe and around 18 million in the USA (15 million of which were non-imports). But in Europe, the average car price was around $56,000, compared to $23,400 in China. At roughly $49,000, American vehicles were cheaper than in Europe – but in terms of total market sales, the USA led the field with $882 million, while China managed just $730 million, only slightly more than Europe. The bottom line: The US market is still the biggest. So as Lindemann put it: „Let's discuss at this symposium, what the best drive technology is for the US market." This much is clear: drive systems diversity will be around for a while, there is a new kid in town called REEV, and the Software-Defined Vehicle has already arrived. The focus of value creation is shifting – and that means excellent opportunities for the US industry.

Electrification: slow, but steady growth

Since these 'best drive technologies' will increasingly be electrified in North America, too, a review of the „Electric Vehicle Ecosystem" in the USA is a good place to start. In his presentation „US EV Industry Update", **Brent Gruber** of **J.D. Power** said there was continuous growth in BEVs and HEVs, but PHEVs were still not really gaining traction. In 2025, HEVs accounted for 13.2 % of all new registrations; BEVs achieved 9.5 %, and PHEVs just 2.2 %. Over the past three years, the number of BEV models in the market had risen from 27 to 62, most of them in the premium segment. Gruber asked why the EV market wasn't growing faster. One reason, he said, was political uncertainty concerning tax incentives. But unless registrations grew faster, the US would miss its emissions targets. Charging infrastructures were another issue. Satisfaction levels were actually dropping here: 19 percent of EV drivers reported non-functioning charging stations, and the number of EVs was growing twice as fast as the number of charging stations. On the other hand, more than 4 in 5 people charged at home, while the average EV user drove less than 50 miles a day. Nevertheless, J.D. Power expects EVs to grow their market share from 2026 onwards, and predicts roughly 26 % by 2030.

Range Extenders for the USA too?

REEVs (electric range extended vehicles) are very successful in China, alongside BEVs. Given the sheer size of the USA, could they make sense there too? At the symposium, the acronyms REEV and EREV were both used, and are interchangeable. **Joe Tolkacz** presented the **Stellantis Ramcharger**, calling it the „right vehicle at the right time" for the US market. The RAM 1500 Ramcharger is the first light truck in an REEV format, and the performance data are impressive. The independent electric drives on the front and rear axles deliver 250 and 248 kW respectively, while the V8 combustion engine supplies up to 202 kW to a generator with 202 kW peak and 130 kW continuous power. The battery capacity is 91.8 kWh, and Stellantis puts the total range at 690 miles. Being a light truck, the Ramcharger comes with an automatic transmission, plus a range of extra modes such as snow, trailer or off-road. Of particular interest to US customers is its V2X (Vehicle to X) compatibility, which means the Ramcharger can supply power to tools, other vehicles, and also to homes. This generator function is the main differentiator between the Ramcharger and a normal BEV. It can power a home for 11 to 22 days on a single tank of fuel, or even a whole neighborhood if refueling is an option – in theory, for as long as necessary.

At the symposium, opinions differed as to whether REEVs will really have a future or not. During the OEM panel discussion, **Micky Bly, Stellantis**, said a vehicle like the Ramcharger made sense because it could fully meet all consumers' everyday needs. Stellantis currently offers two systems – the REEV for large body frame applications, and P2 PHEV solutions for models like the Jeep – and intends to pursue both options. **Norman Peralta, GM**, said PHEVs made sense for large cars and trucks since customers do not want to buy a BEV with today's battery technology. Like his colleagues at Stellantis and GM, **Thomas McCarthy** said **Ford** wanted to give consumers a choice and would therefore keep supporting drivetrain diversity. **Dante Boutell, Toyota**, foresees a gradual shift from PHEV to REEV, but said BEV would ultimately prevail, especially if ranges continue to grow. During the Q&A session after his presentation, J.D. Power expert Brent Gruber made it quite clear that, in his opinion, REEVs, like PHEVs, were neither fish nor fowl – and were unlikely to take a sizable share of the market.

Electrification of Large and Work Trucks

The Truck Electrification Panel discussed the best drive system for large trucks. **Jason Gies** of **Windrose** thinks long-haul trucks will be fully electrified, too. He said Windrose was currently pursuing BEVs only, with ranges of up to 420 miles and a charging time of 38 minutes from 20-80 % SOC. However, a high-performance charging infrastructure was „hypercritical." By contrast, as **Jerome Gregeois** explained, **Hyundai-Kia** is pursuing three options: BEV, fuel cell, and EREV. **Andreas Kammel** of **Traton** also saw room for all options, depending on the application, but said, plug-in solutions were a niche, and BEV would also prevail in long-haul applications. **Kevin Robinet** of **Scout** said designing REEVs as a BEV architecture variant for smaller applications would make sense. „If BEV energy density quadruples, everything speaks for BEV – but when is that going to happen?" According to **Ruidong Yang, BYD** is also backing purely battery-electric drive systems for long-range trucks. He said REEVs made sense for some applications, but were technically more complex, and ultimately yielded less range per kilowatt.

As **Chad Smith, Oshkosh**, showed in his presentation „Advancing Powertrain Solutions for Work Trucks", electrifying vocational and work trucks comes with its own set of requirements. Vocational trucks are commercial vehicles whose primary function is to „work." Depending on the application, electrification levels vary greatly. Concrete mixers, for example, need to run continuously, so they are either HEVs, or ICE-only. Oshkosh also offers BEV garbage trucks with high recuperation levels, and a battery designed for the vehicle's lifetime. Charging is not an issue here, he said, as operators had their own charging stations. Smith said Oshkosh also offered PHEV rescue and firefighting vehicles for airports. These had 28 % better acceleration and sufficient range for normal daily use, and „German customers love them." Military vehicles were a completely separate category; charging in an austere environment was impractical. That said, an HEV design made sense and could cut consumption by up to 30 percent, whereby the extra weight and complexity needed to be factored in. Smith finished up by mentioning several challenges in work truck electrification, including training and service for high-voltage applications, the availability of drive components, and ensuring the future availability of domestically produced batteries. Given the short production runs for work trucks, he said, the supply situation was more difficult than for large-scale manufacturers.

Battery Production as seen by a Volume Manufacturer

By contrast, Stellantis has to master large-scale production requirements on an international scale. **Tim Grewe, Stellantis**, talked about the challenges of „STLA Multi Energy Battery Systems & Industrialization" in HEVs, PHEVs and BEVs. For example, Stellantis has to deal with the fact that European cars are smaller than American vehicles. Hence, the company portfolio includes three unibody platforms (small, medium, and large) with electric ranges of 300 to 500 miles, plus a body-on-frame platform for trucks with a range of up to 500 miles. The frame platform was just as suitable for ICE drives as for BEVs, FCEVs, xHEVs, and REEVs such as the Ramcharger. Grewe noted that Stellantis already offers 30 hybrid models in Europe under its Alfa Romeo, Fiat, Citroën, Peugeot, Opel, Jeep, and Lancia brands, with six more to follow in 2026. He said Stellantis tackled one major task over ten years ago, by standardizing battery production across all global locations. Using a cloth stretched across the stage, the speaker effectively demonstrated how delicate battery separators are and how critical even the slightest damage is. „You put a hole in it, and the lithium is going to find a way to cause trouble." This applied to all batteries: hybrid batteries may have different and more frequent duty cycles, but the core requirements for production reliability were always the same. Each location needed be able to produce everything. Standardized processes were essential in order to meet customer needs quickly, globally, and promptly.

The Road to Software-Defined Vehicles

Lucid Motors is at the other end of the spectrum. It makes just two EV models – the Air and the Gravity – and follows a rigorous in-house development approach. In his lecture „Vehicle Efficiency Through Integrated Design of Drive Units and HV Battery", **Emid Diala** described how Lucid developed most of its hardware and software in-house, from the battery system and electric motor to the power electronics and beyond. The company also designed its own development software. This enabled it to model and simulate all components and the overall system as early as possible. Before the first prototypes were built, developers even balanced battery properties (such as charging speed) and driving capability in the simulation. For Lucid Motors, its vehicles were the best examples of Software-Defined Vehicles (SDVs) – not just in terms of OTA software updates, but also in the high degree of hardware and software integration along the whole development chain. This would not have been possible using bought-in modules.

SDV in general is playing a growing role at CTI symposia, as illustrated by the presentation „Continuous Everything – Automotive in Transition to Becoming a Software Industry" by **Florian Rohde, iProcess**. Before becoming a consultant, Florian Rohde worked at Tesla on the Software-Defined Vehicle, „which wasn't called that back then." Up till now, he said, dealers sold and serviced cars. But today, you could retrofit features via software, and sometimes even sell them as a service. You could update the user interface, interact with customers, have a complete feedback loop, offer preventive maintenance, and avoid physical recalls. All of this required software-oriented processes and work structures. Using Tesla as his example, Rohde described how making changes to both software and software involved basing the work on schedules, as opposed to features. „If you have a software feature ready on time, it can go into the release train; if not, you have to stay where you are." Traditional, component-based development also no longer made sense. Since the hardest aspect was integration at system level, everyone had to be in constant communication. It was vital to bring all the developers together as early as possible, and to test vehicle functions continuously and automatically throughout development. „When people are developing a new feature, allow them into the car", the speaker explained. „Allow what is called feature branches." In other words: develop features in an encapsulated environment, then integrate them back into the higher-level software tree.

From the developer viewpoint, Software-Defined Vehicle seems set to replace traditional component-based development rapidly – and not just in BEVs, as Florian Rohde noted. Feature-oriented development offers new possibilities, and new customer benefits. As Emid Diala put it: „An SDV doesn't age during operation, it actually becomes more modern in terms of functionality." **Christine Thelesklaf**, the Bosch representative on the Supplier Panel, added that in terms of brand differentiation, drive systems would matter less, while the way brands integrate their electronics and design their user interfaces would become more important.

Deep-dive contents and a new forum for innovative startups

The CTI Symposium Novi offered a comprehensive program of deep-dive presentations in addition to the plenary presentations and panel discussions. There were 53 in all, grouped under the following session headings: Electric and Hybrid Drives, E-Drive Components, E-Motors, Batteries, Thermal Management, Development Tools, AI & Testing, Commercial Vehicle Propulsion, Development Tools, Testing, and Lubrication.

In a new format that will be repeated at future events, seven startups introduced themselves briefly during the two days, and offered guided tours of their exhibition booths. For this new format, CTI has partnered with **GAMIC**, a non-profit organization with the mission to identify, mentor, and promote global startup innovations targeting the North American mobility market.

Dive Engineering Software offers a browser-based smoothed particle hydrodynamics software that enables virtual drivetrain lubrication and cooling analysis. **EcoNova Tech** has developed innovations using the Geneva mechanism or non-circular gears for uninterrupted shifting with EVs. **eLeap-Power** provides advanced power electronics solutions tailored for off-highway, light commercial, and passenger vehicle applications. **Emil Motors** is working on the next generation of electric motors, being entirely free of rare earth material. Limestone Engineering Services **(LES)** offer consultancy in areas like transmissions, ICE, BEV and specific fields like FE analysis, NVH, tribology etc. **Marel Power Solutions** is a power electronics company, focused on advancing electrified powertrain systems. **Orbis Electric's** patented technology is a lightweight axial flux motor-generator with unrivaled power & configurability.

Software, Electronics, and Semiconductors are growing

Summing up, North America will continue to see a diverse range of drive concepts in years to come. Given the sheer distances involved, a one-size-fits-all solution seems unlikely to appear anytime soon. Will the relatively new vehicle category of REEVs gain traction in the USA too? We look forward to monitoring developments in this sector. One strong argument in their favor is their ability to serve as power generators, including in V2X applications. But as the discussion at Novi made clear, P2 PHEVs may still have their place wherever ICE hauling power has priority.

The trend towards software-defined vehicles is evident. SDV offers new service models, streamlined development processes, and tangible extra consumer benefits. How far will Software as a Service go? Will we eventually just sell functionality, not vehicles? Other areas whose growth will be matched by their coverage at future CTI Symposia include power electronics for electrified drives, where interesting advances are being made in the field of power semiconductors. What role can GaN play as an alternative to SiC, for example? Will highly efficient inverters trickle down to lower-cost applications? At the **CTI Symposium Berlin (December 2 and 3, 2025, Estrel Hotel, Berlin)**, all this and more will be up for discussion.

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