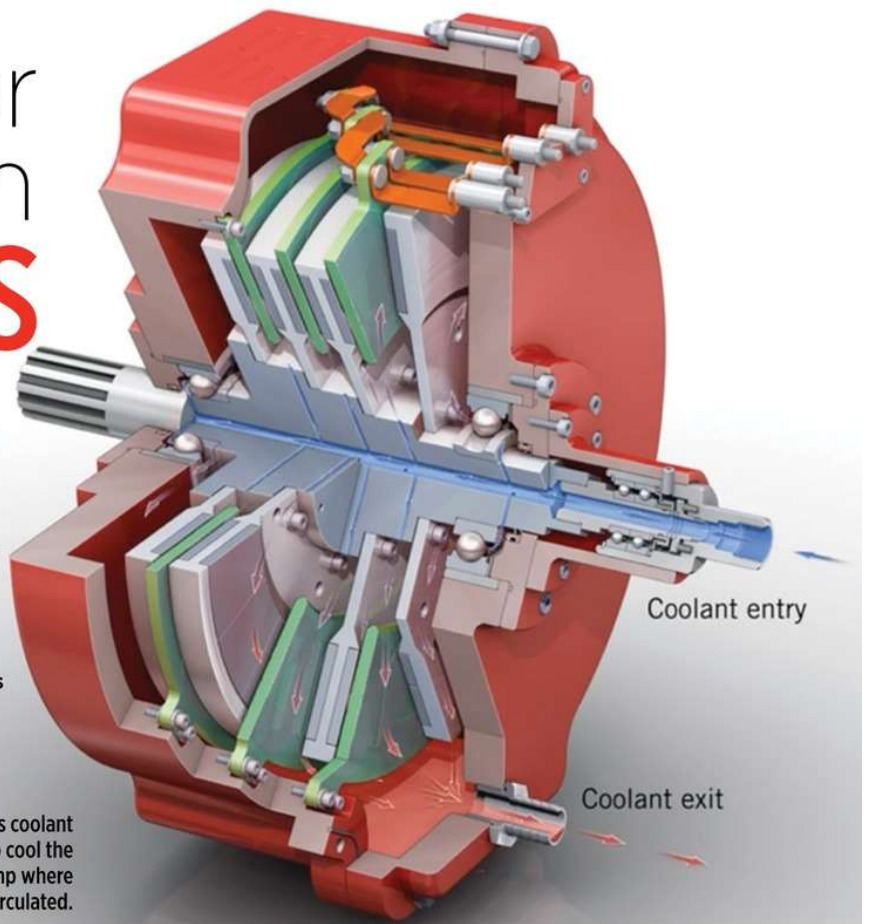


The push for e-propulsion **PROGRESS**

Upstarts and heavy-hitter suppliers alike are fast-tracking advances in existing technology — as well as radical new solutions.

by Chris Clonts

Infinitum's axial-flux arrangement delivers coolant directly into the center of the mechanism to cool the stator and other parts. Coolant drains into a sump where it is recirculated.



Electric powertrain development continues at a fervent pace as OEMs, suppliers and startups try to optimize current technology while forging ahead into new areas. Although battery engineering and development enjoys almost daily industry discussion, traction motor and power electronics remain the investment focus of many established and startup suppliers. Efficiencies gained in these systems can significantly reduce an EV's required amount of expensive battery capacity.

It's a rapidly expanding market, seemingly with plenty of room for myriad new players and fresh ideas. **Vitesco Technologies**, the powertrain supplier spun from **Continental** in 2019, has committed to electrification in all future development. As a result, it generated \$888 million in revenue in 2021. Thomas Stierle, head of the company's Electrification Solutions division, said it expects revenue to increase to \$10 billion to \$12 billion by 2030.

The **Schaeffler Group**'s North American executives said at a corporate technology showcase in fall 2022 that although the company intends to divide its near-term investments at a roughly 50/50 ratio between internal-combustion and electrification development, Schaeffler acknowledges the future is electric and is driving hard on designs to squeeze more efficiency from traction motors and their associated systems. "Electricity is the right choice," said Patrick Lindemann, president, e-mobility and chassis systems. "There is no doubt."

Getting there means companies are stretching current technology and introducing new motor and power-electronics designs. Drive motors and electronics already are efficient, but there's massive investment underway for innovations to get even more from the limited onboard power EVs can carry. A selection of recent developments:

Infinitum drives for smaller, lighter motors

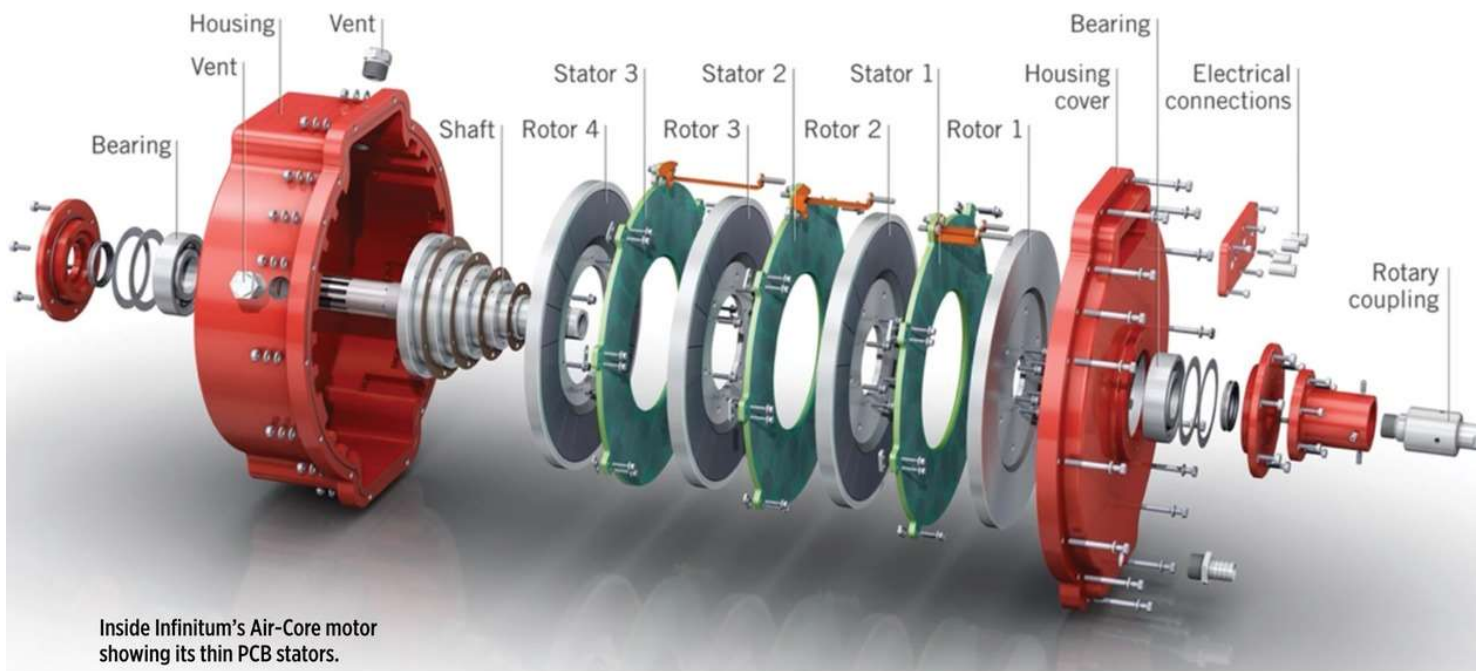
Infinitum Electric claims it has engineered a 50% smaller and lighter axial-flux motor by pulling all the iron out of the core and the copper windings from the stator, replacing it all with a printed circuit board (PCB) stator with etched copper conductors.

Ben Schuler, founder and CEO of the seven-year-old Austin, Texas-based company, said the motor design eliminates all the core losses — such as from torque ripple, cogging, stator hysteresis and eddy current — from the stator, resulting in "drastically higher efficiency." It's also smaller and quieter, with higher efficiency over the full operating curve, Schuler explained. He added that in a traditional motor, that core loss always is there and it gets worse at higher RPMs.

Infinitum, which initially sought to tackle inefficient HVAC motors, is concentrating on industrial markets, which Schuler says can help the company grow because of the relatively quick development cycles (compared to automotive's typical years- or decades-long cycles) that lead to immediate revenue. He also said it's a big opportunity to help save energy, as 50% of the world's power goes to driving electric motors.

The company produced 5,000 motors in 2022 and is projected to deliver 50,000 this year and 150,000 in 2023. Those are for industrial

INFINITUM



HVAC units, compressors and material-handling applications. Current partners include **Rockwell**, **Caterpillar** and **Chevron**.

At CES 2023 in January, Infinitum announced its latest step forward. Its Air-Core motor, paired with the PCB stator, is a liquid-cooling system that channels coolant directly to the motor's heat source. "We inject the coolant into a hollow shaft and release it over the entire area of the stator. That lets us get four to five times the power density of a traditional radial-flux motor," Schuler asserted.

Most other cooling methods on radial and axial-flux motors only get coolant into a jacket around the motor. Once Infinitum's system gets coolant to the center of the stator, centrifugal force pushes the liquid to an outer jacket, where it drains into a sump to be recirculated. The result is a motor with 150 kW (201 hp) continuous and 300 kW (402 hp) peak power that runs with 95% efficiency at 7500 rpm.

Schuler clarified that Infinitum is not the first to develop a PCB stator, but first to "productize it in an effective way for a market." The company, which holds 32 patents with 44 patents pending, believes it is the first to deploy a PCB stator and liquid cooling in the same package.

The Air-Core motor uses silicon-carbide MOSFETs to enable switching at a higher speed. "That allows us to overcome the lack of inductance and operate the stator effectively," he said. The motor also can receive over-the-air updates.

The size of the motor, or whether to use multiple smaller motors instead of one larger one, is driven by the application. "There are practically no limits on the technology from the technical perspective," Schuler said. "We are an axial-flux machine, so we tend to be a larger diameter and a shorter length."

In some industrial applications, it's far better to have ten 10-hp motors than a fan driven by a single 100-hp motor. He said that having multiples does allow redundancy, helpful in many applications such as eVTOLs.

The Air-Core motor is designed for a circular life cycle. The copper laminate panels are etched using off-the-shelf FR4 glass epoxy as insulation. This results in ten times the reliability of a standard stator, the company said. Why? "All of our copper laminate and insulation has an equal coefficient of thermal expansion. As it heats and cools over and over, it does that at the same rate. That means no mechanical interference is ever created, which means it will never fail," Schuler said.

As for the ramp-up to the mobility market, which Schuler says could benefit even more than the HVAC market from the Aircore Mobility Motor's efficiency, the company is willing to license the technology and already has a handful of agreements with OEMs in the commercial trucking, eVTOL and other markets, for which they expect to deliver units in the second and third quarters this year.

Schaeffler: Systems efficiencies

At Schaeffler Group, historically a provider of stampings and advanced bearings, e-motor development is coming fast and hard. The company is applying its expertise to traction motors that optimize established materials and achieve more efficiency via a higher degree of systems integration.

Jeff Hemphill, CTO of the Americas, said Schaeffler is looking to make permanent-magnet motors more efficient, by misaligning the magnets, for example. And it also is directing attention to externally excited

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Ben Schuler,
CEO of
Infinitum
Electric.

motors with no magnets. Magnet-less induction motors typically are less efficient; Schaeffler's engineers claim externally excited motors can be developed with efficiencies "on par" with a permanent-magnet motor.

The company's most-recently revealed idea, the "4in1" e-axle, integrates the traction motor, transmission, power electronics and thermal management, achieving an incremental efficiency gain over its 3in1 e-axle. A collaborative move to SiC power electronics delivers more than 99% efficiency, the company claims.

Schaeffler's new 4in1 e-axle can incorporate a shifting mechanism for a 2-speed transmission, which some believe is a worthwhile addition for larger, higher inertia-weight vehicles favored in the U.S. market. There also is provision for a decoupling unit.

The company isn't eying only EVs. It believes hybrids will play an important transitional role, so Schaeffler is focusing on hardware and electronics to introduce "much higher voltages" for HEVs, said Markus Steinberger, director e-mobility R&D.

ZF enhances motor power density

In November 2022, ZF revealed an all-new electric powertrain with many benefits, including the capability to accommodate either 400V or 800V architectures. The flexibility comes from the controller chip and inverters with individual power switches.

The company asserted that this architecture results in fewer components than today's power modules. The system baselines at 100 kW (134 hp) per axle and can generate as much as 300 kW.

An aspect of ZF's new e-drive system that likely will intrigue competitors is the new braided-wiring technique that enables higher power densities to be achieved. "Hairpin wiring, the state of the art today,



eLeap Power's integrated inverter takes advantage of the windings of an electric motor (when it's not moving) to replace a vehicle's onboard charger and its artificially slow charging speeds.

eLeap Power is under contract to deliver 15,000 integrated inverters for use in delivery vans made by Chery Automotive.

was introduced five to seven years ago, [and] requires hundreds of laser welding points," said Roland Hintringer, head of e-motor product lines. He said ZF's braided wiring is formed and braided in one step, saving time and requiring less space, with a winding head of 15 mm versus 28 mm for hairpin winding. "It only requires 24 welding spots," he said, adding that the new technique also reduces the raw material used by 10%.

Meanwhile, ZF joins Infinitum in the liquid-cooled stator movement. In addition to the water-cooled motor housing, cooling oil is pumped not only around the stator housing, but also through slots in the braided windings themselves.

Hintringer said the result is an 85% increase in peak performance, a 50% increase in power and use of only 1% of the rare earth materials compared to current technology.

eLeap Power: A charger-deleting inverter

eLeap Power also pitched at CES 2023 with a proposition that has unquestionable appeal: The Canadian company says its inverter technology eliminates the need for an onboard charger and voltage converter by leveraging the already existing windings of the drive motor. The result, eLeap said, delivers many benefits:

FROM LEFT: INFINITUM; eLEAP POWER



ZF's motor uses braided windings to increase power density and use less raw materials.

- 800V charging speeds but compatibility with 400V systems
- Eliminating the onboard charger reduces vehicle weight by 30-40 kg (66-88 lb.), increasing range
- Near-universal compatibility with all current EV powertrain architectures. It's also cost-effective in that it can accommodate 800v architecture while using less-expensive, lower-voltage switching components available today
- Is fully bidirectional in AC and DC. This allows direct charging of the vehicle battery from renewable resources such as wind and solar, while allowing the vehicle to "give back to the grid" at peak demand times
- The inverter uses either a split-battery or dual-battery system that results in better reliability. If a part of the system fails, the vehicle remains usable

While some observers at CES who examined eLeap's innovation may have been skeptical, **Chery Automotive** isn't. eLeap Power is under contract to deliver 15,000 integrated inverters for use in delivery vans made by the Chinese manufacturer.

"Overall, our system is a heck of a lot smarter and more powerful," said eLeap CEO Russell Pullan. "What they see in our technology is that it allows their vehicle to charge faster, go further with each charge, save costs for manufacturing and end users, and it's greener."

The heart of the eLeap system is in the

way it harnesses the magnetic fields and windings, combined with software, in a motor to "create a very fast flow of electricity to charge the battery." Pullan noted that a contemporary onboard charger is a major bottleneck and that

by eliminating it, vehicle charging times can be up to three times faster.

Project manager Jonathan Dooley said that in addition to removing the onboard charger, vehicles such as the **Lucid Air** that use a 400V/800V boost

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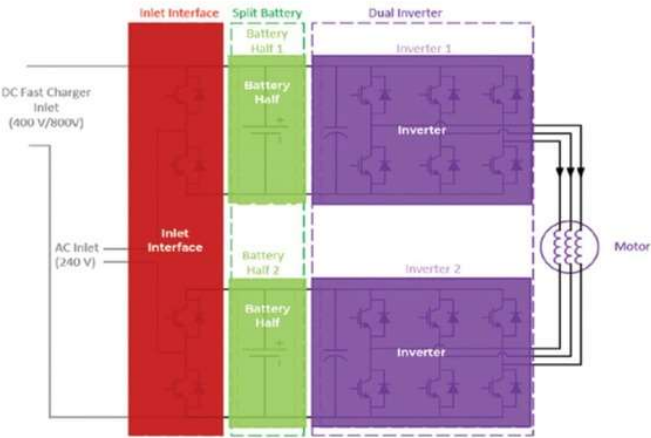


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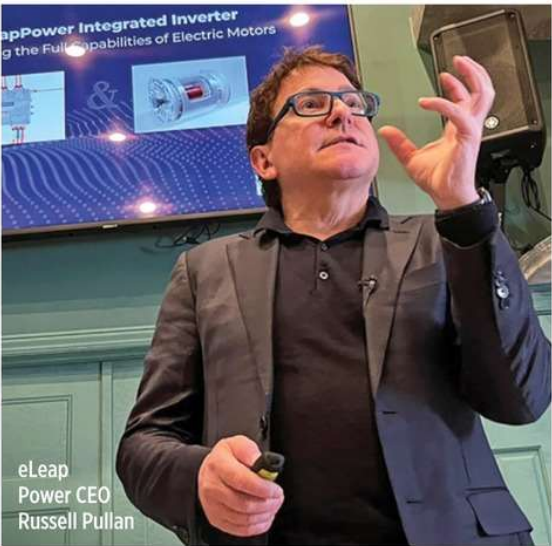
Integrated Inverter Schematic



Parameter	Equation	200kW Example*
400V DC charging	$400\text{ V} \times 3I$	416kW
800V DC charging	$800\text{ V} \times 3I$	208kW
1 ϕ AC charging	$240\text{ V} \times 3I$	125kW
3 ϕ AC charging	$208\text{ V} \times \sqrt{3} \times 2I$	125kW

* Assuming 173Arms per phase
Power is "up to" – meaning that the inverter can handle it, but potentially limited by charging infrastructure

eLeap says it overcame problems experienced by other companies' attempts at inverter integration by splitting the battery, essentially putting the inverter in the middle of the process.



converter can also eliminate that hardware.

"Another one of the ways we're able to achieve a big cost advantage is that we're using the motor in the charging operation," he said. "So inductors and transformers that would normally be there aren't necessary."

As for potential concerns about additional wear on the motor, Pullan argued that "charging is motionless, with no rotation of the motor and no vibration."

Dooley acknowledged that others have tried this technology but could not overcome problems. SAE Media asked engineers at suppliers and OEMs about eLeap's technology, and while most did not want to comment for attribution, they did say, essentially, "if they've figured that out, more power to them."

Beginning with Chery will speak to another of the benefits about which Pullan is enthusiastic. "If you're



Schaeffler's 4in1 e-axle seeks to maximize systemization by incorporating the traction motor, transmission, power electronics thermal-management, which can include a heat pump.

a fleet-logistics company, there are savings per vehicle," he said.

"We have savings on the OEM costs, but potential savings on infrastructure also. If you have a DC grid in your depot, you don't need any fast chargers. They're gone! That saves space."

Pullan offered that among Chery's end users, one third of their depot space is taken up by fast chargers. "In downtown Chicago or Shenzhen China, that's [a big cost]," he emphasized.

Even the IP of eLeap's system is unique, containing more than 50 pieces. Pullan said the core IP, developed with the **University of Toronto Electric Vehicle Center**, was granted by the U.S. Patent Office with no questions because it is *suis generis*, a mixture of software, hardware and system architecture not derived from any existing patents. ■

— with reporting by Bill Visnic