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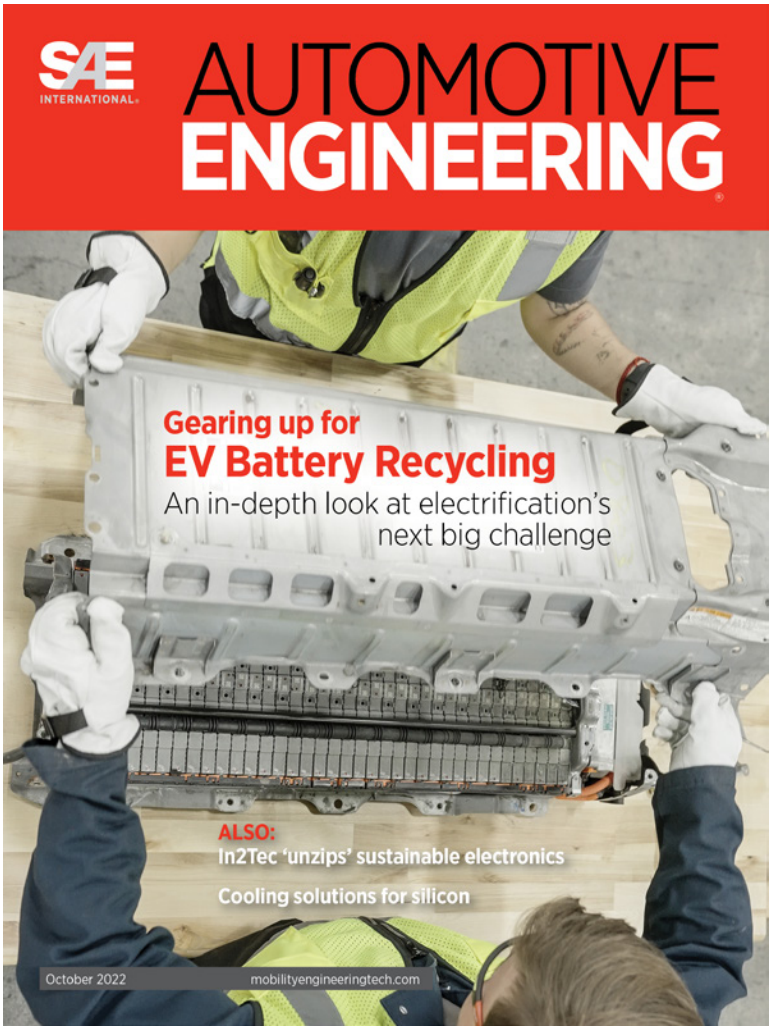

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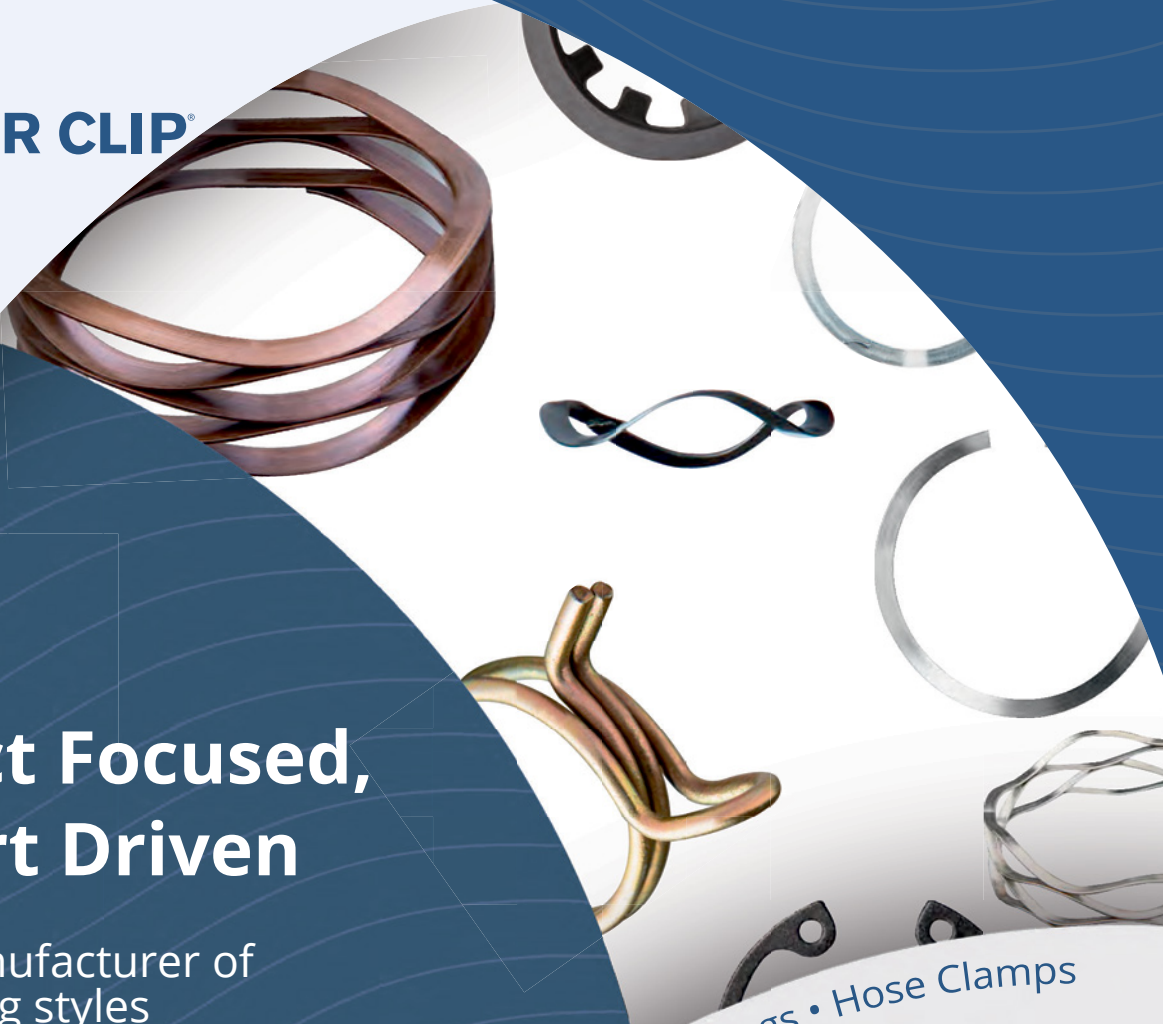

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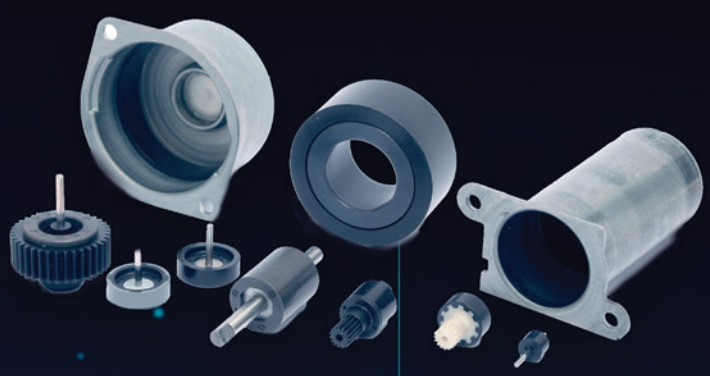

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ON THE COVER

A Toyota battery pack undergoes disassembly at Redwood Materials facility near Reno, Nevada. Development of a robust EV battery recycling industry has moved from a net-positive sideline to a necessity, as OEMs and suppliers transition away from internal combustion. (Redwood Materials)

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EXPERT Insight

Sheldahl Leverages History of Flexible-Circuit Expertise for New Era of Vehicle Electrification

For SAE's Expert Insight, Enid Kivuti, Director of Engineering and Program Management at Sheldahl, a flexible-materials, films and circuits technology specialist with a variety of innovative automotive applications, provides perspective on the auto industry's rapid expansion into electrification and the need for increasingly sophisticated materials solutions. SAE's Automotive Engineering *spoke with Kivuti about how the company's thin films and insulation, flexible circuits and printed electronics can enable advanced and durable innovations for all manner of electrification applications.*

***Automotive Engineering:* Provide a bit of an overview of Sheldahl's technology — what are your most important differentiations?**
Kivuti: Our expertise and 'technical toolbox' is really wide. We manufacture our own materials; we buy films and foils, but we formulate and we engineer adhesives. We put these dissimilar layers together and that's really the core of our technology. Our differentiation is to really begin with the end in mind. What is it that you're trying to do?

Today, there's a lot of work going into vehicle electrification, and when you think about a flexible circuit, there's several things that it needs to be able to do in that application. We're actually going to make something that's going to be able to be flexible, be able to help with thermal management, to be able to fit and be light so that you can have the efficiency that you want, that will have the sensors that are needed for safety. And all of these things can be integrated. Why? Because we understand the materials. We understand how they work together. And we listen to what the customer needs and we work with our materials to enable that solution.

Enid Kivuti, Director of Engineering and Program Management at Sheldahl.

***Automotive Engineering:* Electrification is top of mind for the automotive industry. What are Sheldahl's chief touchpoints in automotive, Enid?**
Kivuti: The ability to make a really long, continuous circuit. Sheldahl has a lot of automation and has had it for a long time. We make all of our products with roll-to-roll technology, which means you can have as long a circuit as you want. Of course, anyone who is an expert knows that there are certain limitations to that. Also, we are able to work with different types of materials with different electrical and mechanical properties and bring those together in a format that will work well for the end use. As vehicles move towards electrification, whether they are hybrid or fully electric, there are important requirements, especially as far as the interconnect is concerned. We believe that flexible circuits are a big answer — and especially with Sheldahl technology, because we'll go all the way from the material itself up to the assembled circuits.

***Automotive Engineering:* Sheldahl also has a presence in other high-reliability applications in medical and in aerospace?**
Kivuti: A very exciting application is the James Webb Space Telescope. Its purple sunshield material is all made at Sheldahl. It took about 13 years of innovating together with other aerospace companies.

In medical, one of the things that's really moving, as people try to control medical costs, is at-home monitoring, whether it's for health and wellness or actually medical. Wearable medical devices are really important. One of the key areas of focus within Sheldahl is printed electronics. We do that in automotive for touch sensors.

***Automotive Engineering:* Sheldahl was formed in 1955, nearly 70 years ago. What do you think are the strengths that have kept the company relevant?**
Kivuti: Innovation, really. And at the base of innovation is people. It's the core group of people who are working to solve problems, to seek to understand what it is that the customer really needs — not just what they *say* they need, but what is it that they're trying to solve and working through that. And that has been really the core of [Sheldahl's] innovation. For example, we were one reason the first transatlantic phone call was made. We had these metallized balloons and the signals bounced off them to make that first transatlantic call. Using materials technology to enable innovation and to enable other parts of science to come together. ■

Watch the full interview with Enid.

EDITORIAL

Engineering Sustainability

Watching a junked school bus being fed into a mammoth hammer mill, which loudly pummeled the bus into fragments of metal, rubber, and plastic, was a sight I'll always remember. I was visiting Huron Valley Metals, a major scrapyard and recycling facility near Detroit, during reporting for an article on automotive recycling. Seeing that big yellow bus chomped up, with practically 100% of its steel, iron and aluminum content collected for reuse, made clear to me the importance of recyclability and materials choice in product design.

But a glance at the refuse and recycling containers awaiting curbside pickup in my small town — all headed for the landfill — reveals how little the public knows, and cares, about product end-use. A lack of ready markets plays a role in what currently gets tossed. So does a hodgepodge infrastructure with myriad definitions and rules. Partly as a result, the U.S. plastics recycling rate is just 5%, according to the Dept. of Energy. Effective materials recycling gets far less attention than tailpipe emissions but is equally deserving of industry focus.

There's a strong push from our OEM customers on sustainability.

Electrification, and the high-value electronics content in vehicles, are making materials reuse a key tenet of OEM and supplier business strategies. This month's cover feature on EV battery recycling, by veteran environmental reporter Jim Motavalli, details the global enterprise that's emerging, at scale, and the opportunities and challenges involved. We also look at innovative "zipper" technology, developed by U.K.-based In2Tec, for reclaiming nearly all the high-value components on discarded PCBs.

Sustainability is the buzzword du-jour. In some corners it's hyperbole; at others it's a mission. I define it simply as living responsibly and getting the maximum use out of all that is manufactured. For SAE readers, "sustainable" means developing products, methods, and systems efficiently, aiming for zero waste and environmental impact. Businesses, often under pressure from investors, regulators, and customers, now are making sustainability integral to their guiding principles. Their suppliers are being required to follow suit; witness the Greenhouse Gas Protocol's new Scope 3 GHG emissions standard that will impact companies at all tiers.

"There's a strong push from our OEM customers on sustainability, including requirements related to CO2 emissions in their specifications," Giulio Ornella, VP of global engineering at Dana Corp. told me recently. He sees Scope 3 as "a huge opportunity" for Dana. In a separate interview Andreas Wolf, CEO of powertrain Tier 1 Vitesco, concurred.

Sustainability is being institutionalized across the academic and industry landscapes. Stanford University recently launched its Doerr School of Sustainability; MIT has its Sloan Initiative. In business, chief sustainability officer (CSO) is the hottest new management seat. Fortune 500 companies hired more CSOs in 2020 than in the previous three years combined. SAE International is on board, launching its Office of Sustainable Energy to help industry tackle complexities in this area.

The bandwagon is rolling, but my jaundiced eye sees looming controversy as well as benefits. Nuclear power, for example, was deemed "unsustainable" after various reactor accidents. Today, however, "nukes" are widely being reconsidered as a key to meeting net-zero carbon targets. And fossil fuels keep the lights and heat on when renewables can't deliver. Unexpected externalities have a way of turning ideals into compromise.

Lindsay Brooke, Editor-in-Chief

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SUPPLIER EYE

Good news and bad news for 2023

The Fall season brings the annual rite of passage for the industry – setting budgets for the next calendar year. The balance of building revenue forecasts driven by vehicle demand, while constructing the cost side to establish profitability, is given extra attention at this time. While most suppliers will lay out a three- or five-year AOP (Annual Operating Plan), the primary focus is on the forecast for next year. Budgets determine available capital for reinvestment, labor rates, expected material costs and in the end — a forecast of profitability. Looking toward 2023-2024, forecasting both revenue and costs is more difficult than at any time I can recall in my 35 years of vehicle forecasting.

While historically there have been minor supply interruptions to slow vehicle output, nothing in the past compares with the events that have hammered the industry since late 2019 — a multi-week labor dispute between the UAW and General Motors, followed in the last 12 quarters by more labor stoppages, a global pandemic and a semiconductor supply crisis. For three years, production output has been driven by a supply dynamic, not consumer demand. Suppliers have struggled to find balance as OEMs cut shifts of less desirable vehicles to allocate microchips toward output of more profitable vehicles. Inventories have slipped badly in the process.

The auto industry does not adjust well to a constant barrage of supply disruptions because the business is very linear. One issue at a time, please.

Beyond the slowly improving chip-supply situation, geopolitical events of 2022 and related economic factors have spurred inflation levels not experienced in decades. Russia's invasion of Ukraine and the war that continues, coupled with the reckoning of China's dominance in materials and processes critical for electric vehicles, have driven a new focus on supply security.

Michael Robinet
Executive Director, Consulting, S&P Global Mobility

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Fixed contracts, combined with the lack of volume guarantees from OEMs, have been a gut punch for suppliers.

Complicating the significant material-cost increases has been the inability for many suppliers to raise prices in concert with these rising costs. Fixed contracts, combined with the lack of volume guarantees from OEMs, have been a gut punch for suppliers.

In a previous column, I wrote about ILL — Inputs, Labor and Logistics — impacting the profitability of players at every tier of the supply chain. Many months later, those factors continue to force additional caution into already conservative future planning.

That brings us to setting budgets for 2023. The good news is that many supply constraints are easing, if gradually. The output dynamic is slowly improving. But inflation and shortages of labor and some materials remain significant challenges. So, when can we expect consumer demand to return as the primary factor driving vehicle production output ?

Suffice to say, as global banks quickly raise interest rates to stave off higher-than-desired inflation, retail affordability is compromised. Slower economic activity is the unfortunate result.

The industry eventually will work through the supply-driven constraints, raise vehicle inventories, and reduce waiting times for new vehicles. In the process, understanding how the extreme inflation of 2022 (extending more modestly into 2023) will impact vehicle demand — and knowing how to successfully navigate through it — is key.

S&P Global Mobility expects energy and material prices, labor, and logistics costs to slowly moderate, with the auto industry shifting to a demand-driven dynamic by 2024 — four years after supply constraints were the order of the day.

The industry is beginning to understand how to deal with slow demand while it simultaneously grapples with a constant barrage of supply constraints. ■

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Samar Aidrus, Development Engineer at dSPACE

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The Inside Story on Ignition Coils

In an interview with SAE's *Automotive Engineering*, Robert Nordstrom, Principal Engineer, Wells Vehicle Electronics, discusses the research and development and advanced materials, manufacturing and testing expertise Wells leverages to assure the maximum level of performance, durability and reliability is engineered into the more than one million ignition coils the company manufactures annually.

AE: **Describe some of the sophisticated testing processes you've installed more recently to assure reliability on ignition coils. You've adopted the use of finite element analysis (FEA) for example, correct?**

Nordstrom: Yes, we've developed with our parent company, NGK, some extremely stringent testing requirements. And from their knowledge of spark plugs to that whole area of the engine, they're very well versed in that. So, together, we worked with NGK to develop strong reliability testing and accelerated life testing. The typical life test that maybe somebody would be employing is to create a replica spark gap and [test with] that. We're actually utilizing some other techniques that achieve a high-voltage situation for a longer period of time, as opposed to whenever a spark plug flashes over, that happens in a very short duration. What we're trying to do is to extend that high-voltage time period, which puts the materials in a high-voltage environment for a longer period.

Robert Nordstrom, Principal Engineer, Wells Vehicle Electronics.

I guess the best analogy I can give: you take a hammer and a nail and you hit it once, it might go in a certain distance. But now, instead of hitting it with a hammer, you hit it with a hundred-pound weight. So, now it drives the nail all the way. It's a longer duration — it's more energy into that place.

AE: **Testing an ignition coil for thermal shock also is critical?**

Nordstrom: Absolutely. We do a variety of thermal shock testings with numerous chambers. We go from a hot to a cold chamber — that's kind of the older method; it's like a mechanical system. And now, there are high-performance thermal shock chambers that exchange the air much more quickly, so there are fewer mechanical moving parts. We can get thermal transfer rates of greater than 20 degrees C per minute.

That's really moving heat in and out of the components very quickly. And the reason we're doing that is to check the stress levels inside of the ignition coil to ensure that the dissimilar materials — steel, copper and plastic, and epoxy — all of those things are [thermally] moving at different rates and the last thing you want to have on an ignition coil is a crack.

AE: **Wells even molds its own plastic parts?**

Nordstrom: That's correct. We mold our own plastic parts here; we mold our own bobbins and we mold our housings, injection molding with high grade DuPont resins. We're molding Rynite; PET is a very common polymer used in high-voltage, so we're using that, utilizing glass-filled polymers. Porosity in plastic parts is pretty important — that way, we can control that quality. We've been molding some ignition coil components since the '90s.

AE: **You said Wells manufactures in excess of one million coils a year. How many varieties does that include?**

Nordstrom: We're making probably around 60 different types; we manufacture all our coils in North America. Most OEMs now are doing coil-on-plug (COP). I think the big question is whether they put an ignition module on that coil or they put it on the ECU.

AE: **What's been one of the most significant things you've seen change in terms of manufacture and testing of ignition coils?**

Nordstrom: I think one of the biggest changes I've noted is OEMs getting away from pencil coils. They seem to have been going away from that and back into more of a coil-on-plug (COP) layout. You can get a lot of energy out of a COP. You can get a lot more winding in there, you can get a lot more steel. ■

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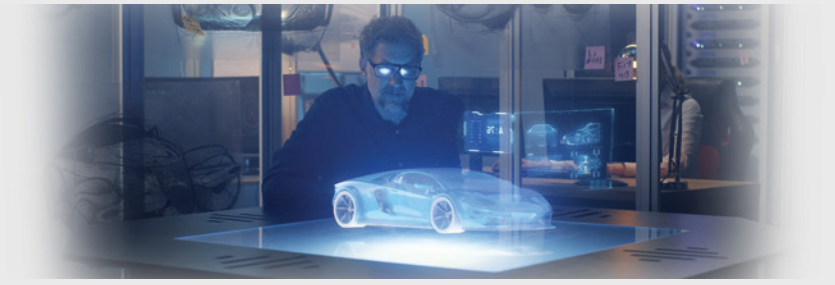

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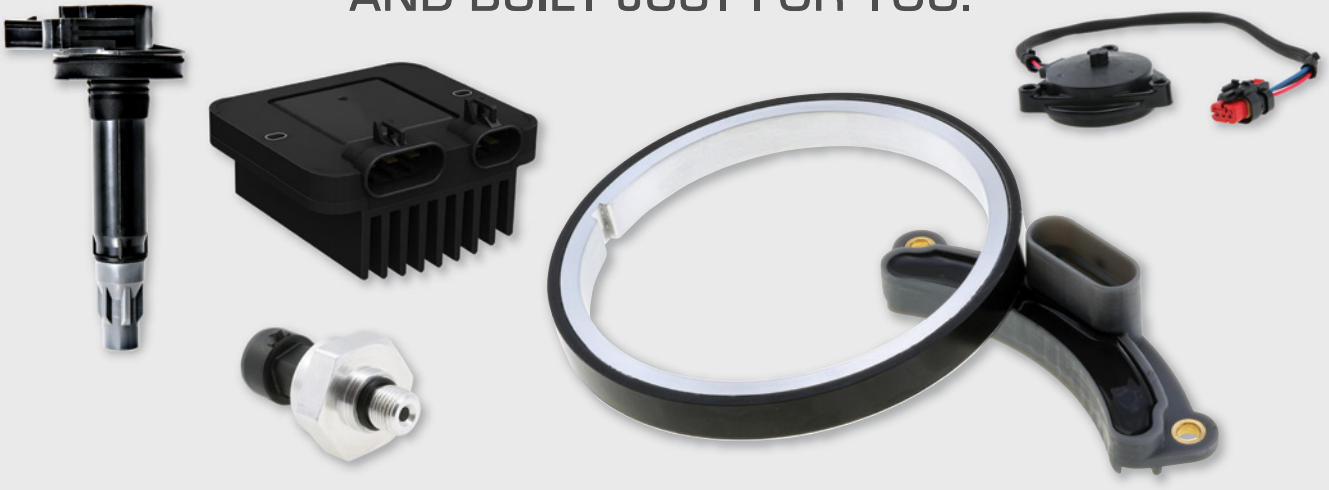

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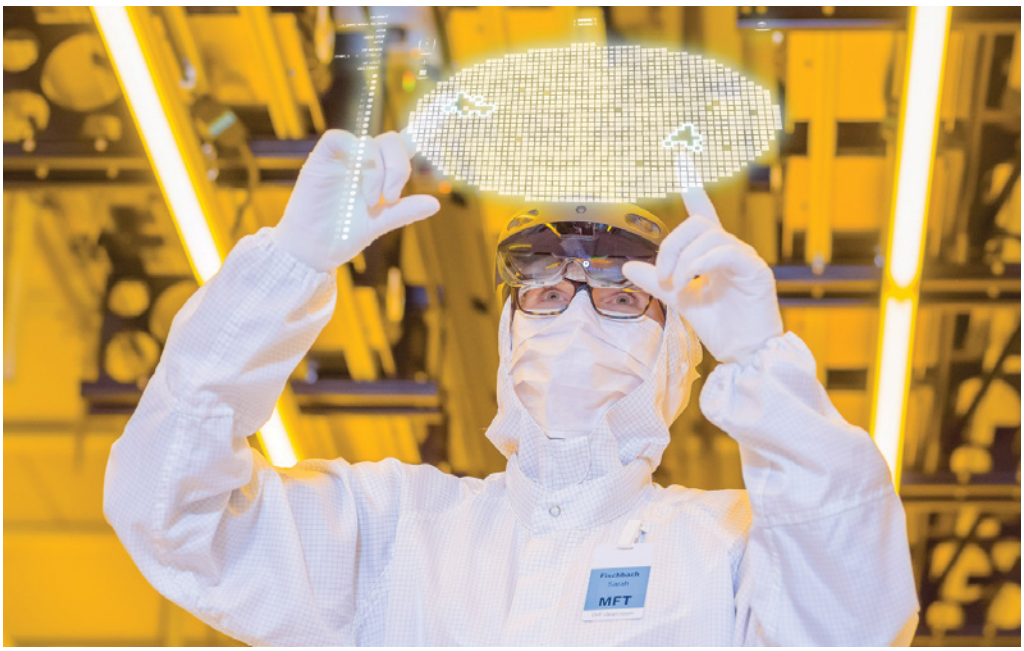
SEMICONDUCTORS

New 300-mm wafer fab is key to Bosch's chip future



The 300-mm silicon wafers can require up to 500 steps to manufacture.

A new semiconductor plant is the single largest investment made by **Robert Bosch AG** in the 122-year-old company's history. The facility, in Dresden, Germany, is welcome news to automakers focused on building regional electronics production in the wake of supply shortages and bottlenecks. It's the latest move in Bosch's strategy to be a major player in the global microchip industry.

Bosch claims that the new Dresden plant, which began construction in 2017, is the first 300-mm (11.8-in.) wafer production plant (known as a wafer fab) to be built in Europe since 1999. Its construction was in step with the European Chips Act announced in February 2022. One of the aims of the Act is to double Europe's share of global semiconductor production from 10% to 20% by 2030.

A 300-mm chip contains thousands of identical semiconductor devices. Producing a semiconductor involves transferring an integrated layout in a three-dimensional structure to silicon. The process needs repeating up to 27 times and can involve around 500 process steps, according to Bosch engineers. This can take several months, depending on the complexity of the required circuitry.

R&D center focus

Bosch already has invested €1B in the Dresden facility, which was part-funded by the IPCEI (Important Project of Common European Interest) special subsidy. The plant currently employs 350 and staffing will increase to 400 by the end of 2022 and to 700 by the time the plant is completed. The new wafer fab is one of two Bosch production facilities in Germany. The other, at Reutlingen near Stuttgart, has produced semiconductors for more than 50 years. Reutlingen produces semiconductors on 150-mm (5.9 in.)- and 200-mm (7.87 in.)- diameter silicon wafers.

A new European funding program, IPCEI 2, is in progress. Within the framework of IPCEI 2, Bosch plans to invest €3B in semiconductor technology and systems by 2026.This will involve an investment of more than €170 million in the construction of two new development centers at Reutlingen and Dresden, with work at Dresden due to begin in 2023. Dresden will be home to a new development center for both semiconductors and microelectro-mechanical system (MEMS) sensors.

Bosch also plans to produce the MEMS sensors on 300-mm wafers; production is scheduled to start in 2026. Over the coming year,

BOSCH

Bosch intends to spend a further €250 million in expanding the clean-room facility at Dresden.

GaN research

Power electronics are key to the needs of electromobility and Bosch already has been able to extend the range of electric vehicles by 6% through using silicon-carbide (SiC) chips, the company claims. Bosch expects the market for these chips to grow by an average of 30% annually throughout this decade. This has triggered a hunt for chips that offer greater efficiency and reduced cost.

For this, Bosch has begun research into gallium nitride (GaN)-based chips, which already are used in smartphone and laptop chargers. The higher voltages needed for EV charging, up to 1,200 volts, mean that more research is necessary before GaN chips would be production-ready for these applications.

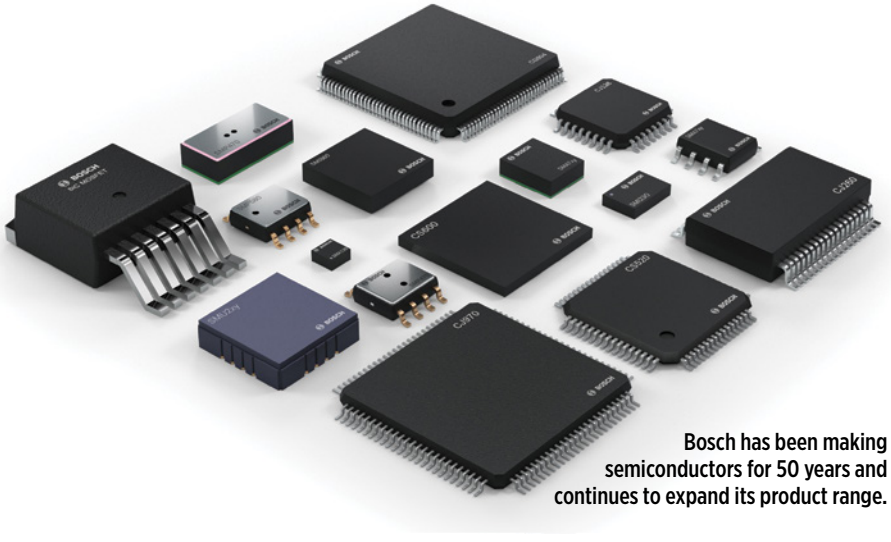
According to Dr Stefan Hartung, chairman of the board of management of Robert Bosch GmbH, "All in all, chips' share of a car's total value will quadruple over the course of the decade — from just under €200 to more than €800."

Bosch recently demonstrated some of its semiconductor applications to a small group of reporters, including SAE Media, at Dresden. Products included a redesigned EV charging cable. European models normally are supplied with two separate cables,

Bosch chairman of the board Dr. Stefan Hartung expects semiconductor share of a new vehicle's value to quadruple this decade.

BOSCH

Bosch will begin producing MEMS sensors on 300-mm wafers by 2026 at Dresden.



Bosch has been making semiconductors for 50 years and continues to expand its product range.

one for charging from a European standard 230-V domestic power socket and the other equipped with a Type 2 connector to charge from either a 7-kW AC wall box domestic charger or 11-kW or 22-kW three-phase charger.

Bosch has redesigned the cable so that one cable serves all needs. This has involved integrating the control electronics to regulate the charging in the Type 2 connector at the vehicle end. At the other end, temperature control and a residual-current device are integrated in the connector. This means that the control box usually integrated in the 230-V domestic charging cable can be eliminated, reducing weight by around 40%.

By equipping the other end of the cable with an interchangeable domestic plug or Type 2 connector, the vehicle can be charged from a domestic socket, AC wallbox or AC three-phase supply.

The company also displayed its pre-integrated systems solutions in its advanced driving module (ADM) rolling chassis, designed as a platform for EV development. Individual systems for drive, steering, and braking are integrated into a single harmonized and flexible system.

Simplified interfaces and a consistent software architecture reduce complexity and ensure optimized communication between components. This modular approach allows OEMs to integrate the ADM with their requirements. The rolling-chassis prototype was built as part of an engineering alliance with Benteler, a chassis and body systems Tier 1 supplier.

Big boost in capacity

Perhaps it's not a surprise that although Bosch needs new machinery to increase its semiconductor production, the shortage of semiconductors also is affecting the supply of that machinery. "It's a huge point — the drying out of the supply chain and on the other hand, the huge capacity need which was then also generated by [COVID-19]," noted Patrick Leinenbach, senior VP for Manufacturing Semiconductor Supply Chain operations for Bosch. "Now we are all looking first to serve our customers, to ensure that our customers are safe. Huge teams are working on it for our company, to look where to take the products."

Although SiC chips have helped to extend EV range, the material presents its own challenges. "The raw material is different. If you're looking for silicon, you have to speak monolith, which is then sliced down in wafers," Leinenbach said. "It's not working for silicon carbide."

This limits the size of wafers that can be produced from the material. Bosch currently can make 150-mm SiC wafers: "You can buy 200-mm wafers at the moment, but the quality is not so good," he stated. "Therefore, it will take time also to adjust the processes to make them better."

Gallium nitride offers an alternative material, particularly for power management in charging systems. But as Leinenbach explained, "Silicon carbide gives us the possibility to go back to silicon and then scale this up on 300-mm. So, there are advantages on the electrical coefficients and the things from silicon carbide, in comparison to the gallium nitride. But the gallium nitride can be produced in 300-mm. So, it's let the market decide what they want."

John Kendall

BOTH IMAGES: BOSCH

CHASSIS

Brembo's Sensify aims to revolutionize braking

Brembo recently demonstrated the company's new concept of braking technology on the skid pad at the **Michelin** Laurens Proving Grounds in Mountville, South Carolina. Dubbed Sensify, the company dubs it an "intelligent" new braking design. Saying its "most advanced braking system" is "designed to ensure the best driving experience and total safety," the system integrates a hydraulic actuator, a series of brake-control units and a pedal simulator with vehicle sensors so that braking at each wheel can be controlled independently.

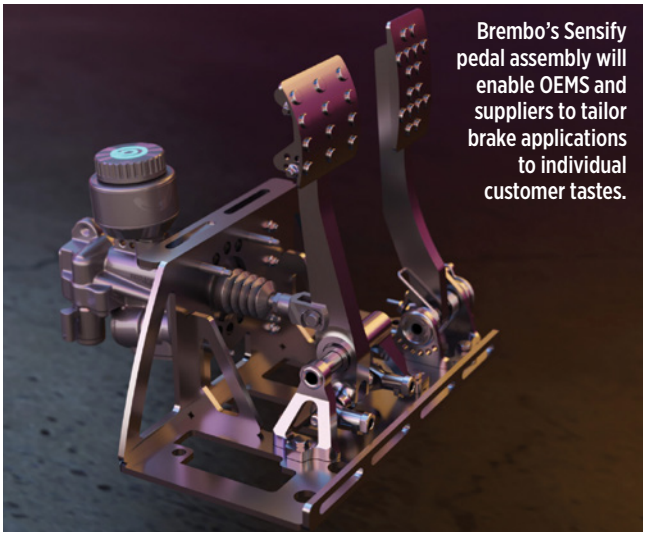
"Sensify serves as another significant step forward in advancing safe, data-driven solutions and sustainability initiatives seen across the automotive industry," said Daniele Schillaci, Brembo's CEO. "This new system uses artificial intelligence to provide drivers a unique driving experience."

By optimizing the independent braking action of each wheel, Sensify provides a greater degree of control for the driver under normal and panic situations. Brembo also states that the system also is capable of controlling pad position, which minimizes drag between pads and discs, improving fuel consumption and range of ICE vehicles and EVs.

Brembo also said that Sensify offers greater flexibility for OEs by simplifying braking-system integration into any electric, hybrid or ICE platform thanks to features such as customizable pedal response, increased stability and control and improved regenerative braking. The design architecture reportedly can be scaled to suit the braking needs of everything from hypercars to commercial vehicles.

Devil in the details

Though on the surface Brembo's Sensify system may seem more evolutionary than revolutionary, it is the integration of the system's components that makes the technology unique.



Brembo's Sensify pedal assembly will enable OEMS and suppliers to tailor brake applications to individual customer tastes.

BREMBO

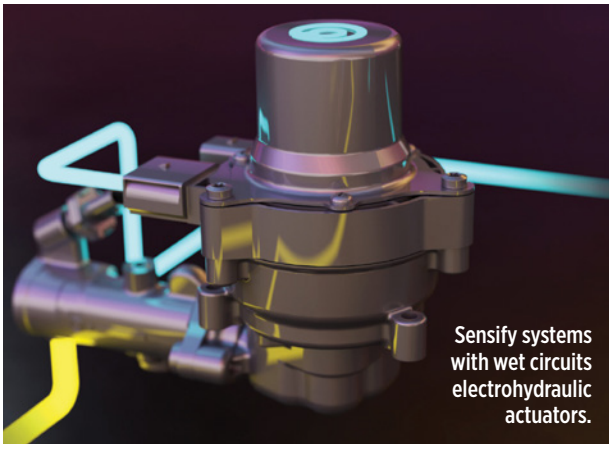
Brembo's new Sensify braking system under test by SAE Media at the Michelin proving grounds.

"Sensify is the tangible implementation of our mission to become a provider of cutting-edge technology in the field of automotive braking," said Schillaci. "For many decades, the braking systems we've been providing have been applying braking pressure on all four wheels simultaneously. Sensify can independently manage the braking forces on each wheel according to the driver's needs, vehicle dynamics and road conditions."

By managing brake application independently, Brembo claims the system will offer the best performance in all conditions. The system is adjustable to customize braking response according to driving-style preferences and conditions.

"The brake system as we know it today is no longer the sum of parts," Schillaci explained. "It is becoming an ecosystem where AI and software play an active role. We're leveraging data collection to improve the driver's experience and allowing the system to be constantly updated and improved. We're also creating a platform that includes software, predictive algorithms, and data management which will allow an active contribution to the cars handling."

The system consists of a pedal simulator with an integrated pressure sensor, a tandem of brake control units to control front and rear channels, and either a hydraulic actuator or an electronic connection depending on brake-system application. Brake-by-wire systems also will feature an electromechanical caliper. Conversely, wet systems will feature electro-hydraulic actuators.


Sensify systems with wet circuits electrohydraulic actuators.

While Sensify is capable of operation in a completely dry/brake-by-wire configuration, it also can be implemented using traditional wet (hydraulically actuated) calipers. Brembo explained that certain markets, such as China, still require a wet system for redundancy purposes. There also are applications, such as hypercars and motorsports, for which the unspring rotating mass of an electric caliper is not desirable. As such, Sensify was designed to work with wet, dry, or tandem systems.

On track impressions

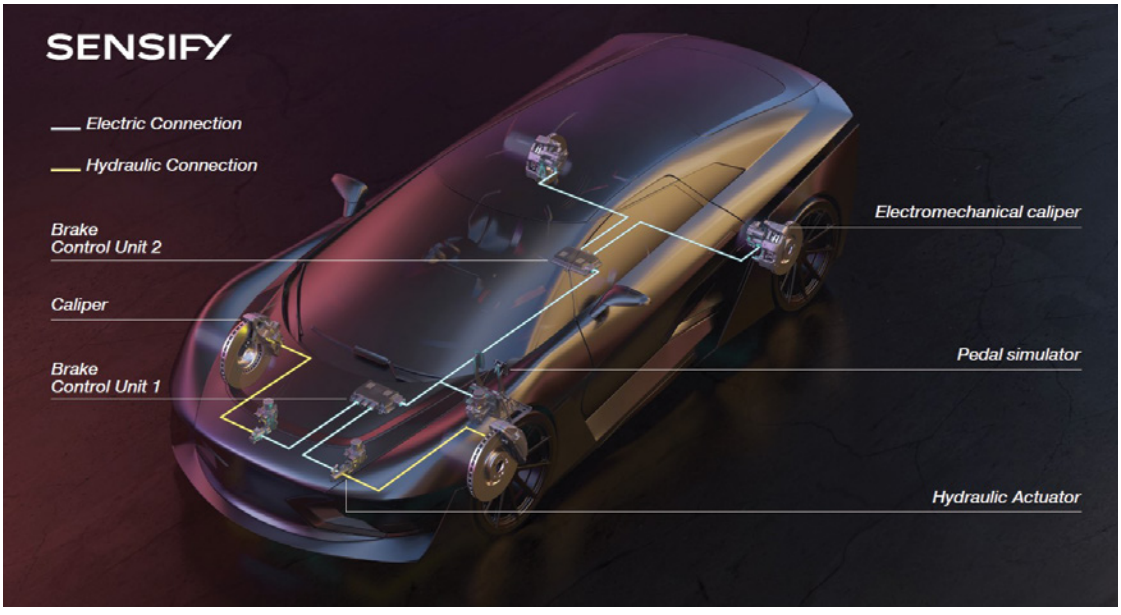
Brembo turned loose the media on the skid pad at the Michelin Proving Grounds to experience Sensify first-hand. The test bed for the system was a pair of **Tesla** Model 3s. One of the vehicles was equipped with the OEM Tesla-spec system, while another was outfitted with Sensify using wet front and dry rear circuits.

The track exercises began with straight-line panic stops on wet and dry surfaces from 75 mph (120 kph). A control test was performed in a stock Model 3 before hopping into the Sensify-equipped car for comparison. For those who have experienced full ABS actuation on a modern vehicle, the Sensify system will require some recalibration of senses. When full pedal pressure is applied, no hydraulic pulses are felt by the driver. Instead, the system modulates brake pressure at each wheel based on feedback from the vehicle's sensors and surface mu.

While the lack of pressure feedback through the pedal may at first disorient seasoned drivers, it becomes easy to trust the system after a few hard stomps. The finite control that the Sensify system has over each individual wheel translates to greater fidelity at the vehicle's limits even when full braking force is being applied. This was especially apparent in the handling portion of the on-track session.

The handling test was held on a wet and dry skid pad with panic stops from 50-70 mph (80-113 km/h). The course consisted of sweeping and decreasing-radius turns with panic-stop sections on wet and dry pavement. Some of the panic stops involved an obstacle-avoidance maneuver through a chicane

BOTH IMAGES: BREMBO



The hardware behind Brembo's Sensify system is scalable for light and commercial vehicles as well as motorsports applications.

BREMBO

delineated by cones while at full brake pressure. These maneuvers truly demonstrated the capabilities and advantages of the Sensify system. While the OEM Tesla brake system acquitted itself well in these maneuvers, the Brembo system provided noticeably improved maneuverability and agility.

Serving several purposes

Brembo has gone to great lengths to emphasize that Sensify was designed to be an intelligent platform meant not only to streamline integration into modern vehicles, but also to provide drivers with greater control and safety. The panic-stop and obstacle-avoidance maneuvers at Michelin's Proving Grounds demonstrated that this system is very close to production readiness and may be one of the largest steps forward in braking technology in decades.

Brembo stated that one of the biggest advantages of Sensify over conventional braking systems is the much faster time to lock. Company representatives stated that the time-to-lock for the Sensify system is about 100 milliseconds, versus a conventional system, which requires about 180 milliseconds.

As of September 2022, Brembo had not announced a date or vehicle on which the system will debut. The company said it is confident the Sensify will be production-ready by 2024.

Matt Wolfe

Seventh-generation of Ford Mustang is highest performer yet

The exterior visuals still emphasize a long hood and a short deck, but the V8-powered 2024 Mustang GT's mammoth air intakes are a telltale that things have powerfully changed. "When you open the hood and see the dual air induction system on this fourth-generation naturally aspirated Coyote [V8] engine, there will be no mistake that you are looking at the seventh-generation Mustang," said Eddie Khan, the Mustang's vehicle engineering manager.

Khan and other **Ford** design and technology specialists were interviewed by SAE Media prior to the iconic sports car's global debut on September 14 at the 2022 Detroit auto show. While the 2024 car's track and other key dimensions are essentially unchanged from the current ponycar, the next-generation model boasts improved aerodynamics, stiffer steering, more power and a cabin infused with new-to-Mustang technologies.

The Mustang's next-generation engines (2.3-L turbocharged 4-cylinder EcoBoost and the Coyote 5.0-L V8) feature various technology upgrades. The V8 replaces the prior composite oil pan with a steel pan. Changes for the 2.3-L include a left-side exhaust manifold, a new twin-scroll, low-inertia turbocharger with electronic wastegate, and revised camshaft timing. While no hp or torque numbers for the 2024 car are yet being released, the 2022 Mustang GT V8 produced SAE-certified 450 hp at 7,500 rpm and 420 lb-ft (569 Nm) at 4,600 rpm.

The 2024 Ford Mustang is rebodied and features revised V8 and 4-cyl. engines.

Ecoboost and aero development

The EcoBoost engine now uses a dual fuel-injection system (port fuel injection combined with 350-bar [5076-psi] direct injection) instead of DI only. To replace the prior airbox-on-the-side configuration, the new engine has an integrated air-induction system designed for better underhood space utilization. The engine also features revised variable cam timing.

A **Getrag** 6-speed manual transmission and a Tremec 10-speed automatic with SelectShift remain paired with the V8, while the EcoBoost still mates only to the 10-speed automatic, fitted with new controls for 2024, added Khan.

The seventh-generation Mustang's aerodynamics and downforce garnered significant attention from engineers and the exterior design team. "You want to make sure the airflow stays with the profile of the car," said Khan. With the exception of the roof, all body panels are new for the 2024 model. The Mustang GT's front air vent on the driver's side is functional, but the passenger-side air vent is blocked for lift and drag benefits.

Steering-related alterations include a new steering rack, faster steering ratio, stiffer cross-car beam, a splined intermediate shaft, removal of intermediate shaft isolator and an upper intermediate shaft that's roughly three times stiffer than the prior setup.

Contemporary cabin tech

In the driver's side of the cockpit, interior restyling emphasizes a 12.4-in (315-mm) flatscreen gauge cluster and 13.2-in (335-mm) center-stack touchscreen. On Premium and higher trim grades, the screens seemingly appear as a continuous display. Other interior features include a segment-first electronic drift brake, part of the Performance Package. The electronic drift brake facilitates drifting capability while retaining the look and functionality of a traditional mechanical hand brake.

Pricing for the 2024 Mustang will be announced at a later date. The seventh-generation pony car is slated to start production in 2023 at the Flat Rock Assembly Plant in Flat Rock, Michigan.

Kami Buchholz

The 2024 Mustang cabin features a flatscreen gauge cluster and center-console touchscreen that, on higher-trim models, gives the impression of a continuous piece of glass.

BOTH IMAGES: FORD

Jeep springs its first BEVs

Four all-new, battery-electric models will spearhead **Jeep**'s plan to electrify 100% of its product lineup by 2025, the **Stellantis** brand announced on Sept. 7. The quartet of BEVs includes the 4-door Jeep Recon and an electric Wagoneer code-named Wagoneer S, to be built in North America, and the Jeep Avenger, a compact 5-door SUV that will be built and sold in Europe. Jeep executives noted a fourth new BEV model also is in the near-term launch pipeline but provided no details.

The Avenger enters production next year, with Recon and the Wagoneer S following in 2024, said Christian Meunier, Jeep brand CEO. The "4xe" used to delineate Jeep's current range of plug-in hybrid vehicles will also serve as an umbrella for the new battery-electric models, with Meunier explaining that "4xe is a forward-thinking strategy" aimed at transforming Jeep into "the leading electrified SUV brand in the world" (www.youtube.com/thejeepchannel). The BEV escalation aims for 100% of Jeep's European sales and 50% of U.S. sales to be all-electric by 2030, in line with Stellantis's corporate net-zero carbon emissions-reduction target.

Jeep currently manufactures two PHEVs, the Wrangler and Grand Cherokee. The plug-in Wrangler is the top-selling PHEV in North America, according to Jim Morrison, head of the Jeep brand in the region.

Jeep Recon offers a pushbutton retractable roof. Exterior door hinges ease door removal for open-air driving.

Code-named Wagoneer S, the first electric premium Jeep SUV features a new focus on advanced aerodynamics.

BOTH IMAGES: JEEP

Jeep Recon and Wagoneer S BEVs

Picking up the Recon badge from a current Wrangler off-roading package, Jeep creates a vehicle that fits in the product lineup between Wrangler and Cherokee, but "definitely inspired by Wrangler," noted Ralph Gilles, Stellantis chief design officer, during the vehicle reveal. Recon's removable doors and glass, power-operated retractable top, locking electronic drive axles, extensively skid-plated underbody and U-Connect telematics should serve it well as a **Ford** Bronco fighter — one with no tailpipe emissions. Jeep Recon will be sold in major global markets.

The premium 5-door midsize electric Wagoneer S is expected to share elements of its modular battery and propulsion system with those of Recon, according to Stellantis engineering sources who spoke with SAE Media. The longer-overall Wagoneer will carry a larger, more energy-dense battery pack that Meunier said will help it deliver an estimated 400 miles' (644 km) range on a single charge. Generating an estimated 600 hp (447 kW) peak, the electric Wagoneer S will be capable of 0-60 mph (96 km/h) acceleration in around 3.5 seconds, he said.

Gilles highlighted the focus on aerodynamic efficiency in the Wagoneer S exterior design, including a notably EV-like nose (fitted with a very narrow, LED-lit take on Jeep's slotted grill) and a slickly-executed "wing" at the rear roof/backlight intersection that harkens to the classic Dodge Daytona and Plymouth Superbird, albeit in lower-profile form.

Jeep Avenger for Europe

By the end of 2022, Jeep's product range will be 100% electrified in nearly all European markets. The entire range will be BEV by 2030, the company promises.

First revealed in early 2022, the Avenger compact SUV will be produced in Stellantis's Tychy, Poland, plant and sold across Europe and in Japan and South Korea, as well as other markets. Vehicle range per full charge is targeted at roughly 250 miles (400 km). Avenger will debut October 17 at the Paris Motor Show and go on sale in early 2023.

Lindsay Brooke

CLOSING THE LOOP ON EV BATTERY RECYCLING

New battery cells proceeding through the final manufacturing stage at the GM-LG Energy Solution Ultima Cells factory in Ohio.

Recycling battery materials is vital to the electric-vehicle future, but the way forward faces a host of hurdles.

by Jim Motavalli

Development of a robust electric vehicle (EV) battery recycling industry has moved from a net-positive sideline to a necessity as automakers, and their suppliers, transition away from internal combustion. Experts say that global mining operations are simply not on track to produce the virgin raw materials needed to meet the dramatic ramping up of the world's battery production. Additionally, the sourcing of these materials raises numerous red flags in terms of conditions for workers, site pollution, geopolitical complications and concentration of ownership.

The good news is that the Biden Administration's recently enacted Inflation Reduction Act provides incentives for automakers to use recycled minerals in their batteries. Startup companies, including one founded by the former longtime CTO at Tesla, are taking on the recycling challenge and partnering with carmakers. Automakers are also concentrating on proven technologies such as hydrometallurgy (often, leaching, which involves immersing the cells in acid to dissolve the acids into a solution) and pyrometallurgy (burning and smelting), to efficiently recover a very high percentage of key metals from used lithium-ion (li-ion) EV batteries. But there's a conundrum: battery companies are working to reduce the amount of problematic, hard-to-source metals in their cells, which has the potential to also reduce their viability for cost-effective recycling.

Another approach, which has drawn federal research funding, is direct recycling or recovery, with the advantage of retaining the intact cathode material. According to Jeffrey Spangenberg, the materials recycling group leader in the applied materials division of Argonne National Laboratory and head of the national ReCell Center R&D initiative, the hydrometallurgy process destroys the cathode. "If we can keep the cathode as a cathode then it can go right back into a battery and save quite a bit of money," he explained. "But there are a lot of challenges with it. For instance, battery cars are likely to last 20 years, in which time technology doesn't stand still. We have to figure out how to make old cathodes marketable."

Problematic materials

One key aspect of the looming materials problem is in the need for nickel, which often gets overlooked as the focus is on lithium and, to a lesser extent, on cobalt.

According to Sam Abuelsamid, principal research analyst for e-mobility at Guidehouse Insights, for every 100 kilowatt-hours of battery in an EV, 61 to 66 kilograms of nickel are needed. If EV penetration reached 100% (unlikely until the 2040s) roughly 5.8 million metric tons of nickel would be needed annually if we rely solely on

GM

nickel-rich batteries, he said. But according to Statista, total global mining of nickel produced only 2.7 metric tons in 2021. The industry would have to more than double worldwide production—unless recycling was a factor.

"Recycling is absolutely essential," Abuelsamid said. "We don't want to be dumping batteries with these essential metals into landfills. We need to recapture as much as possible, because we will need way more EV batteries than we currently can build with available virgin materials."

Complicating the nickel supply is the disruption of the Russia-Ukraine war. Russia is the third-largest global nickel supplier, and in first quarter 2022 prices doubled to $100,000 per ton on potential disruption fears. Nickel is only one of the problematic metals that make up today's li-ion batteries—which are still the state of the art, at least until production-ready solid-state batteries (without liquid electrolyte) are available.

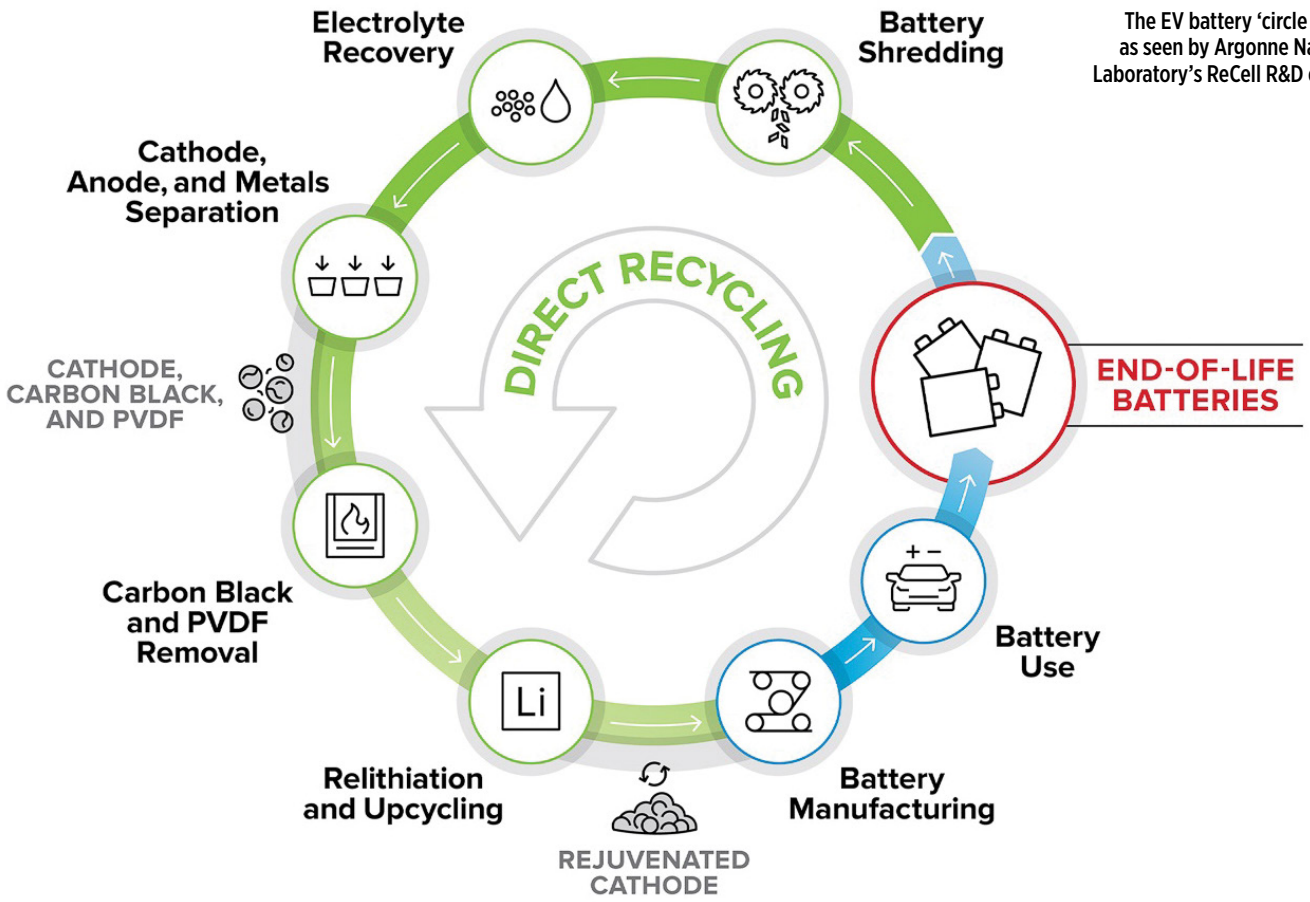
Henry Sanderson, a former *Financial Times* commodities and mining reporter who now works for Benchmark Mineral Intelligence, is the author of *Volt Rush*, a new book that focuses on the problematic materials in li-ion batteries. "We have to open our eyes to the supply chain behind the move away from fossil fuels," Sanderson told SAE Media. "It is hidden, almost opaque, and currently mostly controlled by China. And it involves more than putting up some solar panels—it's about raw materials and mining."

Lithium is heavily sourced through evaporation processes in arid basins in Chile, Argentina and Bolivia. And according to the Natural Resources Defense Council, the practice "contributes to the ecological damage of internationally recognized wetlands and protected areas, where water resources are already exhausted for local and indigenous peoples." Many of these communities have no say in—and receive little benefit from—the mining operations, NRDC reports. Chile, a major producer, has debated nationalizing its lithium resource, for both economic and environmental reasons.

More than 70% of the world's cobalt comes from the Democratic Republic of the Congo, where there are severe child labor issues (up to 40% of the cobalt work force), ongoing human rights abuses and horrendous working conditions with minimal safety.

Like lithium, cobalt is mostly refined in China, and Chinese companies, operating through the massive 'Belt and Road' international development initiative, own or have financed major stakes in lithium and cobalt mines—including 80% of the cobalt in the DRC, reports GlobalEDGE. After an international outcry, the leading Chinese companies have made some modest improvements in DRC mining practices. And some crude refining is now done locally, economically benefiting locals in the DRC.

CLOSING THE LOOP ON EV BATTERY RECYCLING



The EV battery 'circle of life' as seen by Argonne National Laboratory's ReCell R&D center.

The metal remains a flash point. "Cobalt is a 'dead man walking' in lithium-ion batteries," said Lewis Black, who heads Almonty Partners and has 15-years' experience in mining tungsten—another battery metal, with a 50%-recycled supply.

The battery industry—aware of these issues—has steadily reduced the amount of cobalt in its cells, but so far it remains an essential metal. Nickel, also problematic, is often mined in an environmentally destructive way. The massive Chinese-owned Ramu nickel mine in Papua, New Guinea, for instance, was estimated to dump 680,000 tons of waste into Basamuk Bay annually, leading to a $5.2 billion lawsuit from a local coalition.

More sustainable lithium mining, including a U.S. domestic supply, is under development (see sidebar) but recovering the metal from used EVs is a proven process. A ton of battery-grade lithium can be produced from 250 tons of ore and 750 tons of brine, or from just 28 tons of used lithium-ion batteries, the U.S. Dept. of Energy (DoE) said. The only problem is that less than five percent of battery lithium was being recovered in 2019, said DoE. But the industry is growing fast.

The big ramp-up

Kunal Phalpher is the chief strategy officer at Canada-based Li-Cycle, whose stated purpose is to "recover critical materials from lithium-ion batteries and reintroduce them back into the supply chain."

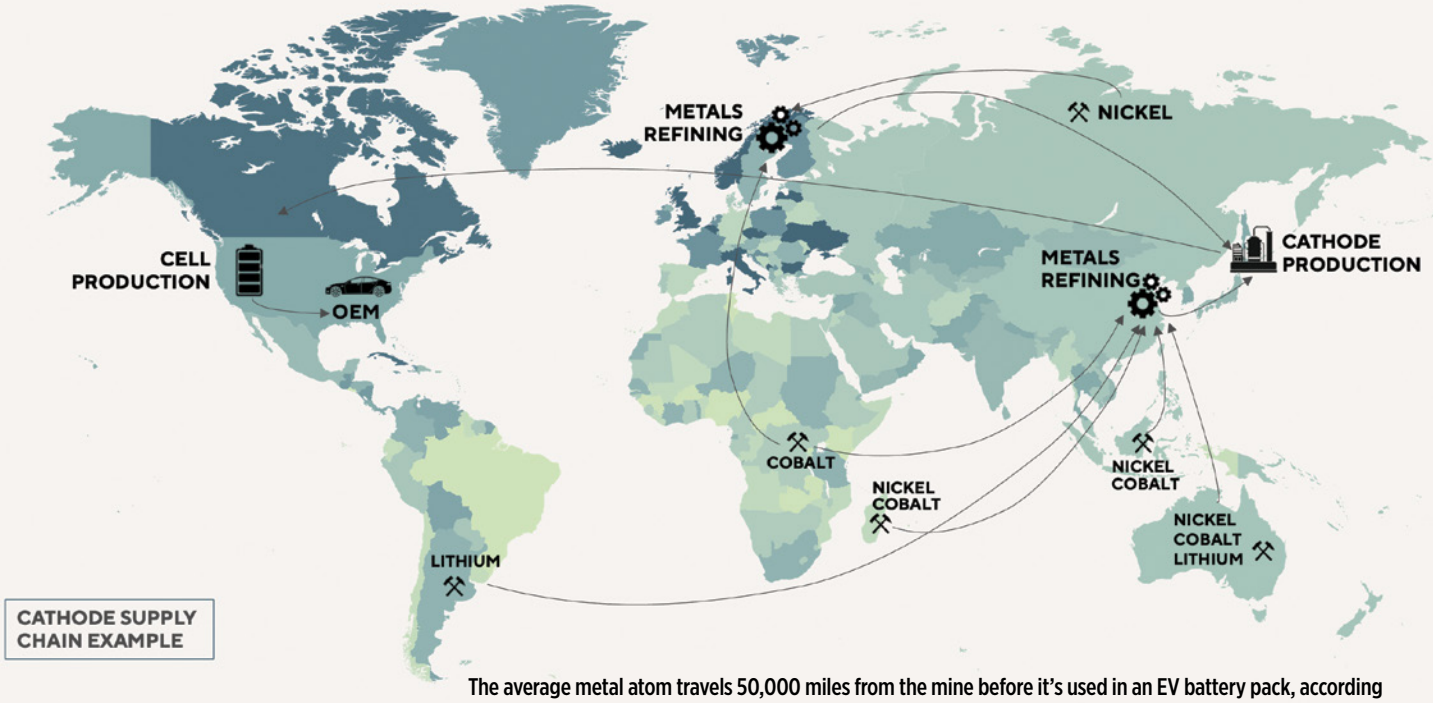
Phalpher said Li-Cycle takes whole packs and shreds them, producing plastic, copper and aluminum that can be sold on to recyclers. Using hydrometallurgy the company develops so-called "black mass," containing cobalt, lithium and nickel. "At high purity levels, it can go back into the supply chain and help create domestic sources," Phalpher said.

Li-Cycle, which went public on the NY Stock Exchange in 2021 through a SPAC deal, estimates that approximately 15 million tons of lithium-ion batteries will have reached the end of life by 2030, up from 1.7 million tons by 2020. The company has a "hub and spoke" organization: The spokes create the black mass from scrap batteries, and the hubs separate out the metals and prepare them to reenter the supply chain. Last April, LG Chem and LG Energy Solution chose Li-Cycle as their preferred recycling partner for North American operations—providing black mass to the hubs. Soon after, Glencore said it would supply scrap and end-of-life li-ion batteries to Li-Cycle and like LG Chem, will "offtake" black mass and other materials from the recycler.

Another Li-Cycle partner is General Motors. By 2023, Li-Cycle will launch a recycling center near GM's Ultium battery-cell plant in Ohio. Li-Cycle opened its

ANL

"There's the recycling path, the secondary-use path and the refurbished path. We don't yet know where the market will go."



The average metal atom travels 50,000 miles from the mine before it's used in an EV battery pack, according to Redwood Materials. Recycled metals will make up 30% of the materials in the company's cathodes by 2025.

REDWOOD MATERIALS

third spoke facility in Arizona last May, with the ability to process up to 10,000 tons of battery manufacturing scrap and depleted li-ion batteries annually.

The company's hub operation in Rochester, New York is being enlarged by more than 40%, increasing its processing capacity from 25,000 tons of black mass to 35,000 annually. That translates to 90,000 tons of EV batteries, Phalpher said. "We think the batteries from 180,000 EVs can be shredded every year," he stated. "The secret sauce is building a system and flow sheet optimized for black mass. It comes out as a wet black powder that is 40% graphite. Keeping it wet prevents the nickel and cobalt dust from becoming airborne."

Tim Grewe, director of electrification strategy and cell engineering at GM, said the company is pursuing various paths to keep batteries out of landfills and deliver metals at less than the cost of mining them—including the partnership with Li-Cycle in Ohio. "There's the recycling path, the secondary-use path and the refurbished path," he said. "We don't yet know where the market will go."

Melissa Flaherty, director of sustainable EV battery ecosystem at GM, added that the goal is to "maximize the recycled content of the recyclable materials" in its packs. Since 2013, she said, GM has recycled or reused all of the packs it gets from customers, including those replaced through warranties.

Redwood: full-circle pioneer

Redwood Materials, which said in 2021 that it had raised $775 million from investors and venture firms, is headed by former Tesla CTO JB Straubel. With approximately 500 employees (and plans to hire 500 more), the company intends to not only capture metals from old batteries, but process those materials into new cathodes and anode copper foils—critical components now mainly made in Asia. Redwood says it can recapture 95% of the elements—including nickel, cobalt, lithium, and copper—from li-ion batteries, then reprocess them into new battery materials for its customers.

The company currently processes six gigawatt-hours of li-ion batteries annually but is expanding rapidly. By 2025, Redwood aims to ramp up to annual production of 100 gigawatt-hours of cathode

active material and anode copper foil, enough to supply a million EVs. The hope is to expand up to 500 gigawatt-hours of these materials annually by 2030—sufficient for five million EVs.

The company operates a 175-acre campus in Nevada, close to California's large EV market. Production of the anode copper foil will begin in Nevada at the end of 2022, with Panasonic's Gigafactory the first customer. A partnership with Ford was announced in 2022, and the company also has agreements with Volvo, Proterra and Panasonic. In 2022, Redwood linked up with Toyota, initially focusing on end-of-life solutions for the hybrid batteries for vehicles like the Prius.

Also in 2022, Volkswagen Group of America said it was partnering with Redwood to recycle batteries from Volkswagen, Porsche and Audi vehicles. Steven Rufo, VW's director of group service and technology, said that Redwood has already begun recycling the company's packs and modules, and that the pickup will be free for its dealer network. "The volume is still very low," he said. "Our plan was to sign with Redwood before we ramped up so we could learn about what worked and what didn't. So far, we're seeing mostly defective modules replaced under warranty. Complete pack replacements are likely to be kind of rare."

Rufo said VW is looking for more efficient and less-expensive transportation solutions, because battery modules get classified as Class 9 hazardous waste and can't be moved without special handling. "Maybe we need to be collecting the material at our parts depots until it can be transported in bulk," he said.

Alexis Georgeson, VP of communications and government relations at Redwood, said that the company is not primarily a recycler. "Our core business is creating anode and cathode material," she said. "We're not selling black mass; we're using it as a feedstock for ourselves."

Georgeson stresses the need for a closed-loop domestic production process that does not involve shipments to Asia. "We're not solving the full equation unless we keep our materials in the country and start making cathodes here," she said. "The average metal atom travels 50,000 miles

More efficient and less expensive collection solutions are needed for battery materials, said Volkswagen's Steven Lupo.

VOLKSWAGEN

Mining for Domestic Supplies – The Race is On

The race is on to develop U.S. domestic supplies of the metals that go into EV batteries. Currently, three companies are working in California's Salton Sea to develop lithium as a byproduct of the existing geothermal production there. At one time the industry jettisoned lithium as a waste product but, with international prices for the metal soaring and automakers asking for less-problematic sourcing, the resource is under intensive development. Most EV batteries use lithium from water-intensive processes in dry regions of South America, so California's supply could be far more environmentally friendly.

The three companies are Controlled Thermal Resources (CTR, with backing from GM and a purchase agreement from Stellantis), Berkshire Hathaway Energy Renewables, and EnergySource Minerals. None currently are producing commercial amounts of lithium, but EnergySource and CTR plan to be operational and delivering lithium hydroxide as early as 2024. EnergySource is based at an existing geothermal operation and is permitted to begin producing lithium. In its first stage, CTR is building a new 49-megawatt baseload geothermal plant with lithium production of 25,000 tons annually; stage two will add an additional 130 megawatts of power and 50,000 tons of lithium by 2025. BHE Renewables is planning for 2026.

"We are working in lock-step with the auto industry to incorporate the entire battery supply chain onsite," said Rod Colwell, CEO of CTR, which has offices in California and Australia. "Announcing a new Gigafactory is one thing,but securing the raw materials and developing the entire battery eco-system to support it is just as critical."

Eric Spomer, president and CEO of EnergySource, said the company's process "works with almost any kind of brine anywhere," and recovers up to 90% of the available lithium—as compared to just 45% via South American evaporation. The company has four pilot plants, three in the U.S. and one in Argentina. "We haven't announced our offtake partners yet, but we have them," Spomer said. "Lithium is not an uncommon element, but the trick is to decarbonize production and mitigate impact while still remaining economically competitive with other extraction approaches. We think this is a robust and attractive project."

The U.S. is not among the top 10 cobalt producers, according to the U.S. Geological Survey (USGS), though Canada is fifth (producing 4,300 tons in 2021, compared to 120,000 tons in the Democratic Republic of the Congo). Europe has an estimated 151 deposits of cobalt in 12 countries, for a total of 1.3 million tons, but not much actual mining. China is both the world's leading producer of refined cobalt and its largest consumer, via battery production.

It's not as if the U.S. doesn't have any cobalt—reserves are estimated in a report for USGS at a million tons (out of 25 million tons identified around the world), mostly in Minnesota. But production was only 500 tons in 2019. With the exception of the DRC and

ASCEND ELEMENTS

OEMs realize that building EVs at volume includes end-of-life considerations, asserts Roger Lin of Ascend Elements.

from the mine before it's used in an EV battery pack." She said recycled metals will make up 30% of the materials in the company's cathodes by 2025, and its cobalt will be 100% recycled.

Scrap from Tesla's Gigafactory will also be an important feedstock, Georgeson said. "Even if the plant is 95% efficient, it will still produce a lot of scrap," she said.

Ascend Elements' recycling technology was spun off as a business from Worcester Polytechnic Institute in 2015, with the intent of creating new cathode-active material from recycled batteries. "The cathode is the single most expensive component of the battery," said Roger Lin, VP for marketing and government relations at Ascend, based in Westborough, Massachusetts. "And cathodes are now being made only in Asia, with little or no manufacturing capacity in the U.S."

Ascend says its "hydro-to-cathode" process can recapture 98% of the material in li-ion batteries. The company has pilot projects in Massachusetts and Michigan, and is building a commercial-scale, 154,000-square-foot operation near Atlanta to open in late 2022 that will take in material from SK Battery America's plant in Commerce, Georgia. Since 2021, Ascend has also had Honda as a partner, with a deal to recycle materials from Honda and Acura vehicles.

"There's a lot of activity in this space now," Lin said. "Automakers are realizing that if they want to build EVs at volume they have to think about the end of life. It's why we're seeing all these partnerships."

A key question is: If future EV batteries contain far less cobalt, nickel and other metals than they do now, will recycling still be economically viable? GM's Grewe said that the batteries in Cadillac's new Lyriq EV have 70% less cobalt than those in the Chevrolet Bolt. Lin thinks recycling will still be viable as the amount of those metals decline, both because recyclers will be working with older batteries that still contain large amounts of those metals, and because lithium itself—not itself likely to disappear from batteries anytime soon—has skyrocketed in price and value. Sanderson agrees. "With lithium at the prices we're seeing—it's up 400

Morocco, most cobalt is extracted as a by-product of copper or nickel production, and that's true of Michigan's Eagle Mine, which produces both of those metals.

Cobalt is extracted in small amounts, along with palladium, silver and gold. The mine is owned by Lundin, a Canadian company, but it's the only U.S. primary producer of nickel. Unfortunately, the mine's resources are limited and, far from ramping up, it's scheduled to close in 2026 unless further supplies are found.

New mining efforts should be encouraged by President Joe Biden's April order that the Defense Department is to view five metals used in EVs—cobalt, lithium, graphite, nickel and manganese—as critical to national security. The action will allow federal money to pay for, among other things, studies to determine if a proposed mine is economically viable, or if a mine producing one important mineral could also produce another. Early in 2022, the Biden administration set aside $3.1 billion to support domestic production of batteries and key metals lithium, cobalt and nickel.

Even more important, the Inflation Reduction Act signed by Biden in August strongly encourages automakers to both produce cars and source their batteries and rare earth metals (either from mining or recycling) from North American sources if they want to secure the federal $7,500 tax credit. By 2024, 40% of the minerals must be extracted or processed in the U.S. (or a free-trade agreement country). After 2026 the requirement is 80% percent.

The new law has strongly stimulated domestic production of rare earth metals, and there has been a flurry of announcements. Piedmont Lithium said it plans to build lithium plants in North Carolina and Tennessee. The annual production target for just the Tennessee operation is double the current total U.S. production of lithium hydroxide. According to Keith Phillips, the company's CEO, "Piedmont wants to be the biggest producer of lithium in North America." And he said that the federal tax credit is a big driver.

Albemarle, which operates in Nevada the only existing lithium mine in North America, also said the Biden bill's provisions would encourage it to develop new domestic mines and refining capacity for lithium. Canada's Snow Lake Lithium has proposed a plant in southern Manitoba that it said would produce enough of the metal (160,000 tons) to power five million EVs over 10 years. Talon Metals has proposed what it said would be a sustainably operated nickel mine in Tamarack, Minnesota, but there has been some environmental pushback.

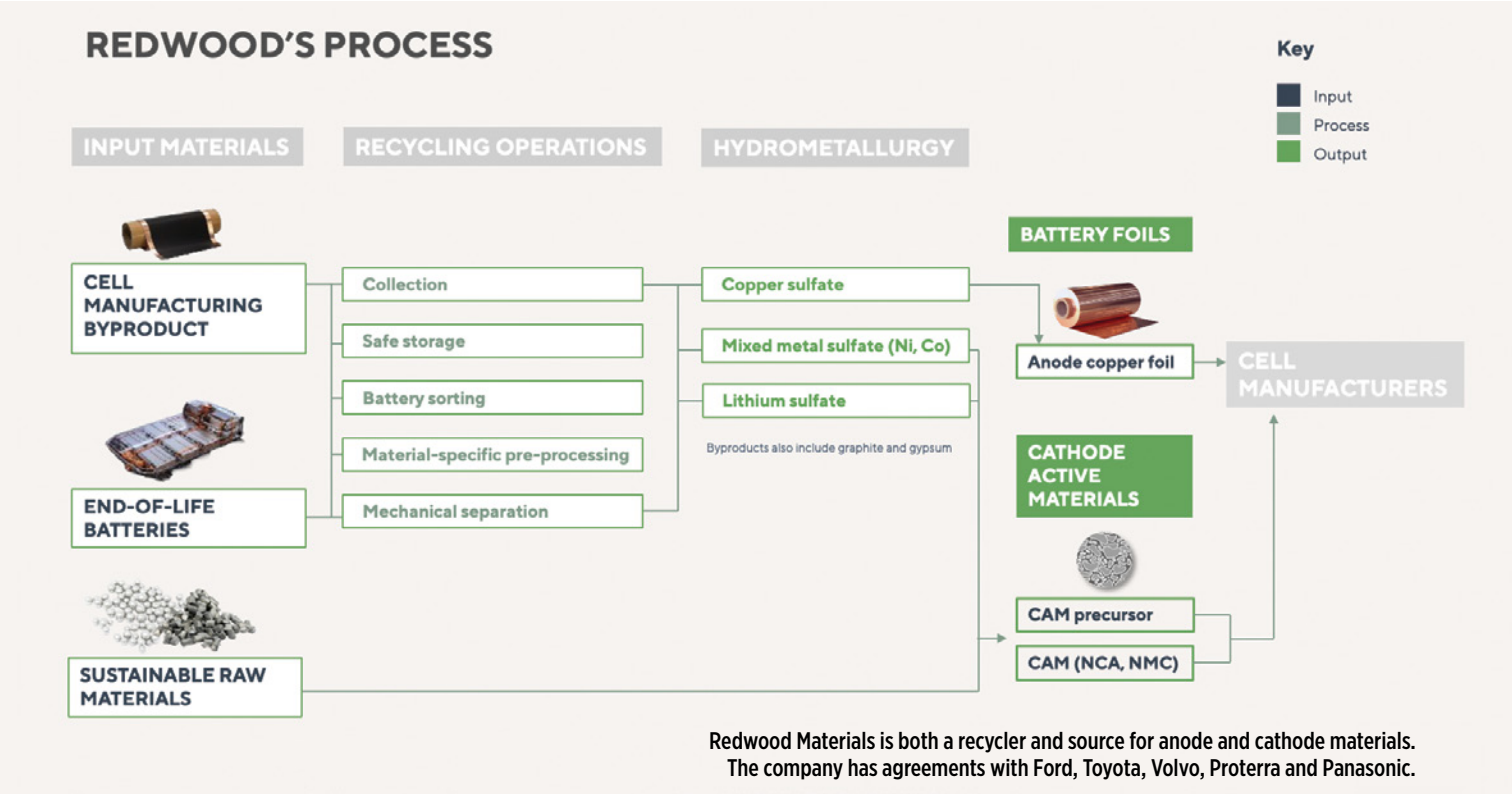
Also facilitating a shift away from problematic production is the Responsible Minerals Initiative (RMI), which has more than 460 member companies. BMW, a signatory, has signed a long-term deal to buy cobalt from Morocco and Australia to avoid sourcing in the DRC. Other automaker partners include Daimler AG, Ford, GM, Honda North America, Stellantis, Tesla, Volvo and Volkswagen.

RMI is also working on improving working conditions for the artisanal cobalt production that's concentrated in two southern provinces of the DRC.

Jim Motavalli

CLOSING THE LOOP ON EV BATTERY RECYCLING

"We need to recapture as much as possible, because we will need way more EV batteries than we currently can build with available virgin materials."



Redwood Materials is both a recycler and source for anode and cathode materials. The company has agreements with Ford, Toyota, Volvo, Proterra and Panasonic.

percent in China this year—recycling is still economically viable," he said.

Georgeson at Redwood Materials explained that because recycling is not the company's primary business, reductions in certain metals shouldn't be a big factor. "Everything we recycle gives us a strategic source of metals that makes cathode and anode components," she said.

It's likely that manufacturers will be able to reduce, but not eliminate, problematic elements from their batteries in the short term, Lin said. Battery chemistries exist that don't use any cobalt or nickel, such as lithium-ion phosphate (LiFePO4, or LFP), but lower energy density remains a problem, he said. Solid-state batteries, which can be made without nickel and cobalt and do away with liquid electrolyte, are another technology in development.

Lithium-ion battery recycling does have some skeptics. Almonty's Black says that some components—including printed circuit boards—can't be recycled, and that handling cobalt will be very problematic for the industry.

Reusing old batteries

Used EV battery packs don't have to be reduced to their component metals; they can also be reused. Two of the more promising avenues are stationary backup for intermittent renewable energy generation, and as storage at EV charging sites to offset utilities experiencing peak demand.

Battery packs can be repurposed from EVs that have been in accidents, or that have reached the end of their useful lives. The second-life battery supply for stationary uses could be more than 200 gigawatt-hours by 2030, with the market propelled by 30 to 70% lower cost, said McKinsey and Co. Even after they're no longer able to power a car efficiently, they may still have 80% of their initial storage capacity, the company's report said. The Union of Concerned Scientists (UCS) estimates that used EV batteries could continue to be of service for five to eight years in secondary applications.

California has 42% of the world's EVs, according to the Orange County Register, and a bill enacted in 2018 calls for regulations to ensure that "as close to 100 percent as possible of lithium-ion batteries in the state are reused or recycled at end-of-life." But getting to that admirable goal is a challenge.

REDWOOD MATERIALS

Redwood Materials will soon produce copper foil for battery anodes, made from recyclate. Panasonic is the first customer.

Jigar Shah, head of energy services at Electrify America—the charging company formed out of the Volkswagen diesel settlement—said the company now has 150 "behind the meter" li-ion battery backup installations at its charging sites in the U.S., primarily to offset utility demand charges.

Unfortunately, Shah said recycled battery packs "don't currently have the performance characteristics we need." And preparing used batteries for reuse involves more than simply plugging them in, said UCS. "To be used as stationary storage, used batteries must undergo several processes [including testing, full discharge and reconfiguration] that are currently costly and time-intensive," the company's report said.

Another challenge is that a robust reuse industry will need a reliable supply of end-of-life batteries. "Most of the batteries are still in the cars," said GM's Grewe. "Our first-generation Volts typically have more than 100,000 miles on them and are still going strong," he said. "There's not currently a high volume of batteries in the secondary stream."

VW's Steven Rufo said that it's possible that second-life battery reuse—proposed before recycling was a viable option—will never get traction. "It may turn out to be better to put the material back into cathode production," he said. "But there's a lot of uncertainty, and we're still very early in this process."

The reuse and recycling of EV batteries is indeed still embryonic, but it is gaining momentum, via research and considerable investment. ■

A mountain of motherboards being collected in Colombia. In2Tec aims to help increase global electronics recycling.

Unzipping the future of SUSTAINABLE ELECTRONICS

In2Tec brings an innovative closed-loop solution to the global e-waste problem.

by Lindsay Brooke

Electronic-systems designers are facing a serious reckoning: How to significantly reduce the environmental impact of more and more electronic content in new vehicles?

E-waste — the mountains of discarded electronic refuse piling up all over the planet — is a global problem that is getting worse each year (see sidebar). And while consumer electronics are the primary constituent in e-waste, the auto industry is steadily exacerbating the mess. With the addition of on-board processors for every new function, and a sensor deluge with no end in sight, a typical passenger vehicle can contain up to 200 electronic control units. Each ECU has a printed circuit board assembly (PCBA) that is difficult and costly to disassemble and reclaim. While the scrapped boards have component and material salvage value, most go to landfill, according to the U.S. EPA.

Discrete solutions for recycling PCBAs and curbing the downstream nightmare have been proposed by industry suppliers. One company, **In2Tec Ltd.**, an electronics designer and manufacturer, is taking a broader view. Its leaders believe true sustainability in electronics requires a circular-economy approach. Their solution combines product innovation with closed-loop, low-impact PCBA manufacturing and reprocessing that company engineers aim to demonstrate in a pilot facility now under development.

"E-waste is becoming like the plastic-bag issue, driven by consumers and government," Neil Armstrong, In2Tec's group managing director, said in an interview with SAE Media. To mitigate the waste stream at its source, the auto industry needs to be proactive, he asserted, rather than "being dragged kicking and screaming into confronting it."

In2Tec's goal, he asserted, is to use its technology to deliver PCBAs that have "the highest recyclability in the industry." To do so, the Kettering, U.K.-based company has focused on flexible-substrate technologies and sustainable electronic solutions since its founding more than 25 years ago, Armstrong stated. It serves an array of industrial sectors including medical and aerospace, and counts **Porsche**, **Aston Martin**, **Konigsegg**, and various Formula 1 and World Rally teams as customers for its package-efficient HMI solutions.

In2Tec has manufacturing plants in the U.K. and China. But with one-third of its resources devoted to R&D, the company has long recognized an opportunity to shift the paradigm in PCBA manufacturing and reclamation toward a sustainable model.

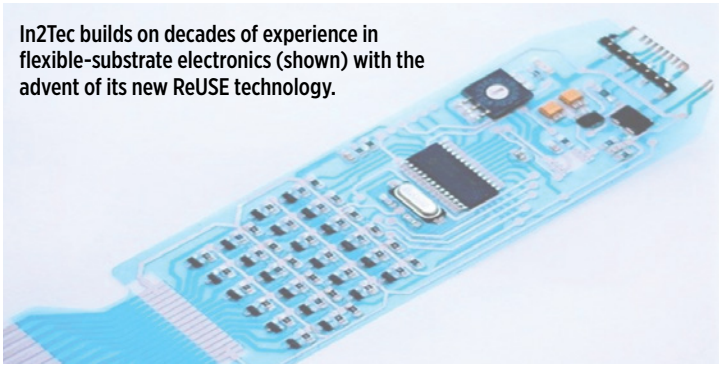
Hot-water separation

The new process has been in the works for 10 years. With funding from Britain's **Technology Strategy Board** (an innovation incubator) and in collaboration with the **National Physical Laboratory** and **Gwent Electronic Materials**, In2Tec has developed ReUSE, described by the company as a trademarked "cradle-to-grave technology that delivers re-usable and undamaged materials ready to provide secondary use."

PCBAs made to the ReUSE spec are "unzippable—meaning we utilize hot water [90-deg. C/194-deg. F], applied within a three-to-six-minute cycle, to remove the components from the flexible substrate," CTO Mark Hudman said. The overall process, most of which is patent pending, consumes minimal energy. It also results in a clean board surface and "provides

CRISTA CASTELLANOS/WIKICOMMONS

CEO Neil Armstrong promises "a very, very low barrier of entry" for his company's 'unzippable' electronics technology.



In2Tec builds on decades of experience in flexible-substrate electronics (shown) with the advent of its new ReUSE technology.

opportunity to reuse about 90 percent of the original substrate and nearly all of the components on that printed circuit board, at some level."

By comparison, currently there are at least a dozen companies including majors **Boliden Group** and **Umicore N.V.** that dismantle PCBAs. The energy and effort required in their efforts is significant. A widely used and rather primitive method is mechanical recycling; it selectively dismantles and crushes the board, then uses magnetic or electrostatic tools to harvest various metal particles. Among chemical and thermal processes are salt and acid baths. One uses methylphenyl silicone oil as a medium to transmit heat ultrasonically to the PCBA.

Today's most common board material FR4 (a rigid glass-fiber epoxy laminate) with soldered component connections offers 5% recyclability, at best, he said. The process is amenable to both flexible and rigid printed circuits. In2Tec offer various substrate materials depending on the requirement of the end application and the program's focus on recyclability, Hudman said. "We have PET [polyethylene terephthalate] and a variety of plastics including nanocellulose structures — essentially biodegradables."

Key enablers of the In2Tec process are the substrate materials and conductive adhesives jointly developed with partner **Sun Chemical**, a New Jersey-based provider of technologies for printed circuits. Hudman said compared with traditional solder and other adhesives, the Sun Chemical-developed adhesives are formulated to break down via high-temperature water, and thus loosen the PCBA components quickly. "This is sustained exposure to hot water for the 3-to-6-minute cycle to reduce the substrate-to-component bond by up to 90 percent," he said. "Neither humidity by itself, nor dry heat, affect it." The process requires certain conditions, in sequence, to produce "a really robust solution," Hudman explained.

The process "provides opportunity to reuse about 90 percent of the original substrate and nearly all of the components on that printed circuit board."

For perspective, conductive adhesives used in PCBAs are much more flexible than solder and are therefore more vibration-resistant, according to experts. They can also be jet-printed or plotted. **MasterBond**, an electronics-adhesive supplier, cites adhesive curing temperatures that are significantly lower than the 450-deg. F (232-deg. C) minimum temperature required for lead-free solder processing. Typical temperatures for rapid cure adhesives are between 250-deg.F and 350-deg.F (121 to 177-deg. C).

"We realize that we won't always be able to reuse the components in the applications they've come out of, say, an ECU or mobile phone PC board," Armstrong noted. "But the reuse opportunities in less complex electronics are mind boggling. And the moment you start reusing electronic components, you have a significant energy and greenhouse-gas reduction on the manufacturing side when you use a component

Buried in e-waste

The United Nations estimates that in 2021, each person on the planet produced on average 7.6 kg (16.7 lb.) of e-waste, contributing to a total of 57.4 million tons generated worldwide and growing annually. Only 17.4% of this electronic waste, itself a physical cocktail of toxic substances and valuable materials, will be properly collected, treated and recycled, the U.N. noted. China, the U.S., and India collectively account for 38% of global e-waste, according to the U.N.'s Global E-waste Monitor. In the EU, which leads the world in e-waste recycling, just 35% of e-waste was officially reported as properly collected and recycled. Globally, the average is 20%; the remaining 80% is undocumented. None is biodegradeable; much of it ends up buried under the ground for centuries as landfill.

Future prospects are not bright: the U.N. predicts global e-waste will reach 74 Mt by 2030. This nearly doubles the total of 2014, due to higher consumption rates of electric and electronic equipment designed for short life cycles and few options for repair.

Lindsay Brooke

BOTH IMAGES: IN2TEC

Unzipping the future of
SUSTAINABLE ELECTRONICS

even one, two or three more times. Never mind the saving on Earth's precious rare materials that are being consumed at a speed that scientists are now saying is un-recoverable."

Unzipping the future

Development of more advanced flexible electronics for use across the vehicle is integral to further advancements in the ReUSE technology. "Flexible electronics breaks down design barriers in systems architectures," Armstrong said. "We've developed solutions for printed and conformable antennas that can be fixed at any point in the vehicle. We've looked at transparent antennas for applications in light lenses. We've patented flat, twisted serial pairs for data communications, which are essentially printed CAN bus architectures."

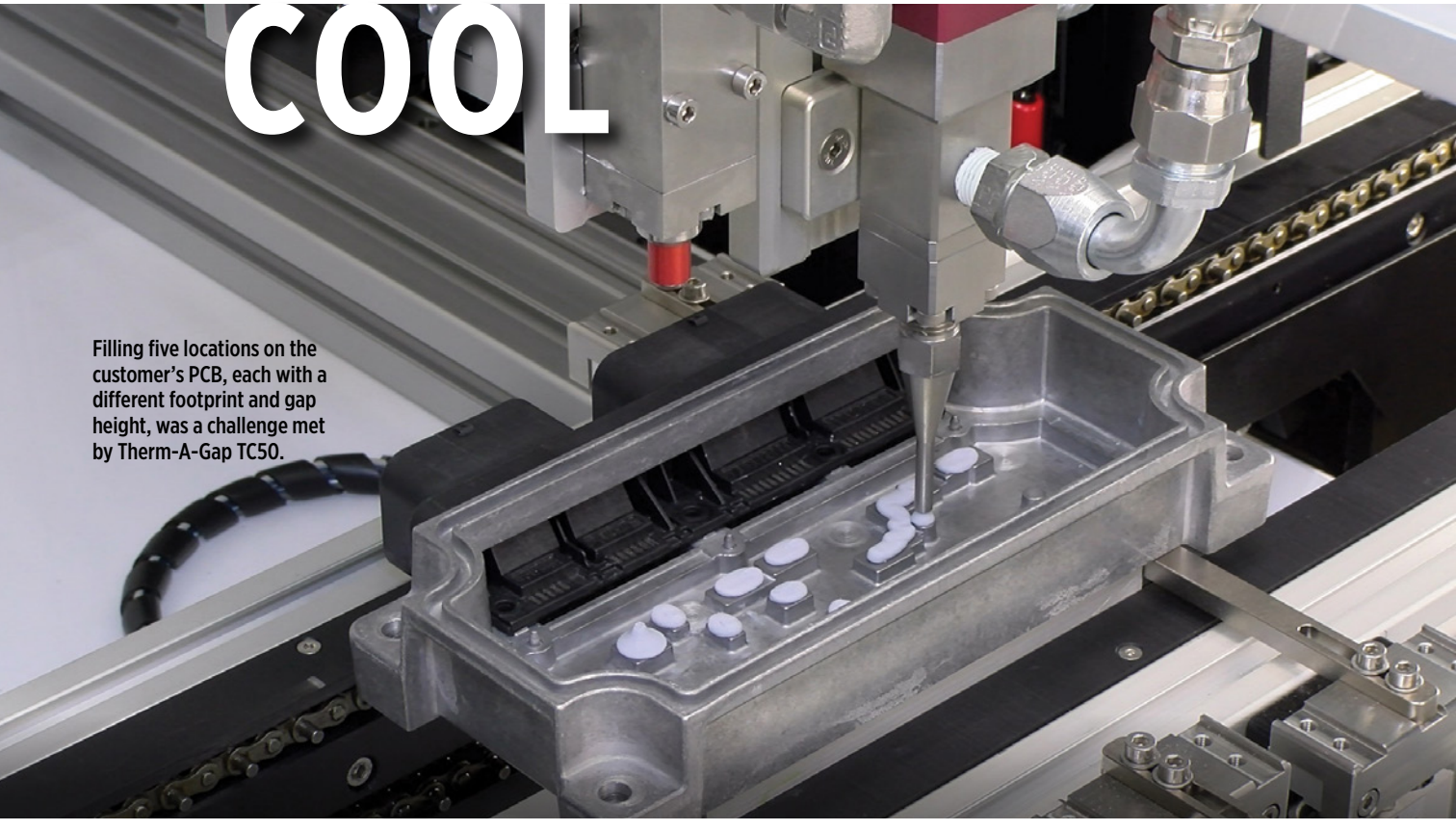
Integrating the electrical harness and PCBA could potentially eliminate connectors, which engineers say are responsible for more than 70% of the failure rate of vehicle electrical architectures. Flexible hybrid electronics (FHE), conductive ink printed on rolls of film-like substrate, was used by Ford on a trial basis in the 2013 Fusion and is being investigated by white-goods makers and the U.S. military (see February 2017: https://www.sae.org/news/2017/01/print-your-next-wiring-harness). The concept can unlock further sustainable electronics innovation from In2Tec, Hudman and Armstrong said.

Automotive OEMs traditionally are reticent when step-change technologies emerge. But Armstrong senses their conservatism has moderated in the past year. "We're engaged with companies that see 'sustainable' in their USP [unique selling proposition], who are now willing to deliver on real sustainability, to reduce CO2e," he observed.

The industry has been without a robust and cost-effective recycling process for electronics. In2Tec will soon be demonstrating its patented approach. Armstrong promises "a very, very low barrier of entry" in delivering its closed-loop solution.

Unzipping microelectronic circuits has only just begun. ■

KEEPING YOUR SILICON COOL



Filling five locations on the customer's PCB, each with a different footprint and gap height, was a challenge met by Therm-A-Gap TC50.

PARKER CHOMERICS

A Parker Chomerics expert shares real-world solutions for the heat-dissipation challenges in onboard electronics.

by Scott Casper

Onboard electronics continue to evolve rapidly. Components are smaller. Systems are more complex. The sophisticated electronics components that make up modern vehicles require precision heat dissipation for reliable operation. To help components and systems designers deliver high-performance, cost-effective solutions, the following are several actual cases illustrating the types of thermal interface material (TIM) and their performance properties,

Challenge #1: The EV/HEV DC/DC converter

Manufacturers of electric and hybrid vehicles must cope with the demands of increasing 12V and 24V accessories that are powered by a DC/DC converter rather than a traditional alternator. This power converter must be reliable, lightweight, and highly efficient, with low electromagnetic interference and low current/voltage ripple. The heat that the converter generates must be adequately dissipated through the housing. An EV component supplier came to Parker Chomerics with a specific list of TIM requirements for the converter they were developing.

The requirements included:

- High material flow rate for high-volume dispensing
- Lower compressive force than competitive gap pads and gels
- Thin bond line for smaller assembly gaps
- Low thermal impedance for effective heat transfer
- Reliability in vertical testing and high-vibration applications
- Provide good dielectric strength to avoid breakdowns

Therm-A-Gap GEL 30 provided the ideal solution. This highly conformable, pre-cured, single-component compound offered a 20 grams/minute flow rate with 3.5 W/m-K thermal conductivity. With a recommended minimum bond line thickness of just 0.004-inch (0.10 mm), GEL 30 provided a solution for tight tolerances and small assembly gaps within the converter. As a material originally formulated for the auto industry, GEL 30 was developed with vertical applications and long-term vibration-exposure reliability in mind. The manufacturer could easily dispense the product in various patterns onto the heat sink. A 300-cc cartridge solution was implemented and will eventually convert to high-volume manufacturing using a one-gallon pump unit and valve dispensing system.

Thermal-interface material must be easily dispensed into targeted areas, with no post curing, to speed the manufacturing process and offer visibility to optical cameras, notes Parker Chomerics' senior engineer Scott Casper.

Challenge #2: PCB with multiple fill locations

A premium automotive system manufacturer was searching for a high-performing TIM for its infotainment module. The TIM needed to be adaptable to filling multiple locations on their boards and it needed to meet a specific temperature threshold.

Specifically, it needed to be capable of filling five locations on the printed circuit board (PCB), each having a different footprint and gap height. The manufacturer needed assistance to determine the best material and the correct amount of gel to dispense in each location, as well as equipment to best dispense in the high-volume application. Compounding the issue, the board with the material affixed would undergo a solder reflow process which would reach temperatures as high as 245°C (473°F). The upper operating temperature for silicone-based gels is 200°C (392°F).

Initially, the customer provided a production PCB for evaluation, which then was replicated for testing using an in-house 3D printer. The 3D printed prototype parts enhanced the five locations for dispensing, so they could be correctly identified for precise dispense location.

Using a precision dispensing system installed in the applications engineering lab, potential materials were evaluated. Therm-A-Gap TC50 dispensable thermal putty was ultimately selected for its high thermal conductivity (5.0 W/m-K) and easy dispensing onto the 3D printed parts for capabilities trials. The prototype parts were successful in representing the actual PCB. The customer's engineering team witnessed the tests and preliminarily approved the material for use.

The board with the material affixed would undergo a solder reflow process which would reach temperatures as high as 245°C (473°F).

Experiments were run to study the effects of elevated temperatures on the thermal and mechanical properties of the TIM compound. TC50 samples were exposed to the 245°C solder reflow process, and the results concluded that the thermal impedance (TI) and viscosity did not deviate over the extended time exposure. Finally, the entire assembly (PCB with the interface material and a cover) was evaluated in the actual solder reflow profile. It was found that the material maintained its rheological structure along with its intended thermal properties and was approved for the program.

Challenge #3: Safety modules for ADAS

As vehicles are relying more on advanced driver-assistance systems (ADAS), automotive camera and motion sensor companies are expanding their technologies to meet stringent compliance requirements. For some ADAS modules, this requires high-performance, robotically dispensed thermal-interface materials. The TIM must provide soft compression, ease of dispensing, and a flow rate suited for high-volume manufacturing. Additionally, the material may need to be visible to optical cameras.

In this case, the customer initially expressed a preference for thermal gap pads over dispensables, due to previous negative experiences with dispensing. However, due to volume production requirements, it became apparent that pads would not be a feasible option. In addition, the thermal material needed to be higher in thermal performance than the pads typically used (> 3 W/m-K).

Through extensive testing, Therm-A-Gap GEL 45 was selected as the optimal TIM for this application. GEL 45 offers a high flow rate suited for high-volume manufacturing (55 grams/min) and has a thermal conductivity of 4.5 W/m-K. The product also is black, so it can be seen by optical cameras on the assembly line. Finally, the camera manufacturer ran a battery of tests to ensure the amount of material dispensed was adequate to the heat and would not damage the PCB during assembly.

Challenge #4: Non-silicone thermal interface for ADAS modules

What if an application involves silicone contamination concerns? The positioning of optic lenses within automotive camera assemblies can present this issue. Additionally, semiconductor image sensors and chips within automotive camera assemblies often require enhanced heat-dissipation efforts.

PARKER CHOMERICS

Returning this fall!

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BATTERY AND ELECTRIFICATION SUMMIT

November 1-2, 2022

The Battery & Electrification Summit returns this November to discuss the latest battery and electric power developments impacting the automotive, commercial vehicle, aerospace, and defense industries.

Join the FREE two-day event to learn how teams at **NASA**, **Atlis Motor Vehicles**, **Ampaire**, and more are leading the charge in renewable energy advancements.

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CEO, Alsym Energy

Edward Lovelace, Ph.D.
Chief Technology Officer, Ampaire

Rodger Dyson, Ph.D.
Power and Propulsion Technical Lead,
Thermal Energy Conversion Branch,
NASA Glenn Research Center

Laurence Toomey, Ph.D.
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Ground Vehicle Power & Mobility Directorate,
U.S. Army DEVCOM

Mark Hanchett
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KEEPING YOUR SILICON COOL

Developed for vertical applications and long-term vibration exposure reliability, the GEL30 material is capable of being applied with confectionary precision.

In its design of a multi-function camera vision system, a global manufacturer of automotive camera systems placed a camera sensor module with a circuit board near where there is an embedded chip emitting heat during power cycles. Because the camera lens is in such close proximity to the PCB, the concern of silicone contamination heightened the specification of the TIM.

As a result, the thermal material was required to be non-silicone-based and to comply with Paint-Wetting Impairment Substances (PWIS) automotive standards. While there are non-silicone thermal gap pads available, due to the high-volume production of the camera assembly, pads were not a feasible option; only a dispensable material could meet the necessary throughput requirements.

With the silicone-free requirement from the customer, it was determined that Therm-A-Gap GEL 25NS met and even exceeded the customer's requirements, with 2.5 W/m-K thermal conductivity, and is yellow in color, which can be recognized by optical cameras on the assembly line.

Furthermore, a finite element analysis (FEA) simulation was conducted to predict the reacting force of the thermal material during and after its installation to the targeted location to ensure it would not cause deformation and/or damage to the PCB/IC during and after assembly.

For these applications, manufacturers need a dispensable material that is highly conformable, with a low compression force and long-term reliability and durability. They may need a non-silicone-based binder to eliminate factory and assembly silicone contamination concerns. The thermal interface material must also be easily dispensed into targeted areas, with no post curing, to speed the manufacturing process, and offer visibility to optical cameras. For more information, visit parker.com and download the recently updated "Thermal Interface Material Dispensing Guide for Thermally Conductive Gels, Cure-in-Place Potting Compounds and Thermal Greases." ■

Scott Casper is senior applications engineer with Parker Hannifin Corp.'s Chomerics Division.

PARKER CHOMERICS

Hyundai's 'edgy' new ideas for safety testing

In June 2022, **Hyundai Motor America** broke ground for its Safety Test and Investigation Laboratory (STIL), an industry-unique testing facility dedicated to root-cause crash investigations and electric vehicle/future-product analysis activities at its Michigan R&D campus west of Detroit. Not long after the $51.6-million STIL's inauguration, the company named Brian Latouf as its first-ever Global Chief Safety Officer to "integrate the engineering resources of Hyundai and HMNA by combining safety field investigations, safety data analysis and safety- engineering performance into a streamlined global technical function." At the STIL groundbreaking, SAE Mobility Media editorial director Bill Visnic spoke with Latouf about Hyundai's crash-safety vision.

Equipping to crash vehicles is a serious undertaking. But you're actually going to crash vehicles at the new STIL facility, correct?
Oh, we are. The Field Crash Investigation Lab is one of the key components of the STIL. But it's non-regulatory — we're going to focus on those crashes that happen in the field with our customers, and things happen. Say the airbags don't deploy, say the structure behaves differently, say you have an electronic short during the crash event and your sensing system is not operable. Things like guardrails, edge conditions, maybe a double impact, we're going to try different roll events. We're going to explore the frontier of safety. Because not everything is replicated by your traditional crash test.

You're going to be more about replicating real-world types of crashes at this facility?
We're going to have a tow line, in a tow track that's enclosed, and we're going to have a building where we're going to be able to put different sorts of abutments or barriers. We have guardrails, poles, other vehicles — and we're going to have it extend outside. We may do 'trip' events.

Say a high-speed edge condition takes out the fusebox. And with the fusebox [destroyed], do you have enough capacitance to command a [airbag] deployment? Those type of things are not understood by a traditional crash test. Do you have backup systems? Do you have capacitant power [in a crash] for a certain amount of time, an energy reserve? That type of thing. Unless you try those things and explore it, you don't understand it.

How important is this facility to EV testing? Because there's a lot that's still not known about EVs?
Exactly. Lithium-ion batteries have their own quirkiness. We're going to have a battery lab here, and an outdoor battery pad; we're going to explore the limits of battery systems. We'll likely combine some of the battery tests with the field-crash lab as well. And cycling systems — introducing flaws into batteries, how do they behave as you overload them — is important. Then having the ability to tear them down and understand the details of the quality challenges. Our future is EVs and EVs will be a big, big part of our STIL.

HYUNDAI

Brian Latouf, a mechanical engineer with an extensive background in vehicle crash safety, is Hyundai Motor Co.'s first-ever Global Chief Safety Officer.

We're going to explore the frontier of safety. Because not everything is replicated by your traditional crash test.

Actual regulatory crash testing for Hyundai — is that all engaged in South Korea?
The development work and DV validation is done in South Korea. The pre-production cars are shipped here; we crash-test them typically at MGA [Research Corp.] or Calspan in the U.S. These are approved test laboratories. So, we ensure we have crash test data from a U.S.-based facility. A lot of the development is done in South Korea, but the final validation is here.

What is your background? Are you a mechanical engineer?
I'm from Canada originally. I'm American now. I have a Bachelor's in mechanical engineering and I have a Master's in mechanical as well, with the major in biomechanics. I specialized in occupant injuries, injury trauma. I went to Wayne State [University] under Dr. Albert King, where the Hybrid III crush dummy was created. ■

UPCOMING WEBINARS

WHEN MILLISECONDS COUNT: THE IMPACT OF ADAPTIVE LIDAR ON PERCEPTION IMPROVEMENTS

Tuesday, October 4, 2022 at 12:00 pm U.S. EDT

For autonomous systems to coexist with human drivers on highways, adequate reaction times are required for safe path planning. Hardware-centric lidars offer passive performance for redundancy but don't optimize data to reduce the perception systems' reaction times based on operational domains. This 30-minute Webinar will examine how new advances in adaptive lidar can optimize output and allow higher-speed vehicle operation with graceful braking.

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For additional details and to register visit: www.sae.org/webcasts

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THE BENEFIT OF END-TO-END EV CHARGING-COMPONENT PRODUCT CERTIFICATION

Tuesday, October 11, 2022 at 10:00 am U.S. EDT

Growing charging network capabilities have fomented electric vehicles (EV) acceptance. The IEC System of Conformity Assessment Schemes for Electrotechnical Equipment and Components (IECEE) Certification Body (CB) Scheme presents an opportunity to have an accredited laboratory test and verify to safety standards key affected automotive components and systems. This 60-minute Webinar offers a briefing on EV charging-system product testing, including an explanation of the benefits of the IECEE CB Scheme for key EV components and systems, and the application and certification process.

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EVERYTHING YOU NEED TO KNOW ABOUT VIRTUAL ECU ABSTRACTION LEVELS

Wednesday, Oct 12, 2022 at 1:00 pm U.S. EDT

Growing electronic/electrical (E/E) architecture complexity and software content in modern vehicles has propelled the use of virtualization-based testing to develop and validate functions and software components more effectively. The simulation of electronic control units (ECUs) as virtual ECUs (vECUs) has found rapid adoption in several phases of automotive development. This 30-minute Webinar will provide a greater understanding of the vECU levels and how to apply them, as well as how vECUs are helping solve current and future software test challenges.

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UPCOMING WEBINARS

STOP VS. DELAY: DESIGNING A THERMAL RUNAWAY PREVENTION STRATEGY

Tuesday, October 18, 2022 at 2:00 pm U.S. EDT

China and the United Nations have mandated that battery electric vehicles provide a 5-minute window for passengers to exit the vehicle after detection of thermal runaway. A better goal, for both the consumer and the industry, is to stop thermal propagation entirely. Battery engineers are tasked with designing a solution that optimizes a vehicle's performance and meets critical safety requirements. This 60-minute Webinar discusses the ways in which aerogel-based thermal-barrier materials can help achieve these goals within realistic space, weight, and cost constraints.

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For additional details and to register visit: www.sae.org/webcasts

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INNOVATIVE MATERIALS FOR ADAS CHALLENGES

Tuesday, October 25, 2022 at 11:00 am U.S. EDT

Engineers of advanced driver assistance systems (ADAS) must strike a balance between performance and safety. 4D radar systems will bring additional challenges, including higher RF reflection and ghost signals. This 60-minute Webinar presents innovative, durable, and dependable engineering polymer solutions to meet OEM requirements for radar and camera technology components.

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OPTIMIZING POWER CONVERTERS: HOW SIMULATION HELPS YOU ENGINEER BEST-IN-CLASS POWER ELECTRONICS

Thursday, October 27, 2022 at 9:00 am U.S. EDT

Power converter design requires engineers to understand and analyze how integrated system requirements are met when making electrical subsystem design choices. From semiconductor selection to filter design, there are many parameters that have effects on performance, cost, and efficiency of power electronics. This 60-minute Webinar will walk through an integrated, communicative approach to design decisions for power electronics cooling and subsystem design.

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Does Your Test Strategy Require Simulating Sensors?

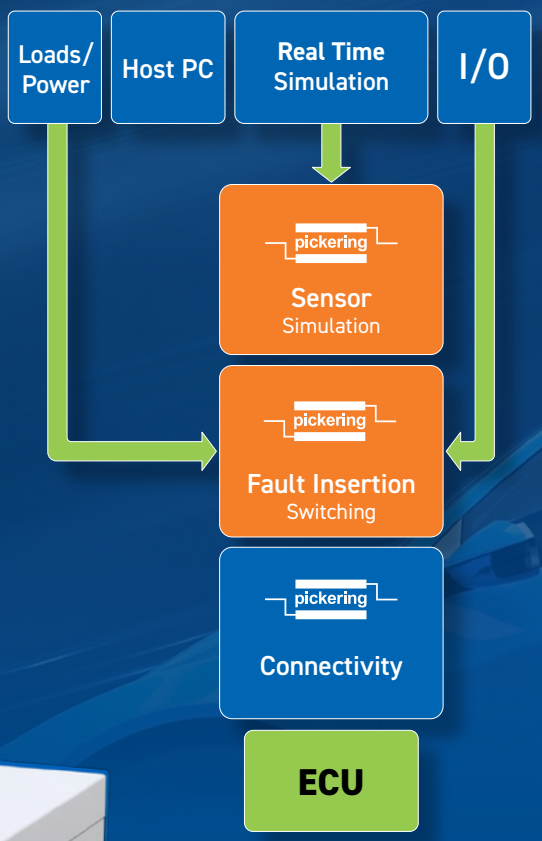
Including pressure, temperature, altitude, strain gauges & displacement

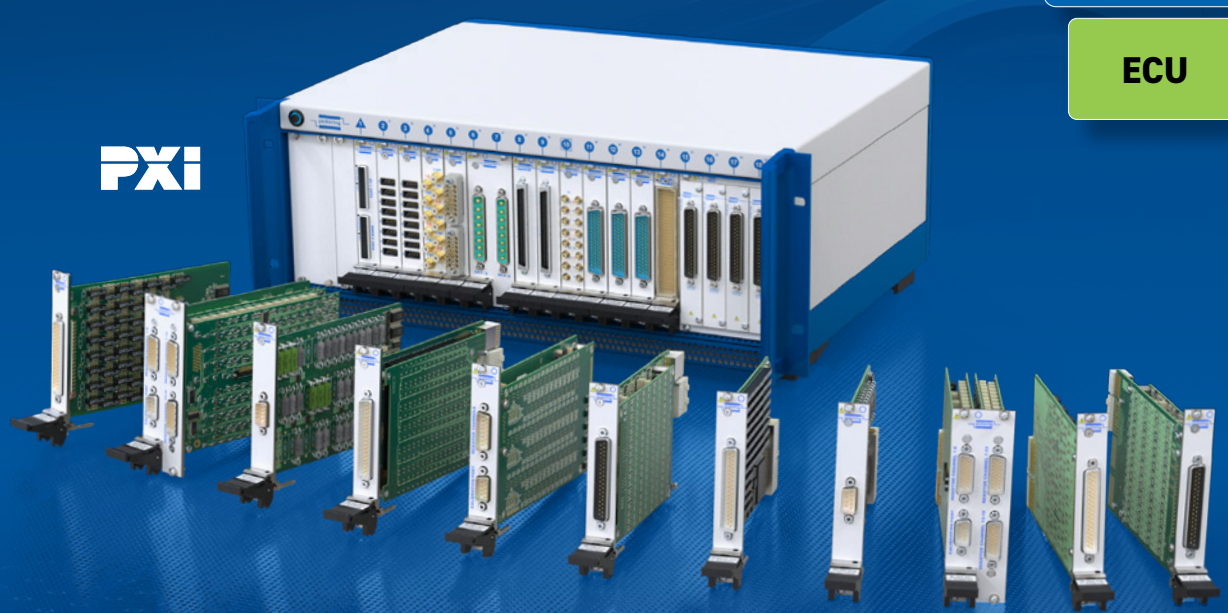
Validate ECU Operation & Software using Hardware-in-the-Loop Simulation

Simulation & fault insertion are essential in mission-critical HIL applications, and companies turn to open architecture PXI-based systems for size, cost, flexibility and choice.

With the largest range of PXI sensor simulation & fault insertion switching—Pickering offers you **35+** years of switching and simulation expertise and a collaborative, creative and agile approach to Hardware-in-the-Loop test system design.

Learn more: **pickeringtest.com/simulation**





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