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Lucid Motors CEO Peter Rawlinson and his development team set the EV benchmark

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April 2022 autoengineering.sae.org

CONTENTS

FEATURES

REGULARS

ON THE COVER

Lucid Motors CEO Peter Rawlinson has built a talented engineering team whose first vehicle, the Air grand-touring sedan, is the new benchmark in EV performance, refinement and systems innovation. (Lucid Motors)

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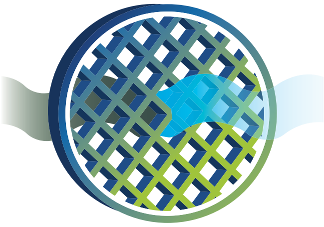

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EDITORIAL

Engine tech a decade later

A securities analyst from New York called recently, to ask about the future of powertrain. Specifically, she wanted my prediction for a timeframe for the demise of both gasoline and diesel IC engines.

Such inquiries by the investment community to auto-industry media are fairly common. Indeed, the specific question of "When will the ICE die?" may be the most asked, most discussed topic of the past decade. And with it come related questions: "When do you see EV sales penetration exceeding XX percent? When do you expect battery cost per kilowatt-hour to drop below that of gasoline engines? Which OEMs will prevail by 20XX?"

A journalist's job is to ask experts and report their views, rather than blabber-on tediously ourselves (which many of us tend to do, anyway). In this issue, my colleague Bill Visnic lets his reporting and industry knowledge do the talking in his "Keeping Combustion in the Conversation" feature on page 18. In Bill's piece, powertrain-technology experts share their outlook for the ICE's evolution. It's fair to say that gasoline and diesel engines will exist in substantial volume for some time.

Related to that on page 5, veteran industry analyst Michael Robinet of S&P Global continues his look at how the shift to electrification will impact the Tier 2 and Tier 3 suppliers whose business is in traditional powertrain. SAE readers who work in that space are already living with the risks and anxieties of the hydrocarbons-to-electrons transition.

While I'm not a crystal-ball guy, I believe history helps align present and future. So, I dug out my reporter's notebook from a decade ago: April 2012. It's a record of who I spoke with and what I saw at the 2012 New York Auto Show, followed by the SAE High-Efficiency IC Engines Symposium. Each page in that notebook provides interesting rearview-mirror observations from those events:

At the 2012 NY show, Nissan's then-boss Carlos Ghosn spoke to media. He predicted that global EV sales would reach 10% of the overall total by 2020. Wishful thinking! But presciently, Nissan also was setting up a new U.S. company for EV battery reuse, he said.

Two weeks later at SAE's advanced engine symposium, much discussion surrounded thermodynamic efficiency, a quest that is eternal in the powertrain world. "No stone can be left unturned," asserted Dr. David Foster of the University of Wisconsin. "Crevice volumes. Friction. Rotating inertia. Heat transfer. Keeping in-cylinder temperatures low," Foster noted, directly works toward minimizing exhaust-energy loss – still an aim of IC stalwarts.

Powertrain engineering has a new crusade.

Achates Power's then-CEO Dave Johnson also presented at SAE, outlining the thermodynamic potential for his company's multi-fuel, opposed-piston, 2-stroke engine tech, aiming its OPOC development at light trucks. An engine, wonderfully compact, was eventually demonstrated in a Ford F-150 before electrification closed in. The company now looks to potential heavy-truck applications.

Downsizing. Downspeeding. Stratified charge. Cooled EGR. Lean burn. Concepts for reduced pumping loss. Digital valve control. A phalanx of boosting ideas. HCCI! No stone should be left unturned.

A decade later, powertrain's crusade for greater efficiency continues, with ICE development still focused on the above technologies. Work continues. But now, better funded attention is going to electric machines, power electronics and batteries.

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The soft underbelly of the EV transition

The list of OEMs and suppliers that are splitting their organizations into traditional ICE powertrain and electric vehicle operations continues to grow. Just follow the money, as billions are being devoted to new battery plants, upstream input supply, charge point investment and revolutionary approaches to next-gen vehicle architectures.

Regular readers of this page already understand our view of the key functional systems/components being classified as either EV-Negative, EV-Agnostic or EV-Positive. And as such, how the industry addresses these capabilities going forward from a capital, talent, timeline (speed) and financial-return perspective is woven into every decision going forward.

Case in point is Ford's recent announcement that it is severing its traditional engine/transmission operations, now called Ford Blue, from its emerging BEV operations, known as Ford Model e. The strategic and tactical split is expected to have a huge impact on every touchpoint — vehicle and systems development, technology, production, retail sales and the aftermarket. Other OEMs have formed JVs with existing auto Tier 1s or new industry entrants to enable their transition to BEV from a technology and timing perspective. Additionally, countless Tier 1s have structurally severed or sold off ICE-focused operations/development as OEMs quickly reduce or restructure these operations.

The speed with which OEMs and larger Tier 1s are pivoting towards EVs and the subsequent refocusing of their business structures has been more rapid than expected. While several industry observers, me included, warned of the inevitable shift towards electrification, the sheer commitment behind it has been surprising. The recent S&P Global (previously IHS Markit) Light Vehicle Propulsion Forecast outlines growth to 32% EV output by 2030 in North America with the rate reaching 36% on a global basis. Years of focused development and careful capital planning towards the EV future has pre-determined the fate of ICE operations.

Michael Robinet
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Tier 2+ suppliers... may lack the ability to transition in cadence with their customers to the EV-driven opportunities.

While the industry has not written off traditional ICE operations — which continue to fund development of EV and other advanced technologies, after all — clearly these are on a different trajectory. While several Tier 1s are working through the transition (and most should succeed), there is less flexibility to pivot at the Tier 2+ level. Tier 2+ suppliers, which innovate and build critical sub-systems and deliver key materials and processes or tooling to support ICE programs, may lack the ability to transition in cadence with their customers to the EV-driven opportunities.

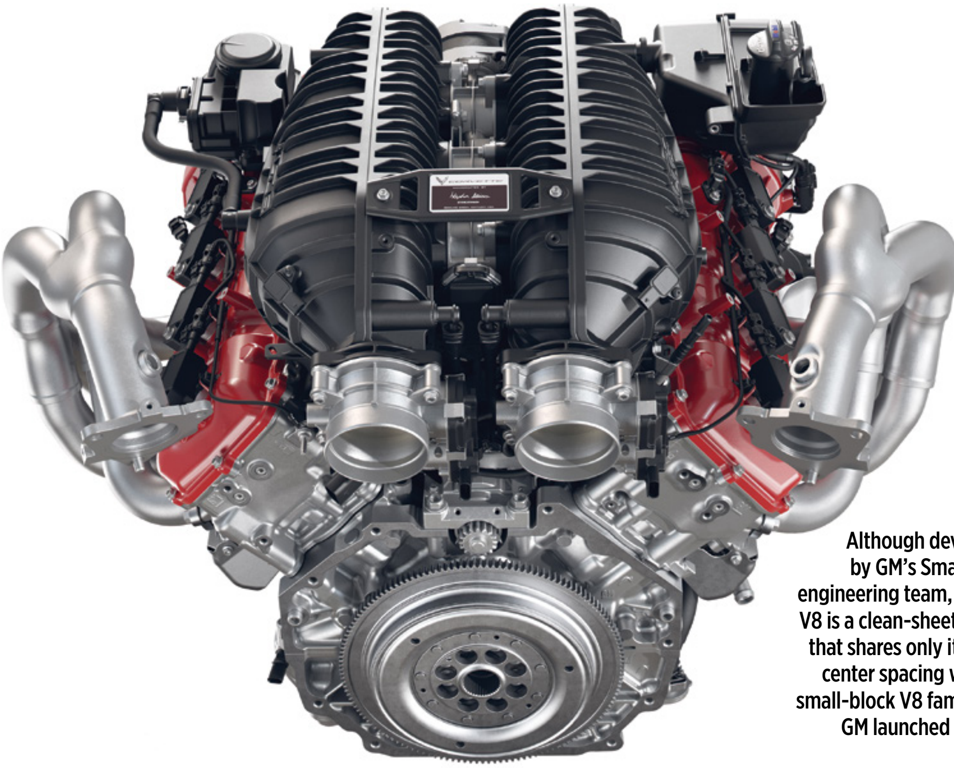
Therein lies the 'soft underbelly' of the industry's mammoth transition. Can key suppliers that are integral to the continuation of ICE production survive the reduced volumes (lower economies of scale) and lack of new programs to replenish margins going into the next decade? And there's another complication: The need to support the ICE aftermarket for 10-15 years after the end of a program. This extended tail already is causing concern for all involved.

Announcements surrounding the structure of EV versus ICE operations will continue as decisions flow upstream into the supply chain. Growing exposure to lower volumes, increased pressure to effectively pay back capital and attract the necessary talent to support ICE supply will dog the industry. ■

Note to readers: In March 2022, IHS Markit merged with S&P Global. S&P Global is focused on supporting our clients with critical capital decisions and powering the markets of the future.

POWERTRAIN

GM details Corvette's new and mighty LT6 V8



Although developed by GM's Small Block engineering team, the LT6 V8 is a clean-sheet design that shares only its bore-center spacing with the small-block V8 family that GM launched in 1955.

If the end of the internal-combustion epoch truly is within sight, **General Motors** intends to see it out with a bang. It's latest – who's to say whether it's the "last?" – clean-sheet V8, internally designated LT6, arguably is its best, considering GM touts it as the world's most-powerful normally-aspirated V8 ever fitted in a production vehicle.

Earmarked for the 2023 Z06 high-performance variant of the **Chevrolet** Corvette, the LT6's most-illustrious design feature is its flat-plane crankshaft, but engineers in mid-February 2021 laid out for media the numerous other unique engineering elements that led to the thunderous **SAE**-certified output of 670 hp and from a comparatively moderate – in V8 terms – displacement of 5.5L. Over its eight-year development that saw the first prototype in 2015, engineers from GM's Small Block engine team dubbed the engine "Gemini" due to its many "twin" architectural elements.

Just don't call the LT6 a "small-block" V8, even if it was developed by the engineering team bearing that name. Apart from its 4.4-inch (111.76-mm) bore-center spacing – the single architectural dimension that connects all five generations of GM's legendary V8 introduced in 1955 – the LT6 has virtually no connection to small-block V8s, declared chief engineer Jordan Lee. Not only does the 90-degree LT6 have the significant difference of a dual-overhead-cam (DOHC) layout rather than the overhead-valve (OHV) arrangement that's a hallmark of the small-block family, Lee confirmed the LT6 shares not one part with any previous pushrod small-block. To further drive home the point, he added, "In today's day and age, it's hard to define an engine by one dimension [the 4.4-in. bore centers]. This is a unique engine on its own."

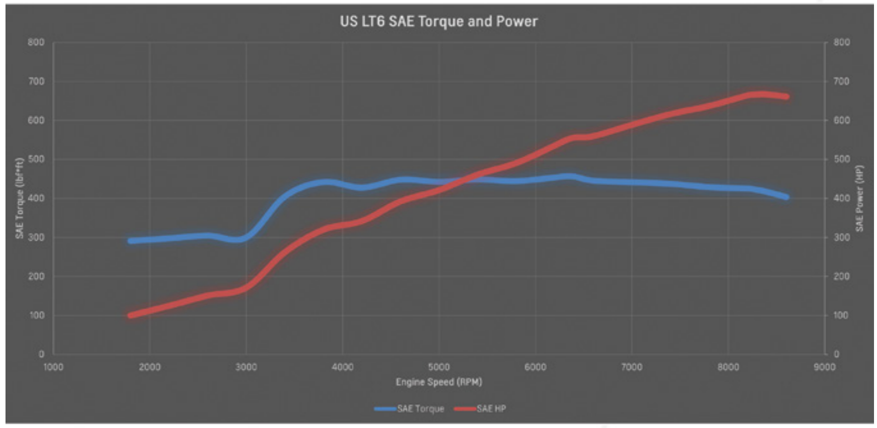
Less mass, better throttle response

To fully exploit the flat-plane V8's intrinsic quick throttle-response and revving ability – redline is a dervish 8600 rpm – lightweighting and reciprocating-mass reduction were key LT6 priorities. At 364 grams each, its forged-titanium connecting rods are 21% lighter than the titanium rods for the LS7 supercharged 7L V8 in the sixth-generation (2006-13) Z06 Corvette, pointed out design release engineer Thomas Halka.

GM

The LT6's forged-aluminum pistons are 8% lighter than the LS7's. A major weight-saving contributor is the flat-plane crankshaft itself, thanks to fewer counterweights compared to a cross-plane crankshaft. But the LT6's crank also has extraneous mass drilled out around the main bearings and other areas. Design release engineer Clarence Smith said the engine's crankshaft is a full one-third lighter than that of the LT2 6.2L V-8 that powers the standard Corvette.

In all, said Gardner, despite having 175 hp more than the standard Corvette's LT2 V8, the LT6 is just 1 kg (2.2 lb.) heavier.



Hundreds of tunable parameters contribute to the LT6 V8's record horsepower and consistent, flat torque curve.

GM

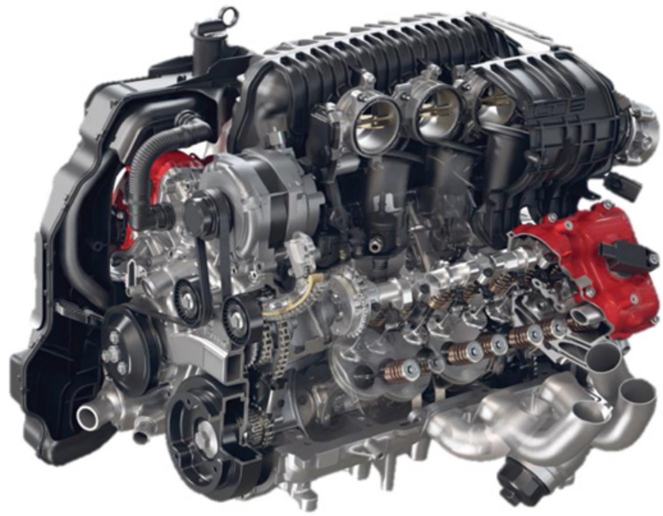
Optimizing around flat-plane

To stay within an optimum displacement range to make the LT6 suitable for worldwide endurance racing and to also help address the vibration issues that can afflict V8s with flat-plane crankshafts, the LT6 fronts a short stroke of just 80 mm compared to its bore of 104.25 mm. The flat-plane V8, a long-standing preference of **Ferrari** (a recent example of which GM purchased from a salvaged model) allows for improved exhaust-scavenging behavior and is a key enabler of enhanced volumetric efficiency and high-rpm power.

The Small Block engineering team initially set a maximum-output goal of 650 horsepower. After some analysis of the engine's characteristics, "We quickly realized we had 650 [horsepower] in the bag," said assistant chief engineer Dustin Gardner. And Yoon Lee, design system engineer, noted that the production engine makes more power than the racing version of the LT6 (endurance-racing rules require intake restrictions that limit power output). "I think it's going to stand the test of time of being one of the true icons," Gardner added.

The LT6 is comprised of a two-piece aluminum block mated at the crankshaft centerline and topped by aluminum cylinder heads. The short stroke delivered a deck height some 23 mm (0.9 in) lower than the standard Corvette's LT2 V8. The 12.5:1 compression ratio is abetted by forged-aluminum pistons that have startlingly short skirts and are supplied by **CP Carillo**, a racing components manufacturer.

The new engine's intake system perhaps is the most visible manifestation of the Gemini concept, its prominent dual-plenum design encasing an approach to air-management that enhances torque production. The system, extensively detailed here (GM details new and mighty flat plane Corvette LT6 V8 (sae.org)), uses an arrangement of three valves to manipulate air movement between the plenums. The result is a variable volume of intake that optimizes induction resonance while boosting torque output to its maximum 460 lb-ft (624 Nm) and at the same time making it more consistent across the rpm range (see chart).



Cutaway shows the direct-mounted oil tank for the dry-sump lubrication system.

The LT6's signature feature: a "flat-plane" crankshaft that locates all four throws 180 degrees apart in a single plane.

The complexities of the intake variables are one element comprising some 41,000 adjustable calibration values for the LT6, which "starts to 'tune' effectively at 3,000 rpm and above," explained chief engineer Lee. The engine's power and torque chart bears out his assertion, showing a distinct rise and leveling to its torque peak between 3000-4000 rpm. Lee summarized by calling it "an incredible amount of power for this displacement."

The LT6's valvetrain, lubrication and thermal-management circuits are fully optimized subsystems designed to handle the punishment of racetrack abuse and deliver day-to-day robustness uncommon to many high-strung performance engines. Most surprising about the valvetrain is its use of solid (i.e. mechanical) valve lifters chosen to reduce moving mass and assure valve performance at high rpm. One of a wide selection of specifically sized steel lash caps is robotically fitted for each valve after automated measurement of 32 different tolerance areas.

Phil Baranek, design release engineer, assures that the fixed arrangement is good for the life of the engine. That guarantee may be supported by the unique actuation arrangement of a diamond-like carbon coating for the roller-finger followers and an integrated oil jet for each finger follower to assure constant and consistent lubrication at this vital interface.

Variable valve timing of course is part of the equation. The intake valves have 55 degrees of crankshaft authority while the exhaust valves are variable over 27 degree of crankshaft authority. The valve timing scheme plays a significant role in the LT6's emissions profile and surely enhances overall efficiency. GM did not detail fuel economy figures or confirm if the engine will be labeled a gas guzzler.

Bill Visnic

BOTH IMAGES: GM

MATERIALS

The origin of EV-crucial minerals

What minerals are used uniquely in the manufacture of electric vehicles? Is the U.S. self-sufficient in these minerals, or does it rely on imports? And if the latter, what are the source countries? These questions are addressed in the two tables below.

Table 1 (top) lists the minerals used in a typical electric car and a typical IC-engine conventional car. The data are from the **International Energy Agency** [https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary]. Importantly, they are applicable for cars and not for vehicles in general, and they are not specifically tailored to the cars made in the U.S. (Note that the relative weight does not necessarily correspond to each mineral's relative importance.)

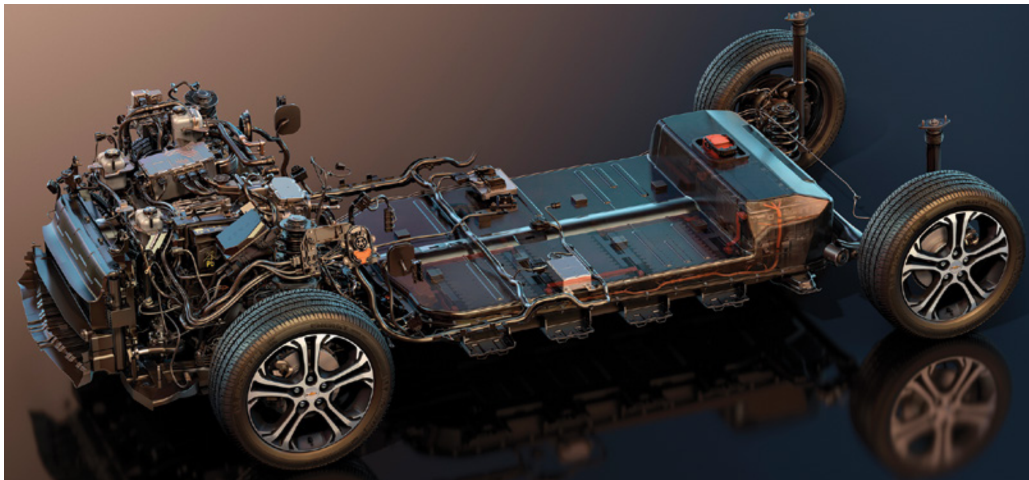
Table 1

MINERAL	CONTENT PER ELECTRIC CAR, IN LB. (KG)	CONTENT PER ICE VEHICLE, IN LB. (KG)
Graphite (natural and synthetic)	146 lb. (66.3 kg)	
Copper	117.2 (53.2)	49 (22.3)
Nickel	87.9 (39.9)	
Manganese	54 (24.5)	24.7 (11.2)
Cobalt	29.3 (13.3)	
Lithium	19.6 (8.9)	
Rare earths	1.1 (0.5)	
Zinc	0.22 (0.1)	0.22 (0.1)
Others	0.07 (0.3)	0.07 (0.3)

Table 2

MINERAL	NET IMPORT RELIANCE (%)	MAJOR IMPORT SOURCES
Natural graphite	100	China, Mexico, Canada, India
Copper	37	Chile, Canada, Mexico
Nickel	50	Canada, Norway, Finland, Russia
Manganese	100	Gabon, South Africa, Australia, Georgia
Cobalt	76	Norway, Canada, Japan, Finland
Lithium	>50	Argentina, Chile, China, Russia
Rare earths	100	China, Estonia, Japan, Malaysia
Zinc	83	Canada, Mexico, Peru, Spain

CHEVROLET



EVs such as the Chevrolet Bolt contain strategic minerals not used in conventional ICE-powered vehicles, and some shared but in much higher quantity.

The data show that of the eight minerals used in electric cars, five are not used in IC-powered vehicles: graphite, nickel, cobalt, lithium, and rare earths. Furthermore, two additional minerals – copper and manganese – are used in electric cars in more than twice the quantity, by weight, as they are used in conventional vehicles. Finally, zinc is used to the same extent in both car types.

Table 2 includes two sets of information. The first set involves the 2020 U.S. net import reliance for the eight minerals used in electric cars. The data, which come from the U.S. Geological Survey (**USGS**) [https://pubs.er.usgs.gov/publication/mcs2021], represent the imports for all uses, and not just for vehicles. The table shows that the net import reliance is 50% or greater for all but one mineral of interest (indeed, it is 100% for three minerals).

Table 2 also lists the major import sources (in descending order of import share) for all minerals, also from the USGS. The main import sources for the eight minerals are Canada (nickel and zinc), China (natural graphite and rare earths), Chile (copper), Gabon (manganese), Norway (cobalt), and Argentina (lithium). It should be noted that the entries for graphite are for natural graphite. The U.S. is a major producer of synthetic graphite.

Michael Sivak

Michael Sivak is managing director of Sivak Applied Research [http://www.sivakappliedresearch.com/] and the former director of Sustainable Worldwide Transportation at the University of Michigan [http://www.umich.edu/~umtriswt]. This article originally posted on https://www.greencarcongress.com/ and is used with permission.

NVH

Valve cuts NVH in GDI engines

When a leading automotive manufacturer struggled with the release of a new fuel-injection engine technology, the company required an immediate solution to maintain launch scheduling, not to mention corporate reputation. Increasingly stringent global emissions regulations have led many OEMs to implement gasoline direct-injection (GDI) fueling technology, which provides improved fuel economy, reduce emissions, and increase power. But GDI can bring problems.

The automaker found pressure pulsations in the engine's low-pressure fuel line, upstream of the single-piston high-pressure pump that pressurizes the GDI injectors. Under certain driving conditions these pulsations created noise, vibration, and harshness (NVH) issues for the customer and fatigue-wear issues in the low-pressure fuel system. The problems – identified 10 months prior to the planned vehicle launch – could lead to significant schedule delays.

The **Lee Company**'s engineering team met with the OEM to discuss the problem, the system layout, mounting options and the high-level performance requirements. The automaker envisioned a component that would dampen pressure spikes returning to the tank, provide a thermal relief function, have a negligible effect on flow to the high-pressure pump, and fit within their system.

In less than a week, Lee engineers designed, built and delivered a uniquely engineered potential solution: a check valve in the fuel line. Testing confirmed the check valve solved the performance problems, reducing the pressure pulsations by up to 90% while fitting within the existing fuel line. The system with the new check valve met all other performance requirements. Over the next six months, the engineers designed and fabricated a completely new production line, supplied Production Part Approval Process (PPAP) parts and initiated production.

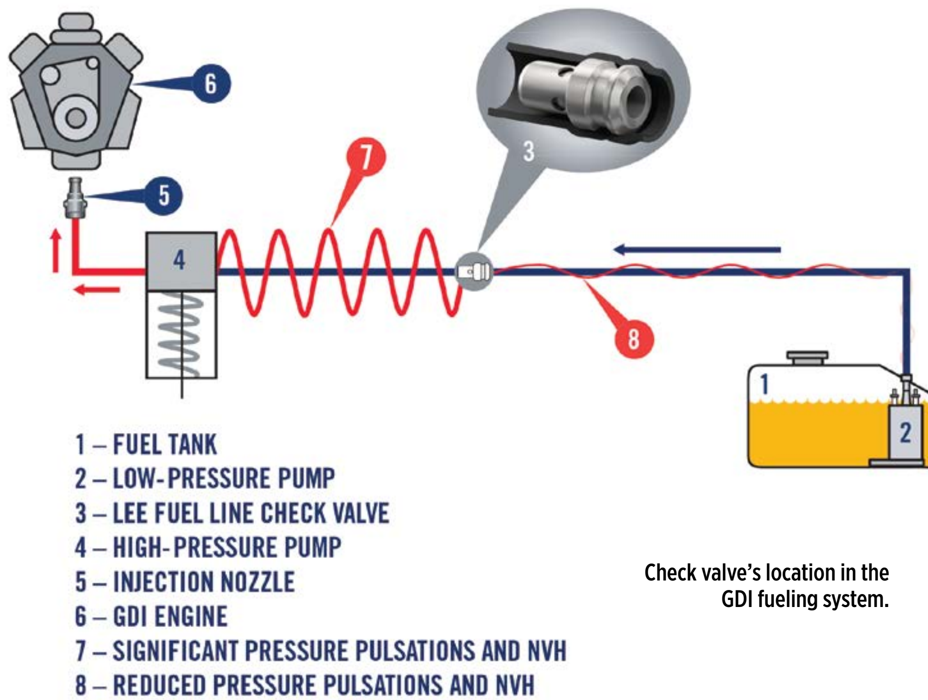
The check valve that helped to dampen the pressure spikes is a multi-function valve that combines the performance of a check valve, a pressure dampening restrictor and a thermal relief function, the company said. Conveniently, the valve is easy to install and doesn't require customized mounting equipment – or add potential external leak paths within the fuel system. The innovative

FORD

valve can be added to the fuel system to dampen residual pressure pulsations discharged from the high-pressure pump and virtually eliminate NVH and fatigue wear on the low-pressure pump.

The quick transition from initial design concept, through validation and into production helped the OEM launch the vehicle on schedule and safeguard their reputation. Since this initial application, the fuel-line check valve has been adopted by multiple global OEMs. The company said designs are available for a variety of standard fuel-hose materials and sizes and this valve has been proven a reliable solution to any pressure dampening application. There currently are more than 35 million currently in use. To learn more, contact The Lee Company at www.theleeco.com/contact.

Gregg Shanley, Technical Marketing Manager for the Automotive and Industrial markets, The Lee Company



Check valve's location in the GDI fueling system.

THE LEE CO.

Airing on the side of INNOVATION

In the EV vanguard: The 2022 Air on the road. Lucid is using its technologies to drive down EV cost.

Lucid Motors' home-grown technologies are setting the pace in electrification. Top engineers tell how and why they're building a benchmark.

by Lindsay Brooke

Is there a proven formula for creating a top-notch engineering organization and benchmark product from scratch? **Lucid Motors** CEO Peter Rawlinson shared his approach at the company's Newark, Calif, headquarters.

"We have a very small team of brilliant engineers that we've managed to attract to the company with a vision: to do the best electric vehicle ever," he explained. "It will be outstanding for your career; it will be stimulating," he told them. "And they came." Rawlinson, who previously led Model S development at **Tesla** and was top engineer at Jaguar and Lotus before that, used a similar talent pitch at Tesla. The then-obscure startup had just six engineers when Rawlinson joined in 2009.

"Peter is the amalgamating leader at Lucid," noted Eric Bach, the senior VP of product and chief engineer who left Volkswagen to join the Lucid crusade. He said Rawlinson looks for "raw intellect times hours," meaning drive and desire. "With raw intellect, it doesn't matter if the other people on the team are from automotive, aerospace, or elsewhere," Bach explained. "Because it's all about engineering fundamentals."

No question that Lucid's leadership, including senior engineering director Dr. James Hawkins (ex-**Aston Martin**), design chief Derek Jenkins (**Audi**, **VW**, **Mazda**), and their colleagues squarely nailed the fundamentals for their first production vehicle, the remarkable 2022 Air. The luxury electric sedan, built at Lucid's Casa Grande, Arizona, plant, is impressing customers with its industry-leading range, its blend of speed, agility and mile-eating comfort, and its innovative technologies.

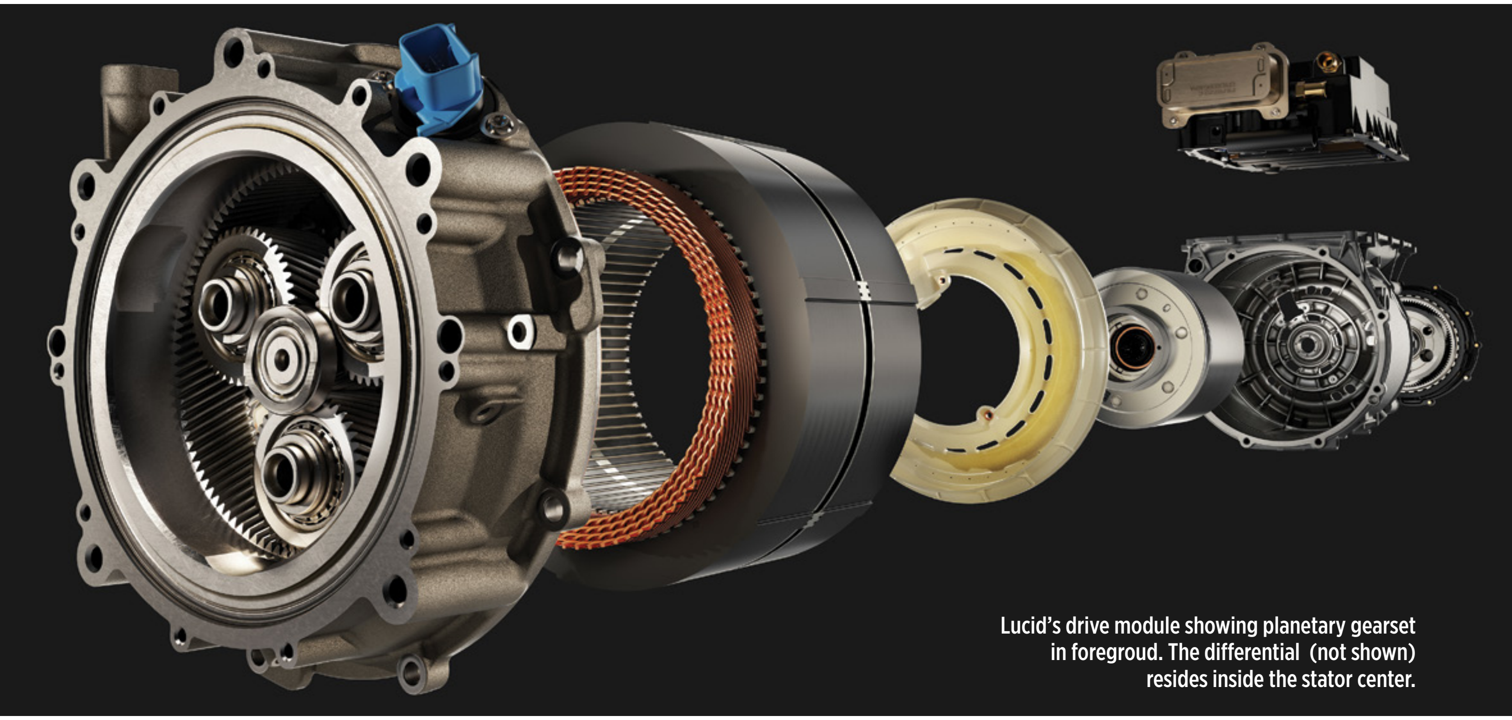
But beyond establishing the Air as an EV pace-setter, the team's mission is "to advance the state of the art in electric cars; to show what's possible — and to use our technology to drive the price down," Rawlinson asserted. Total vehicle efficiency is the team's mantra, exemplified by the Air Grand Touring model.

The GT's 926-volt, 112-kWh battery pack consists of 6,600, cylindrical 21700-type cells arranged in 22 modules, 300 cells per module. The **LG Energy Solution** cells nestle in a simple and robust Lucid-designed single-shot, injection-molded structure, incorporating a cold plate on its back side. "It's super cheap to make," Rawlinson said. "The design can be mass produced by the millions." Most importantly, the Air delivers a maximum 516 miles/830 km range on the **EPA** drive cycle, which equates to 4.6 miles per kilowatt-hour. "There was no single enabler for this efficiency achievement," Hawkins told SAE Media. "It comes from attention to systems engineering and gaining a percent here and a percent there. They add up."

The next Air model, called the Pure, launches later this year with a smaller, lighter 88-kWh, 18-module pack and 400 miles/644 km range, at a significantly lower price point ($77,400) than the limited edition $169,000 launch model.

The team is leveraging a mass-compounding factor by optimizing total systems efficiency, with focus on the powertrain, Hawkins said. Less battery weight means less structure to carry it around, less cost and greater simplicity; every 15 kg (33 lb.) of vehicle mass saved yields about one extra mile of range. But as he and Rawlinson admonish, there is too much emphasis on the battery in many EV discussions. "It's [the battery] just the gas tank of the EV," Rawlinson quipped. "The motor and inverter are more important to how we get the range and efficiency — we've got a more

LUCID MOTORS



Lucid's drive module showing planetary gearset in foregroud. The differential (not shown) resides inside the stator center.

efficient motor than anyone else. We've got a more aerodynamic car."

Using Rawlinson's "space concept" vision, the Air was designed from the inside out, creating a car that's smaller on the outside than a Tesla S but featuring a roomy interior with more rear seat legroom than a long-wheelbase **Mercedes-Benz** S-Class. It's also agile and, with 1,080 hp (805 kW) available through all four wheels, fun to drive.

The team didn't aim for king-of-the-hill 0-60 mph acceleration in its target setting. Instead, it aimed for range, efficiency and "mid-range punch." Deft aerodynamic work by Jenkins' designers and Lucid aerodynamicist Jean-Charles Monnet, hired from the Red Bull Formula One team, resulted in an aircraft-inspired exterior form boasting a .20 Cd(A). Rawlinson believes Air is slipperier than a Mercedes-Benz EQS. Even the underside of the Air's battery pack is slightly radiused for lower drag, "to achieve better airflow attachment toward the back of the car," Monnet said. An underbody diffuser is mounted from the B-pillar rearward. But the key to optimizing total vehicle efficiency was minimizing the electric powertrain.

In-house design engineering focus

Rawlinson said the Air program's biggest achievement, and biggest risk, was undertaking the 'space concept' without the powertrain technology (at the time) to make it work. "If it [powertrain] couldn't be miniaturized, the concept wouldn't fly," he explained. The first Air prototype was only two-wheel drive because the new, ultra-compact drive module being developed in parallel, in-house, wasn't ready. "I don't think any other company would be crazy enough to do that," he said.

The Lucid team members are stalwarts of in-house development for bar-raising technologies including exterior lighting, bi-directional charging and the drive module. The latter integrates the power electronics, e-motor and transmission into a beautifully compact, 74-kg (160-lb.) package. Rated at 670 hp (500 kW), the drive module looks tiny compared with the similar hardware from Tesla (Model 3) and GM (Bolt) on display during SAE's visit.

"You cannot buy the technology that we've got," Rawlinson opined. "If all I wanted to do was another car, I would have done that with suppliers. A whole bunch of [EV] startups and established OEs are just buying stuff. But where is the value of a company that just buys-in its motors, for example? For some items, of course, we're not going to reinvent the wheel; **Bosch** does a great i-boost [braking] system. **Akebono** does great foundation brakes. **Pirelli** and **Michelin** do great tires for us." The company also designs all of its printed circuit assemblies (PCA).

Lucid's objective to advance the state of the art in EVs "sounds like bullshit, but it's true," Rawlinson said. "It's what is necessary to achieve accelerated widespread adoption." He believes electrification is a technology race, with the first milestone (500-mile range) achieved. The next milestone is significant cost reduction "so that the man in the street can afford an electric car." Added Hawkins: "We need to understand the entire system, and every bottleneck within it. If we had somebody else design an inverter for us, there is always some part that we can't control. And if we can't control it, we can't optimize the entire system. With our own technologies we have command over our destiny."

LUCID MOTORS

Lucid lighting experts engineered the Air's LED-based headlamp modules that use a microlens array optical system featuring switchable light channels and a solid-state high beam linked to the car's steering. Each microlens has a direction and a focal length. Miniaturization of the modules enabled designers to give Air the industry's slimmest lighting apertures.

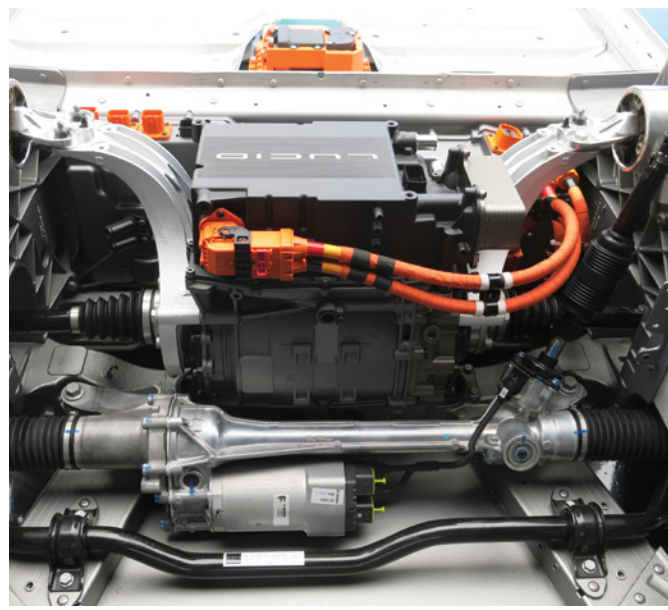
Inside the unique drive module

Among the Air's tech stars, the drive module may shine brightest. It's a triumph of systems engineering and thorough analysis of electromagnetics, motor topology, power flow and cooling. According to Bach, the geometry and physics that went into the design are what give Lucid's motor its formidable power density. The drive unit can be used for the front, rear, or on both axles in the vehicle; only the motor mounts are different. In the Air, the rear drive unit is rotated 90 degrees to make it "flatter" in profile and thus provide more luggage-compartment volume.

The electric machine is an oil-cooled permanent-magnet design, optimized to reduce internal resistance to free spinning, Bach said. Uniquely, the differential is located inside the rotor, "our secret sauce," he calls it. Rawlinson describes the arrangement as "a single rotational inertia system" that avoids the tolerance-related losses inherent with many motor-gearbox pairings. The design engineering is most remarkable when viewed in a cutaway display motor at Lucid HQ (unfortunately, photos were forbidden during our visit). The engineers said they looked forward to teardown specialists Munro & Assoc. fully dissecting an Air and reporting their findings.

While brainstorming the motor concept in the context of power density and miniaturization, the team discussed how to utilize the space within the center of the rotor. "We realized that it was the most logical space for the differential," Bach recalled, "because the center of the rotor doesn't generate torque; it's typically dead mass within the lamination stack." They decided to sequester that space and engineer a small, lightweight, high-speed/low-torque differential to reside there. With the diff inside, two planetary gearsets (one each for left and right differential speed) were engineered into the transmission design.

The planetaries and their tooth profiles also were designed in-house to meet the team's stringent spec for "perfect gear meshing under high- and low-load conditions," Bach explained. Again, every percent of efficiency gained is important. The gearing is oil-lubricated via a small pump that delivers oil from a compact sump, through an annulus to cool the stator and end windings. It also lubricates the differential.



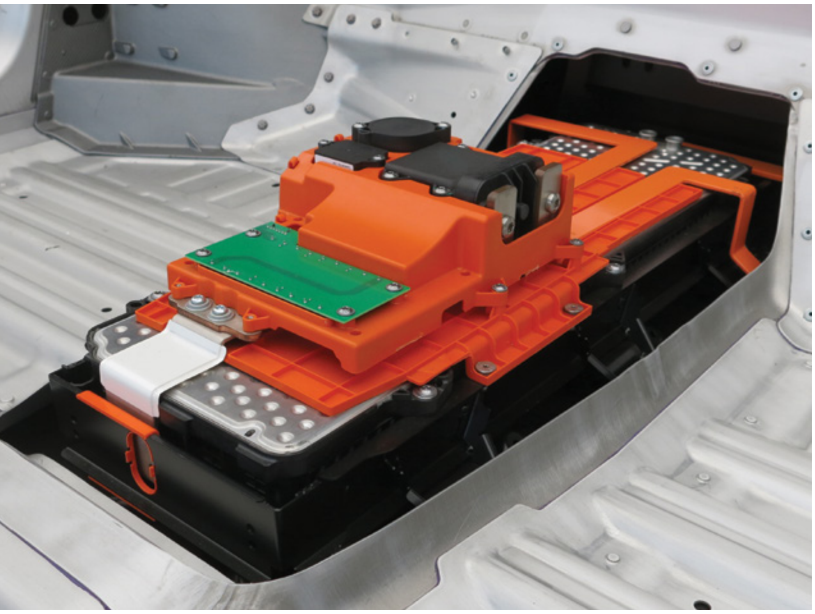
Drive module with integrated inverter at top, installed in the Air sedan.

"It's all optimized for efficiency. You can't achieve the efficiency we wanted in this system by going to an outside supplier," he said. The heat exchanger mounts directly on the electric machine; pressurized coolant flows in to cool the inverter in situ, transferring the heat into the oil which then cools the drive unit. A look inside the cutaway property reveals the resolver, also an in-house development. Integrated with the rotor shaft, the resolver determines the clocking angle of the rotor. "A motor supplier would not have come up with the idea of integrating the resolver and rotor shaft," Bach asserted.

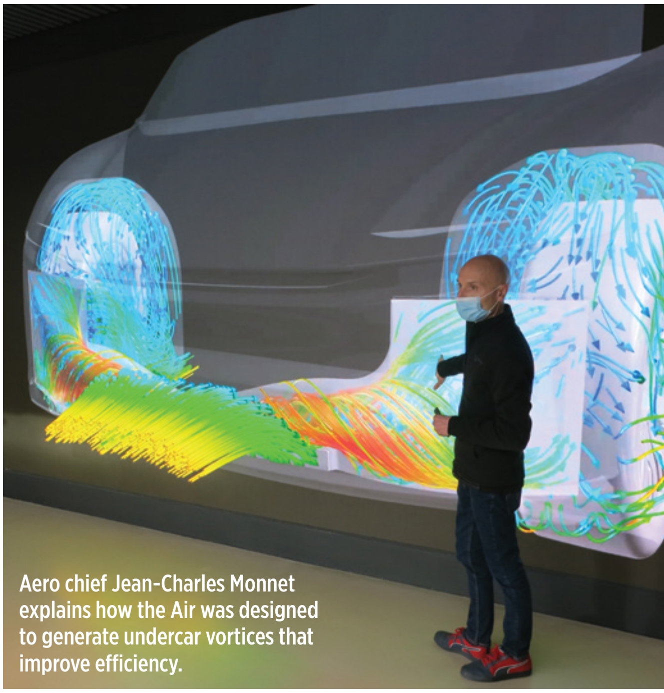
FROM TOP: LUCID MOTORS; LINDSAY BROOKE

Airing on the side of INNOVATION

The battery is just the gas tank of the EV. The motor and inverter are more important to how we get the range and efficiency.



The 'wonderbox' 19.2-kW bi-directional charger located centerline in the Air. Developed in-house by Lucid, the unit enables vehicle charging up to 924V and includes a DC-DC converter for a 400V intermediate bus to power vehicle systems. With DC fast charging, the system can charge the Air at a rate of 300 to 350 kW, delivering roughly 20 miles of range for each minute charging.



Aero chief Jean-Charles Monnet explains how the Air was designed to generate undercar vortices that improve efficiency.

Thermal management is another detail noted by the engineers. "We found space for the cooling channels right next to the copper, where the motor heat is created," Bach explained. "Nobody else has done motor cooling this way because they feel it would weaken the electromagnetic flux," he said. "But we cultivated an electromagnetic 'dead zone,' as we call it, that doesn't contribute to torque generation. We cool faster than anybody else. This comes from simulating everything in-house."

Another Lucid technology asset at play on the manufacturing side: The company owns unique, continuous-wave winding equipment to do its motor windings in a dedicated Arizona powertrain factory. Bach describes the machinery as "fully automated, highly scalable, and engineered for high-volume manufacturing."

How is Lucid approaching reduction of rare earth metals? The current motor design includes neodymium magnets and "low amounts" of dysprosium, according to Bach. "Our roadmap includes new materials to get rid of rare-earth metals as much as is humanly possible," he shared.

Like the Lucid motor, transmission unit and battery pack, the power electronics hardware and software are extensively patented. The inverter is a 500-kW design that uses silicon-carbide (SiC) MOSFET semiconductor technology. It features a proprietary connection system that's positive and virtually error-proof: It connects to the motor when it's bolted down during assembly.

The unit's close proximity to the motor (about two inches/5 cm), helps unlock more efficiency in transporting electrons from the inverter, at three-phase, into the motor. The inverter-to-motor distance on Tesla Model S — admittedly a much older vehicle — is about two feet, Hawkins observed: "Another vital fraction of a percent," he said.

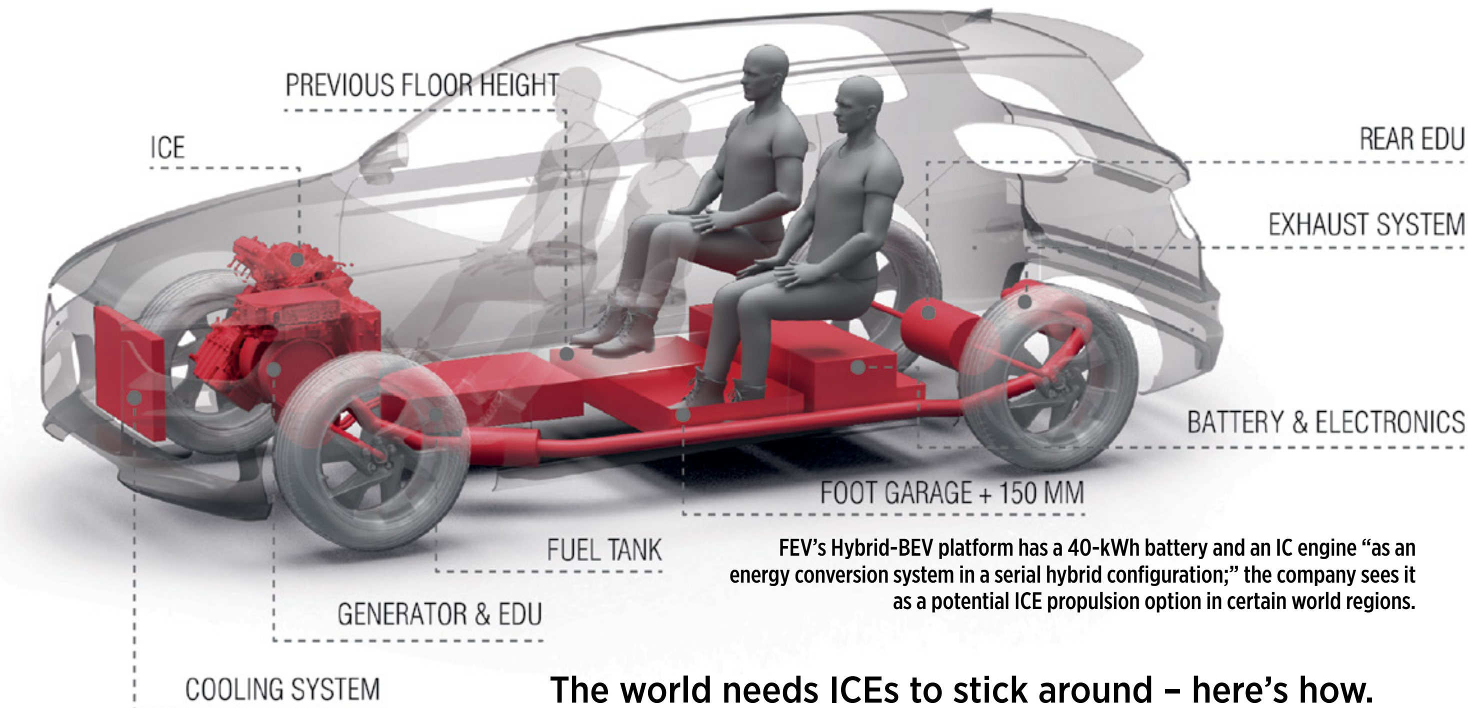
Scaling up

Scale is critical to reducing cost, and the Lucid engineers said their designs will scale according to volume demand without issue. "We realize the ability to manufacture economically is a guarantor of success and for being competitive," Hawkins stated.

As the company scales-up beyond its first product, the team realizes the need for greater rigor in design freeze, further DFMA (design for manufacturability and assembly) advances and meeting start-of-production (SOP) timing. To that end, another VW veteran, Ralph Jakobs, was hired for the new role of VP of program management. "He leads our cycle planning," Rawlinson said. "It shows how we're maturing." Added Bach: "All of our critical thinking has been focused on the Air, but now we are parallelizing the work and creating functional units per the classic matrix organization. But we aim to keep that nimble edge." ■

BOTH IMAGES: LINDSAY BROOKE

Keeping combustion in the conversation



FEV's Hybrid-BEV platform has a 40-kWh battery and an IC engine "as an energy conversion system in a serial hybrid configuration;" the company sees it as a potential ICE propulsion option in certain world regions.

The world needs ICEs to stick around – here's how.

by Bill Visnic

Signals are everywhere that the days are numbered for internal-combustion engines for passenger vehicles. **Volkswagen** CEO Ralph Brandsteatter told a German magazine in early 2021 that VW would follow its closely-linked Audi brand in ceasing development of any new IC powerplants. A report from South Korea in late 2021 said the massive **Hyundai** Group had eliminated its engine-development unit. **Mercedes-Benz**, as historically linked to ICE as any automaker, stated in July 2021 that all newly-launched vehicle architectures would be electric-only starting in 2025.

Although those pronouncements seem to have a Draconian finality, nearly all reasonable industry experts believe the end of the ICE for light vehicles will be a protracted sunsetting involving multiple market-dependent, regulation-dependent and regional variables. The ICE will be powering vehicles long after these ostensible deadlines – but it's going to need new technology and new thinking to carry it through the industry's propulsion transition.

Dean Tomazic, COO at vehicle and propulsion development R&D firm **FEV** North America, sees global emissions, fuel economy regulations and regional market preferences as the chief shaping agents for the ICE in the next decade or more. "In Europe, we are talking about Euro 7 [emissions regulations] now – which is still not 100-percent defined – and we're talking about [in California] LEV IV. We're looking at new fuel economy legislation. We are looking at environmental groups. We look at the politicians and, of course, city mandates in some parts of the world that say, 'We don't want diesel engines anymore,' or 'Starting in year X, we don't want any combustion engines anymore.'

"With that in mind, the different powertrain types we will be looking at in the future – and I think it's true for the entire world – start at micro-hybrids, up to mild hybrids, full hybrids and HEVs," Tomazic said. Citing the four main categories where combustion engines will continue he sees ICEs playing a major role for years to come, in two configurations. One is conventional high-tech engines, including micro-hybrid and mild hybrids. The other is what he defines as 'dedicated' hybrid engines, which are more applicable to full-hybrid applications, as well as PHEVs. Tomazic and others note ICE isn't destined for the graveyard nearly as soon as the end-of-development announcements may suggest. But with the onrush of electrification and the seemingly certain prioritization of EVs in the propulsion-investment landscape, R&D for the ICE seems destined to follow a dual-path blueprint: one of emissions improvements to keep pace with tightening global regulations and a parallel course of evolution imparted by mostly known and proven technologies to conventional engine architectures.

Nothing exotic

The auto industry's maturation has winnowed the variety of production-vehicle ICE propulsion options to gasoline or diesel, inline or vee four-stroke reciprocating engines. "Exotic" architectures that even recently

Toyota and Yamaha collaborated on a hydrogen-fueled variant of Toyota's 5.0L V8, which point the way for further hydrogen combustion-engine projects.

Mahle's Jet Ignition pre-chamber injector for use in a hydrogen-fueled diesel engine.

have been in production or were being considered – the rotary (Wankel) and opposed-piston layouts, for example – have lost momentum. Most propulsion experts expect that tightening R&D resources will virtually guarantee the status quo.

"I think by 2030, everybody's talking about maybe 50 percent market share for EV but that clearly leaves 50 percent of the vehicle population still with some kind of engine in it – that's a very significant portion," said Mick Winship, CTO at **AVL** North America. "We won't see a significant 'stack' change in technology, I believe. You'll see technologies iterate from where they are today."

Added Thomas Howell, AVL's Conventional Powertrains Segment lead, "I think the fundamental base modern engines are probably capable of achieving what needs to be done for the future. There will be development required to achieve the legislative targets." He added that some of the older platforms, which are steadily being retired, will have to be retired because they will not achieve the targets."

That's not to say alternative ideas are no longer percolating. There have been on-again, off-again reports that **Mazda**, the dogged proponent of the Wankel, would use the rotary as a range extender for its new but battery-capacity-challenged MX-30 EV. As this story was written, a U.S.-based Mazda official could not confirm that the company would be taking the leap to once again fit the rotary engine in a series-production vehicle (at least for the U.S. market). A similar scenario played out with Mazda's innovative Skyactiv-X gasoline compression-ignition I-4, which was released in Europe but has yet to appear in any U.S.-specification Mazda.

The same is true of various opposed-piston engine designs, such as that of **Achates Power** [https://www.sae.org/news/2021/03/achates-power-opposed-piston-two-stroke-engine] which hold promise, but have not made the final cut for production. Meanwhile automakers are assiduously cutting back engine families in favor of electrification investment. **BMW** announced the elimination of its gasoline V12; light-duty diesels of all kinds are on a fast decline (in 2021, **Ford** quietly dropped its 3.0L Powerstroke diesel for the F-150 pickup). And in the truck- and SUV-obsessed U.S., OEMs have started to reduce availability of V8s. Strong rumors indicated Stellantis even is preparing a turbocharged I-6 to effectively replace the vaunted "Hemi" V8.

In summer 2021, the *Wall Street Journal* reported **IHS Markit** forecast data indicating new-engine launches for the year to be less than 10, and dropping "essentially to zero," compared with 20 to 70 new engines launching in prior years.

FROM LEFT: YAMAHA; MAHLE

Keeping combustion in the conversation

Audi's HVO diesel fuel is said to drastically reduce CO_2 from current-production 4- and 6-cylinder diesels. It is available in 600 retails stations in Europe.

Hybrid, long-stroke hope

There no longer is absolute consensus among powertrain developers that hybridization will be ubiquitous in most light-vehicle segments. Not long ago, hybridized ICEs had driven the case for continuing ICE development and was its reason for being. Without hybridization, many experts believe, a conventional ICE powertrain will not be fuel-economy or emissions compliant in many world regions.

The AVL engineers see ICEs for hybrids that adopt and enhance a variety of existing technologies to narrow the engine's operating range even more than in today's "full" hybrids. Such specialized designs' operating characteristics make the engine more of a type of "generator" than a full-range powerplant. Their enabling technologies include some combination of cooled EGR, high compression ratio and longer-stroke dimensions.

"One area which I think still has not been fully exploited – and is under exploration at the moment – is low-pressure EGR in gasoline," said AVL's Howell. "This can be a pretty impressive enabler; AVL's been developing dedicated hybrid engines for quite a while. We've achieved 45 percent [brake thermal efficiency] out of a 11:1 [compression-ratio] engine. That uses a plethora of technologies, which are all known, but it's a matter of optimizing in order to achieve that."

The key enabler for that type of application, Howell explained, is a "very high" stroke-to-bore ratio. But the challenge that comes with that type of application is it requires a 'new' engine. "So, it seems unlikely to be a mainstream in EU and U.S. because of the sunsetting of the IC engine," he said. "But there is a lot of interest in China. We've done several engine platforms in the Chinese market."

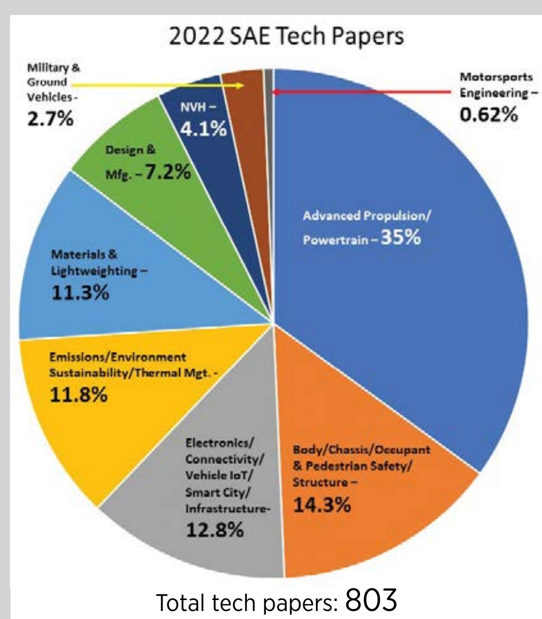
FEV's Tomazic sees a developmental difference between ICEs designated for micro-hybrid and mild-hybrid duty, versus "dedicated" hybrid engines that would include those designed for HEV and PHEV applications. OEM strategies will range from, "You would only add as much technology as you need to meet the regulatory requirements, up to putting in everything you can right now," he noted. "There's a wide array of different technologies — efficiency optimization obviously plays a very big role – otherwise from a CO2 and fuel-economy perspective, you won't meet the targets."

He also mentioned the menu of existing technologies that can be improved in the quest for the "better" ICE, particularly "higher stroke-to-bore ratios combined with cooled EGR to deliver higher efficiencies at stoichiometric combustion." Tomazic added that "[fuel]-injection pressures going up beyond 350 bar and pre-chamber applications could also become very important technologies which potentially also would allow us to go very lean to a point where we would see very low NOx emissions — from an aftertreatment perspective, that could mean some relief."

Powertrain, propulsion continue to lead SAE tech-paper topics

For 2022, advanced powertrain/propulsion-related topics continued to dominate the categories of published SAE technical papers, more than doubling the number papers in the next most-prolific general topic area. Some 281 powertrain/propulsion papers were written for 2022 publication, comprising 35% of the 803-paper total.

Despite the difficulties imparted by the COVID-19 pandemic, 2022's technical-paper production was down less than 10% compared to 2021. The powertrain/propulsion category includes papers addressing ICEs and hybrids and there continued to be considerable contributions in IC-related areas of combustion for spark-ignited and compression-ignition engines, fuel-injection and use of alternative and advanced fuels.



TOP: AUDI

Keeping combustion in the conversation

Another look at alt fuels

Those seeking to extend the viability of ICE also have recharged the industry's sporadic interest in alternative fuels — particularly for on- and offroad commercial-vehicle applications. But there is alt-fuel potential for certain specific light-duty vehicle segments, too. Hydrogen, thanks to its potential to be derived from CO_2-neutral processes and the comparative ease with which ICEs can be adapted to use it, is experiencing renewed development focus as a zero-emissions alternative fuel.

Toyota (which has proceeded cautiously in the EV race) and Yamaha made news in February 2022 when they announced Toyota had commissioned Yamaha to adapt the automaker's production-vehicle 5.0L V8 to run on hydrogen. Modifications were made to the injectors, cylinder heads, intake manifold and other components, resulting in output of "up to 450 hp at 6,800 rpm and a maximum 540 Nm (398 lb-ft) at 3,600 rpm.

Several commercial-vehicle engine and vehicle OEMs also have active programs for hydrogen fueling of diesel engines. One of the most recent developments was announced by **Mahle** Powertrain and offroad machinery manufacturer **Liebherr Machines Bulle SA**. The collaboration involves the use of Mahle's prechamber jet ignition system (MJI), originally developed for gasoline applications.

"The challenge has been to get it to run with stable combustion without resorting to reductions in compression ratios to avoid engine knock and pre-ignition. Our common work with Liebherr suggests we have the answer," Mike Bunce, head of research for Mahle Powertrain U.S., told SAE Media earlier this year.

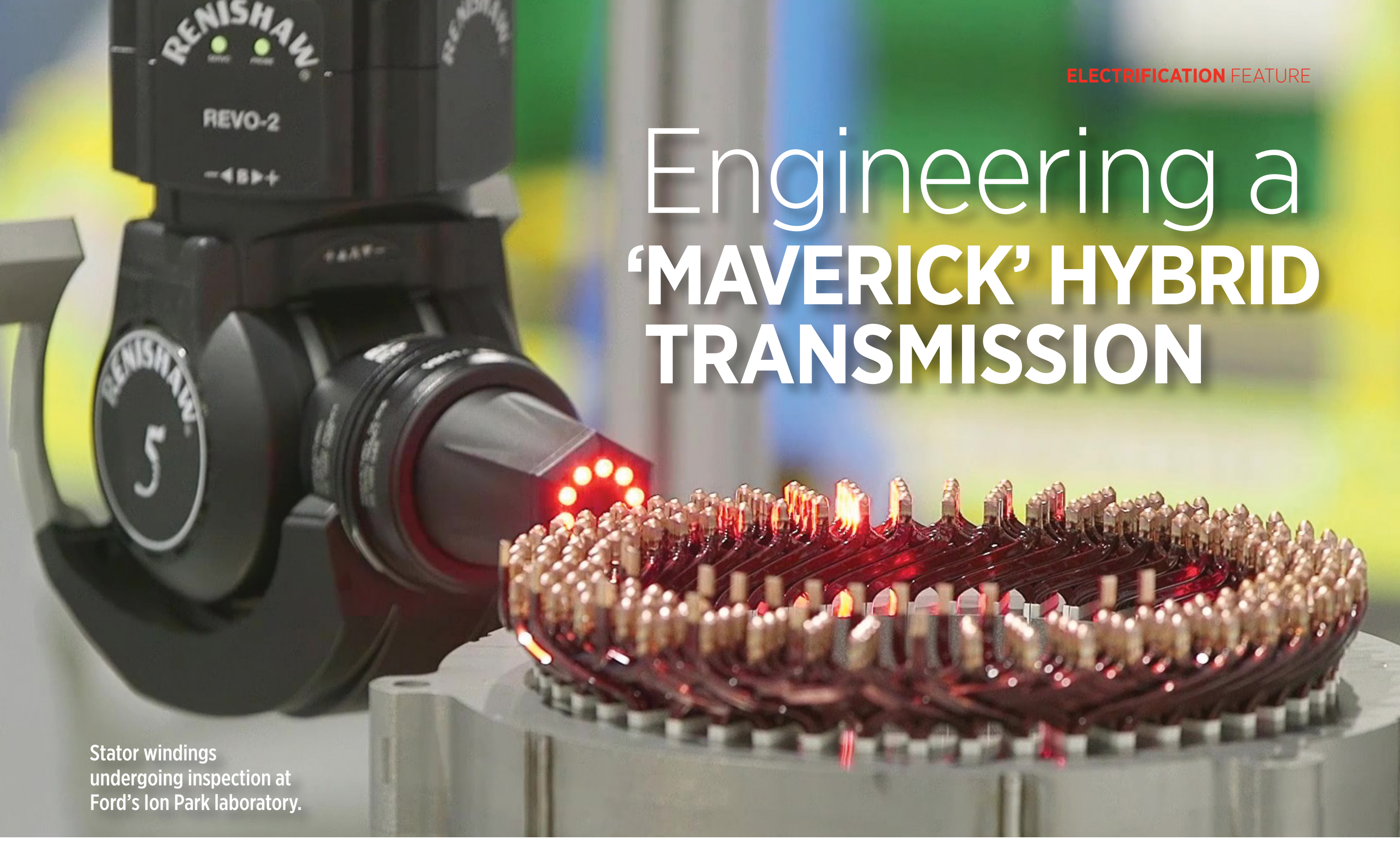
Another option to keep light-duty diesel in the conversation came in early 2022, when **Audi** (which has pledged to end ICE production in 2033) announced production vehicles with V6 diesels would be capable of using new hydrotreated vegetable oil (HVO), a biomass-to-liquid (BTL) fuel.

In addition to a 70-90% reduction in CO_2 emissions, Audi said HVO has a 30% higher cetane rating than fossil-based diesel.

For commercial vehicles, "The combustion engine is still the best solution right now," said FEV's Tomazic. "The infrastructure is there. The energy density is there. Now, if we want to decarbonize fuel and go to hydrogen, this can be done. Yes, there will be changes to the engine system, to the engine hardware, to controls, to the aftertreatment system, etc. But we know what needs to be done.

"What has to happen, of course, is that we have a hydrogen infrastructure," he said. ■

Engineering a 'MAVERICK' HYBRID TRANSMISSION



Stator windings undergoing inspection at Ford's Ion Park laboratory.

FORD

Ford Powertrain engineers marry their new in-house electric machine with the proven HF45 transmission — under aggressive vehicle program timing.

by Lindsay Brooke

Ford's 2022 Maverick combines many practical attributes that earned the new compact pickup its North American Truck of the Year title, among them a standard hybrid powertrain which delivers a 42-mpg city (37 mpg combined) EPA fuel economy rating. MCA (Maverick) program chief Chris Mazur called the truck's aggressive $20,000 base price "a rallying cry" and a "wildly audacious goal" for the development team. Their work included integrating and validating a new **Ford**-designed electric machine into the two-motor HF45 hybrid transmission, on what engineers describe as "a dramatically accelerated" timetable.

"The biggest challenge for us was time," Manny Barberena, the hybrid powertrain supervisor, told SAE Media. "Go-fast programs make engineers nervous, but we were able to overcome it by being efficient" – taking the learnings, development and base calibration from the Escape Hybrid powertrain that was basically carried over and applying it to Maverick. "It really minimized the amount of re-development," he said. "We did have to do some tuning to make things work properly with this new transmission but it sure saved a lot of time in going from Escape to this program on the common C2 architecture. It enabled us to hit the ground running."

Working on the vehicle-development critical path, the powertrain engineers set up two teams to optimize efficiency. Barbarena's team focused on the vehicle level, encompassing emissions, on-board diagnostics (OBD) and driveability, particularly the NVH transitions from when the 2.5-L IC engine is running to when it's off. "The transition should be invisible to the customer," he noted, "but NVH with electrified vehicles is a challenge because the IC engine masks certain noises, some of them rather quiet." A second team, led by Abdul Hajiabdi, the E-drive system and applications supervisor, focused on the Maverick's powertrain from a component and systems level.

In addition to the new e-motor - the first of its kind developed in house by Ford — Hajiabdi's team also juiced up the power electronics for higher voltage and current, and upgraded the other e-machine that serves as the HF45's generator, "pushing its boundaries" he said.

"We were able to design the in-house motor [which Ford engineering sources said is currently manufactured by Toshiba] in such a way that it shares the footprint and all the transmission interfaces with the machine that's used in Escape," Hajiabdi said. "That was one of the major enablers, the synergies, in keeping the cost down without affecting other components."

The team also revised both the rotor and stator, changing from round distributed winding to flat-wire, hairpin-type windings on the stator. The hairpin design resulted in an e-machine with higher current density and higher torque density, paving the way for a slightly smaller overall motor with about a 20% mass savings. On the rotor side, magnet orientation and tension were re-engineered with innovation: The magnets are molded into rotor core, rather than adhesively bonded.

Hybrid-powertrain engineer Manny Barbarena's team focused on the revised HF45's vehicle-level functionality.

The collaboration between Design and Manufacturing engineering to support the Maverick HF45 was an engineer's ideal, said Abdul Hajiabdi.

Close collaboration between the Design and Manufacturing engineering groups made it happen.

"Until the in-house motor and Maverick program came along, the relationship between the Design team that I represent and the Manufacturing team at Van Dyke [Ford's Electric Powertrain Center factory] was typically a three-way conversation that included suppliers," Hajiabdi noted. "That changed with the introduction of the in-house program, because now the full design ownership is with Ford. The full manufacturing ownership is still with Ford. So now we have a full in-house team that works with what we call PTME, the manufacturing-engineering team, producing the parts together.

"We were able to come up with the design, take it to the shop, prototype build it, check it for process and quality prove-out," he continued. "In doing so, we noticed that there are certain design criteria that looked good on paper but were not manufacturable." The result was "what the true engineer looks for," he said: the 'sweet spot' between the high function sought by the designers, and manufacturability at scale, with high quality and low cost. "It's the start of in-house electric machines to come, including F-150 Lightning," he asserted.

The Maverick hybrid's 2,000-lb (907-kg) trailer-tow capability put transmission thermal management into focus. Initially this presented a challenge, the engineers recalled, because taking an all-new electric machine with its own heat-rejection signature and cooling it in the carryover HF45 "was not a straight plug-and-play," Barbarena noted. Clever internal "tuning" and attention to lubricant flow ensured the hybrid pickup withstands SAE J2807 tow testing and has helped the powertrain team close the tow-capacity gap with Maverick turbo gas-engine models, which is 4,000 lb. (1814 kg). ■

FROM TOP: FORD; LINDSAY BROOKE

HF45's Ford-Aisin-TRW heritage

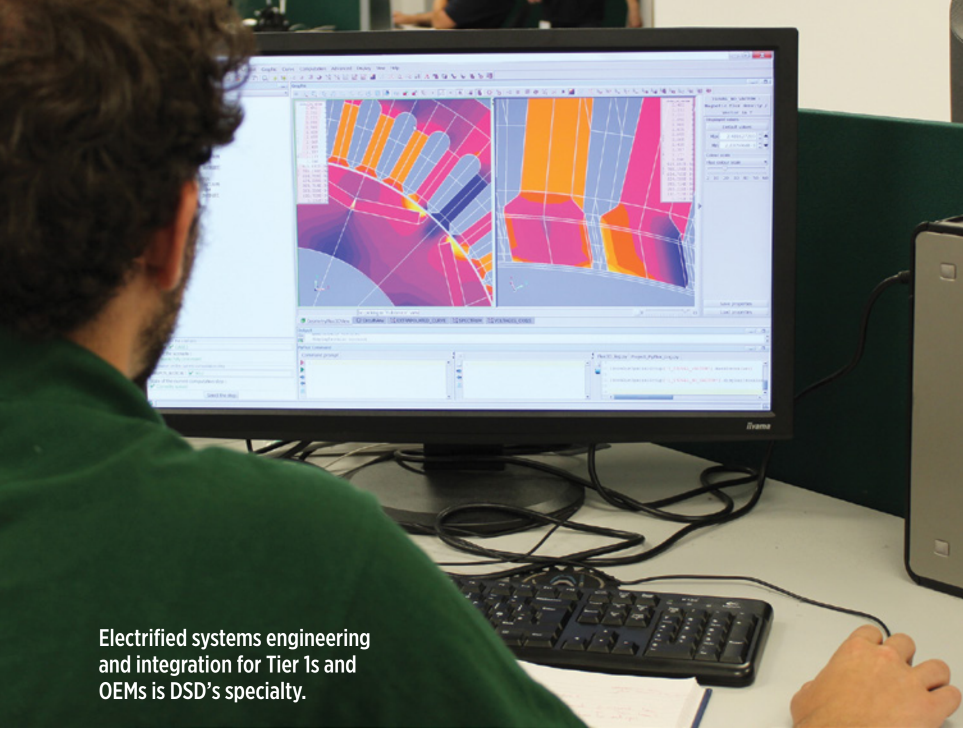
The HF45 has an interesting heritage, according to Craig Renneker, VP product engineering at **American Axle & Manufacturing**. Its predecessor HF35 was one of 18 transmissions launched by Ford between 2000 and 2018, when Renneker was a chief engineer in the company's Transmission & Driveline Engineering.

"The HF35 was one of the great successes," he said proudly. It was based on the Aisin AW PowerSplit architecture (itself inspired by early-1970s TRW technology) enabled by an agreement between Ford and **Toyota**. The deal allowed Ford to use the powerflow of the first-generation **Aisin AW** models HD-10 and HD-20 for their own product. According to Renneker, the powerflow of the Aisin and Ford HF35 "are nearly identical, as are the motors and Denso inverter architecture."

Ford Escape taxi cabs operating in New York City proved the basic design's durability. Renneker recalled getting a hybrid Escape cab back from the field with 450,000 miles (724,205 km) on it that "was still running fine with the original battery." A full teardown revealed transmission internal parts that looked perfect, "good for many more miles," he said.

Renneker points out that contrary to some media articles, the HF35/HF45 design is "not a typical CVT in which the torque multiplication ratio between the engine and the wheels can be varied continuously." He noted that with the Toyota/Aisin PowerSplit concept, the ratios themselves are fixed, but in Ford's unit, one of the electric motors is used to control engine speed to optimize best-fuel-economy or best-power conditions. All of this is managed by the software, with no driver input required. "This speed control is continuously variable, so the 'CVT' terminology is still okay," he said.

Lindsay Brooke



Electrified systems engineering and integration for Tier 1s and OEMs is DSD's specialty.

DSD

DRIVING electrified powertrain systems design

Drive System Design punches beyond its weight class in meeting customer needs for electrified powertrain systems engineering services. DSD's North American chief Jon Brentnall explains.

by Lindsay Brooke

The risks that come with electrification leave OEMs and Tier 1s little room for miscalculation in their product planning and development. The costliest mistakes loom largest in the powertrain space where hardware, software and energy-storage technologies are fast evolving, explains Jon Brentnall, president of **Drive System Design** (DSD), the North American arm of the U.K.-based powertrain engineering consultancy.

"There's an awful lot of learning going on within the automakers and suppliers," Brentnall told SAE Media in an interview at DSD's suburban Detroit tech center. "They're having to pivot their business models and quickly become proficient at designing and industrializing electric machines integrated into gearboxes with an integrated power-electronics system. They're often competing for the same engineering talent. And initially, many of them are going 'vertical' [developing core technologies in-house and owning the IP, rather than outsourcing] which I think is the right thing to do."

Even for incumbent automakers and suppliers, the learnings in this uncertain and dynamic space are huge. And DSD's business is growing steadily as a result. Founded in the U.K. by engineers who had built their experience at the large, better-known engineering-services firms, DSD has specialized in advanced powertrain technologies since the company's 2007 launch.

"A lot of customers come to us for help in getting the system-level attributes right," Brentnall said. "Thermal management is a big area. And NVH is huge." He noted that a large German OEM came to DSD specifically for help in solving a difficult NVH problem in an EV; DSD devised a process that led to a solution, delighted the customer and then was refined over time. "We help the Tier 1s establish a 'line of sight,' to get a leg up on the things that keep them up at night: speed of development, reducing risk during development, and the learnings of integrating electrified systems into gearboxes and axles," Brentnall explained.

A fresh customer focus

Being relatively small within the established engineering-services universe gives DSD an agility and operating speed that allows it "to stay one to two percent in front of its OEM and Tier 1 customers," Brentnall claimed. R&D "is always targeted, based on our collaborative customer needs." In terms of revenue, about 75% of the U.K. organization's business is automotive-focused (mostly global passenger-car), while DSD North America's business currently is split 50% commercial truck and about 25% automotive. Defense-related projects are growing steadily, Brentnall said, adding that commercial vehicles are a main growth path.

The notion of setting up DSD came from its founders, including Brentnall, believing they can serve industry customers and develop their engineers "a bit differently and better than we all saw it done at 'the big guys,'" he said. Specializing in powertrain and electrification, rather than being multi-disciplined (i.e. offering body-in-white development) has helped establish and grow the company. "We don't have a wind tunnel," Brentnall said with a laugh.

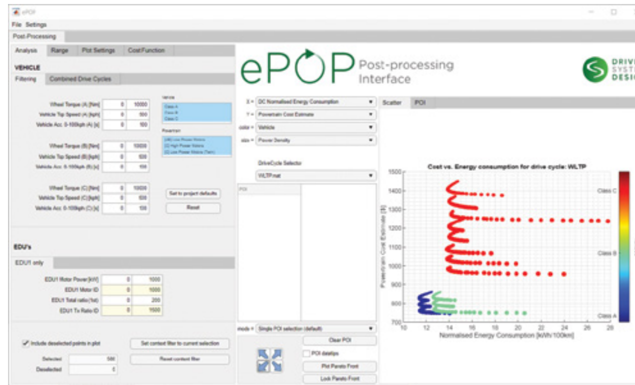
In terms of how DSD serves customers, adhering to budget is paramount, Brentnall asserted, and that helps build the trust that creates long-term relationships. "Our goal is to get our counterparts at customers promoted," he said. "Whatever pains they bring us, we fix them. And we adhere strictly to budgets. Customers remember you for that and so the next time they encounter problems, they're going to call you back. That's how we roll."

DRIVING
electrified powertrain systems design

Customers see "a little company that offers the same level of software and cutting-edge tools as the big guys," says DSD North America boss Jon Brentnall.

He recalled that in a previous consulting experience, the organization was in perpetual search for customers, often because budgets weren't protected and the clients were subjected to a constant churn of staff. "Many of the customers we've had since 2007 are still with us; we just built on them," noted Ben Chiswick, director of engineering business development. He and Brentnall said overheads are kept low and each year since its founding, DSD has reinvested 100% of profits back into the company.

"What our customers see is a little, agile company that offers the same level of software and cutting-edge tools as the big guys," he said. "We have world-class test facilities, albeit on a smaller scale, all for electrified-powertrain development."



DSD's full-factorial ePOP tool produces efficiency maps of all the elements in the powertrain.

The ePOP tool school

Traditionally, OEMs engaged the industry's engineering consultancies when a program fell behind in timing, or planners misjudged resource requirements, or they encountered other hurdles. Electrification is causing both startups and incumbent makers to engage with DSD ever earlier in their development programs. Some customers come with more direction and specific requirements. Others have less focus. For both, DSD offers its proprietary system-level product planning tool called ePOP — the Electrified Powertrain Optimization Process. The ePOP tool helps product developers understand how to meet program and customer requirements within multiple parameters such as battery size and performance, for example. From that tool, DSD engineers work with them in establishing subsystem requirements.

"It's part of our R&D investment," Brentnall explained. "Tier 1s would come to us and ask, 'What's the most efficient transmission, a parallel-axis gearset or a planetary?' But while they're just looking at the gearbox, their customer is concerned about the cost of the battery! They should instead be looking at system-integration synergies. They should be weighing motor topologies — axial flux vs. radial flux? Permanent magnet machine vs. induction? Or, in the inverter, gallium nitride vs. silicon carbide?"

As a full-factorial tool, the e-POP produces efficiency maps of all the elements in the powertrain. It provides "thousands of powertrain scenarios all running against the vehicle drive cycle and produces architecture solutions based on them," according to Brentnall.

The e-POP tool is a significant time-saver for engineers and planners, but it also benefits makers of e-motors and electrified drive modules who sell to Tier 1s and OEMs. "Without an effective tool, how are those companies going to prove to their customers that their electric machine could be part of a system that can help reduce cost of the whole vehicle?" Brentnall asked rhetorically. "With ePOP, they can put their machine into the tool and compare it with the competition. Because if they don't do it, their customer will." ■

BOTH IMAGES: DSD

SPOTLIGHT: PROPULSION SYSTEM SIMULATION

EV Powertrain Simulation

NI (Austin, Texas) in partnership with **D&V Electronics** (Woodbridge, Ontario) has developed two new offerings to enhance testing environments for electric vehicle traction-inverter validation. NI has created a new Inverter Test System (ITS), while D&V has developed the electronics for a power-level inverter test. The companies state that these combined offerings should accelerate testing for EV propulsion systems by enabling integrating testing earlier in the product development lifecycle. They also state that by simulating EV powertrains to perform hardware-in-the-loop (HIL) tests of traction inverter electronic control units (ECUs), the ITS allows EV test engineers to create more life-like scenarios not easily and accurately reproduced on the road.

For more information, visit http://info.hotims.com/82331-400

SPOTLIGHT: ANALYSIS TOOLS

Driving Simulator

Ansible Motion (Hethel, U.K.) has announced details of its production Delta series S3 Driver-in-the-Loop (DIL) simulator. The company states that this is their most sophisticated dynamic driving simulator to date and features the all-new AML SMS2 Stratiform Motion System. The Delta S3's scalable architecture enables it be built and delivered in multiple size options, making it suitable for a broad range of automotive and motorsports product development use cases such as expert driver assessments, chassis dynamics, powertrain drivability, ADAS and active safety function calibration, V2X studies and HMI design evaluations.

For more information, visit http://info.hotims.com/82331-401

Application Testing

Rohde & Schwarz (Columbia, MD) has introduced the R&S CMX500 one-box tester for high-performance 5G automotive measurements. The tester provides comprehensive test coverage including RF, protocol, and application testing. It can cover the entire development cycle from chipsets to TCUs as well as complete vehicles. The R&S CMX500 also provides extensive testing capability, supporting all 5G NR deployments covering LTE, 5G NR FR1 and FR2 in non-standalone (NSA) and standalone (SA) mode, for both FDD and TDD and is capable of reading data rates of 10 Gbps and beyond. Rohde & Schwarz will also exhibit a C-V2X test solution that allows traffic scenarios involving multiple simulated vehicles and the communications between them.

For more information, visit http://info.hotims.com/82331-402

ADAS Processing Chip

Renesas Electronics Corporation (Tokyo, Japan) recently announced the R-Car V4H system on chip (SoC) for central processing in advanced driver-assistance (ADAS) and automated driving (AD). The R-Car V4H achieves learning performance of up to 34 Tera Operations Per Second (TOPS) which enables high-speed image recognition and processing of surrounding objects by automotive cameras, radar and lidar. With a high level of integration, the R-Car V4H allows customers to develop single-chip ADAS electric control units (ECUs). These control units may support driving systems appropriate for SAE automated driving Levels 2+ and Level 3, including full NCAP 2025 features. The R-Car V4H also supports surround view and automatic parking functions with 3D visualization effects such as realistic rendering, the company said.

For more information, visit http://info.hotims.com/82331-403

PRODUCT BRIEFS

Voltage Breakout Modules

CSM GmbH (Filderstadt Germany) has introduced a new measurement technology solution for electric and hybrid vehicles. Their new High-Voltage Breakout Module (HV BM) Split technology not only measures currents and voltages directly in the HV power cables, but also in busbars. The system provides high-frequency measurement of current, voltage and power directly and safely in high-voltage power cables, according to the company. The compact design of the HV BM Split Modules allow measurements in vehicles even where installation space for measurement technology is limited, such as in production intent vehicles.

For more information, visit http://info.hotims.com/82331-404

Simulation Software

Siemens (Munich, Germany) announced that it has collaborated with **NVIDIA** (Santa Clara, CA) on new Computational Fluid Dynamics (CFD) simulation software. Siemens states that the STAR-CCM+ 2022.1 software brings CUDA-enabled GPU acceleration to deliver faster turnaround times at lower hardware investment costs to CFD simulation. By running a set of industrial-grade external vehicle aerodynamics simulations, engineers at Siemens and NVIDIA were able to demonstrate how usage of GPUs could reduce required hardware compute investments by up to 40%. Power consumption also was demonstrated to be down to 10% of the CPU equivalent, while maintaining identical simulation turnaround times.

For more information, visit http://info.hotims.com/82331-405

Uhnder dives into the Ocean with digital radar

While the semi-conductor shortage continues to make headlines, a radar-technology company is readying a first-to-market digital radar chip application on the 2023 **Fisker** Ocean EV, as part of **Magna**'s ICON system. With its staff of some 200 engineers and technology specialists, Austin, Texas-based **Uhnder** has netted multiple patents for its digital imaging technology. CEO and co-founder Manju Hegde spoke with **SAE** Media during a recent drive in Michigan demonstrating Uhnder's technology.

How important is it to be first-to-market with digital radar chips in the passenger vehicle market?
We have been very deliberate in bringing digital radar chips into the automotive market. We've done multiple tape-outs and extensive testing and validation to ensure maturity of the technology, and we've obtained the full complement of certifications. In any technology market, being first is a competitive advantage, but especially so in automotive because products are built to the exacting requirements of the industry. We are not resting on our laurels. We have already begun working on our next-gen product to be in-sync with the increased safety needs as OEMs and consumers push for more [driving] automation.

Manju Hegde says a paradigm shift away from legacy analog radar is underway.

UHNDER

We refrained from making any promises about the product until… we had validated all our claims.

What's the biggest advantage of being a start-up in the digital radar space?
Digital radar is transformative technology for mobility. It addresses the safety shortcomings of analog radar. In addition, the software-defined aspect stimulates innovation by the Tier 1s and OEMs, which will accelerate the enhancement of safety. Only a start-up could take a step as bold as this, because a start-up can dream big, is not hostage to the legacy IP of existing products and not subject to the dogma of the incumbent. Our team brings decades of experience working for some of the biggest names in automotive-specific technology, including **TI**, **Qualcomm**, **NVIDIA**, **AMD**, **NXP**, **Continental**, **Aptiv**, and **QNX**. Our start-up dynamic allows us to move quickly and creatively to pioneer new technologies to meet the needs of the industry.

What is Uhnder's core business plan?
Uhnder is targeting global Tier 1 suppliers and OEMs making automated mobility applications for the movement of people and the movement of goods. Our products are already in delivery robots for last-mile delivery and autonomous container transports for container shipping, and we're excited to make our debut in the electric vehicle market on the Fisker Ocean later this year. We see a huge opportunity to help make automated passenger vehicles safer, while supporting the growth of autonomy in agriculture, construction, mining, shipping, last-mile delivery and warehousing.

Why has Uhnder been an under-the-radar company since its start in 2015?
Uhnder, as a start-up, has had a very close collaboration with Magna, an automotive engineering powerhouse. From that relationship, we learned that the auto industry takes announcements very seriously and expects delivery on what is promised. We adopted this philosophy. And while we discussed the advantages of digital radar technology, we refrained from making any promises about the product until it was done, and we had tested and validated all our claims.

Is analog radar an outdated technology for vehicle applications?
Recent reports from AAA and IIHS have raised serious concerns about the shortcomings of ADAS features in many vehicles currently equipped with traditional analog radar. Legacy analog radar arose from legacy applications, such as cruise control and blind spot detection, where the need was to detect other cars whether at antenna boresight or in an adjacent lane. As the industry moves toward (SAE) Level 2, Level 3, Level 4, the needs are much more stringent: We must detect bicyclists next to the curb, children next to parked cars, stalled cars under bridges, and so on. It is in these use cases that the shortcomings of legacy analog radar, such as insufficient resolution, poor contrast, limited range, and interference susceptibility get exposed and compromise safety. The legacy radar manufacturers are all feverishly putting together many, many, legacy analog radar chips on a system to try and address these deficiencies but these solutions create a new set of issues, such as complexity, power, and ambiguity.

Kami Buchholz

UPCOMING WEBINARS

LIDAR'S NEWEST TRICKS

Thursday, April 7, 2022 at 12:00 pm U.S. EDT

Today's expanding operational design domains are placing new and greater demands on the onboard sensors of advanced driver-assistance systems and automated vehicles that employ high levels of driving automation. LiDAR sensing is a vital aspect of engineering a robust sensor suite, and developers are responding with increasingly sophisticated technology. This 60-minute Webinar from the editors of *Automotive Engineering* examines the latest developments in LiDAR technology that will help advance the capabilities of onboard vehicle sensing.

Speakers:

Alex Coney, Ph.D.
Photonics/LiDAR Expert, Autonomous Group, TTP

Jun Pei, Ph.D.
CEO and Co-Founder, Cepton

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

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TRANSFORM EV DESIGN AND DEVELOPMENT THROUGH PERVASIVE ENGINEERING SIMULATION

Tuesday, April 12, 2022 at 11:30 am U.S. EDT

Engineering simulation technology is helping organizations to significantly reduce the number of physical prototypes and testing, which helps speed development cycles and reduce cost. Simulation can also help engineers have deeper insights into their products, improving product design optimization and quality. In addition, it helps facilitate team collaboration in an organization, as well as between OEMs and suppliers.

This 30-minute Webinar highlights the aspects of simulation in electrification and provides examples of successes from several OEMs and major suppliers. An audience Q&A follows the technical presentation.

Speaker:

Zed Tang, Ph.D.
Global Solution Architect, Electrification, Ansys

Sponsored by: Ansys

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

UPCOMING WEBINARS

TOTAL APPEARANCE MEASUREMENT SYSTEM FOR AUTOMOTIVE APPLICATIONS

Thursday, April 21, 2022 at 2:00 pm U.S. EDT

For maximum impact, the surface quality of an automotive paint finish must instantly produce an appealing visual sensation for the customer. This 30-minute Webinar discusses a new way of quantifying appearance quality by using double-focus image technology to imitate the functions of the human eye and mimic the sensations that take place in the brain.

Topics will include how to define quality and harmony in appearance with a single value, and using contrast, image sharpness, waviness and dominant structure size to produce a comprehensive description of the visual sensation.

Speaker:

Mark Lombardi
Technical Support Manager,
Konica Minolta Sensing

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

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DEVELOPING DISPLAYS AND HUMAN MACHINE INTERFACES FOR ELECTRIC VEHICLES

Thursday, April 28, 2022 at 2:00 pm U.S. EDT

This 30-minute Webinar covers the wide range of engineered material components and stack-ups as well as the design considerations that go into developing high-reliability EV displays, dashboards, and next-generation human-machine interface (HMI) consoles.

Insight on design tips, how components interact, and how to achieve thinner, clearer, better performing multifunctional material solutions through design integration and streamlined design for manufacture will be shared.

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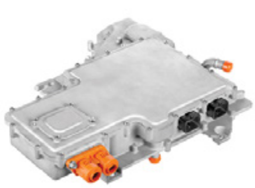
Products/Services Offered

We're making eMobility available to all with our cutting-edge technology and deep electrification expertise. Some of the innovative solutions we're bringing to market include battery systems, chargers, electric drive modules, power electronics, thermal-management systems and more.

Electric Drive Modules

Thermal Management

Power Electronics



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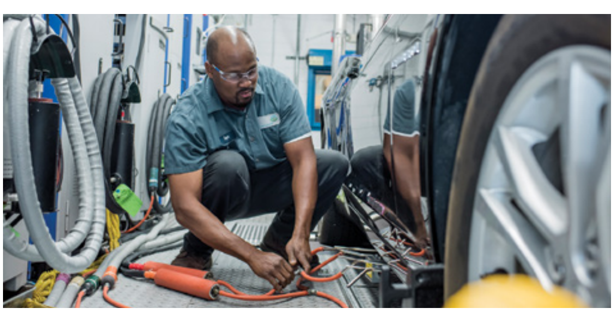
About Our Company

Umicore is a global leader in advanced emission control technology and offers solutions for gasoline vehicles, on-road and non-road diesel vehicles/applications, hybrid and electric vehicles, fuel cells, motorcycles, small engines, and stationary. Umicore's engineers help manufacturers develop and test lighter-weight vehicles, new GDI and diesel engines, new drivetrains, and other approaches with an extensive technology portfolio.

The Auburn Hills, Michigan Technical Center features a state-of-the-art analytical room equipped with six analytical benches for HC, CO, and NO_x measurement, two FTIRs for other gas measurements (NH_3, N_2O) and equipment to measure particle mass and particle number. In addition, dual-roll, 48-in. dynamometers can test 4x4s, all-wheel drive (AWD) vehicles, and hybrids per the U.S. Federal drive cycles and for Europe and Japan.

Target Markets

Umicore targets manufacturers of gasoline-powered cars, trucks, and motorcycles; electric, hybrid, and fuel cell-driven



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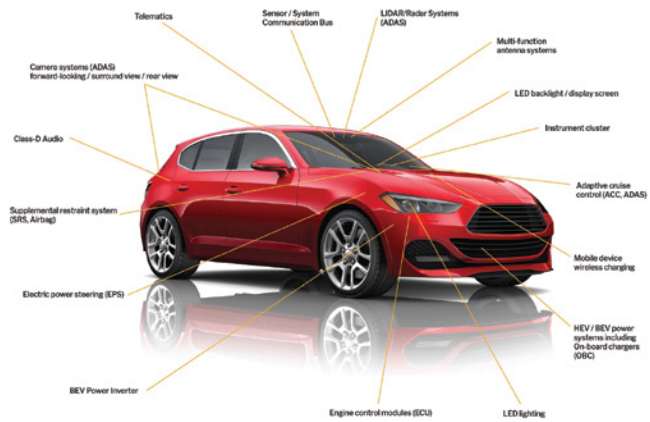

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