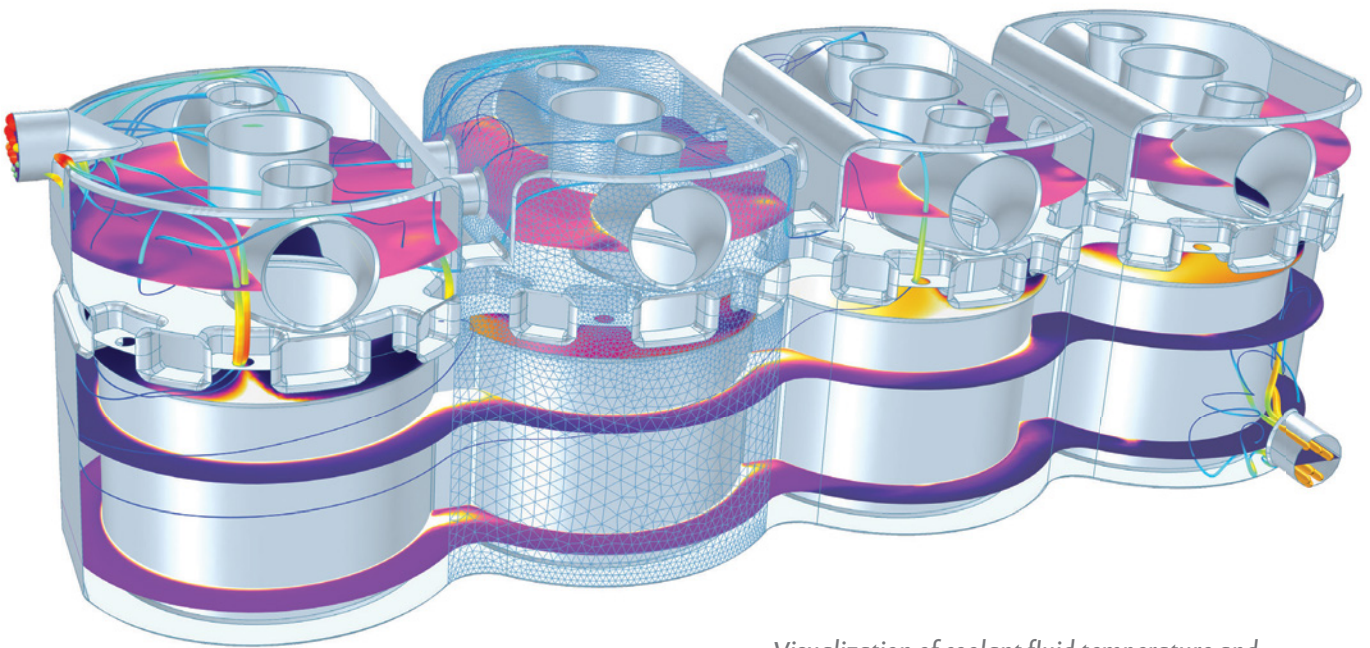


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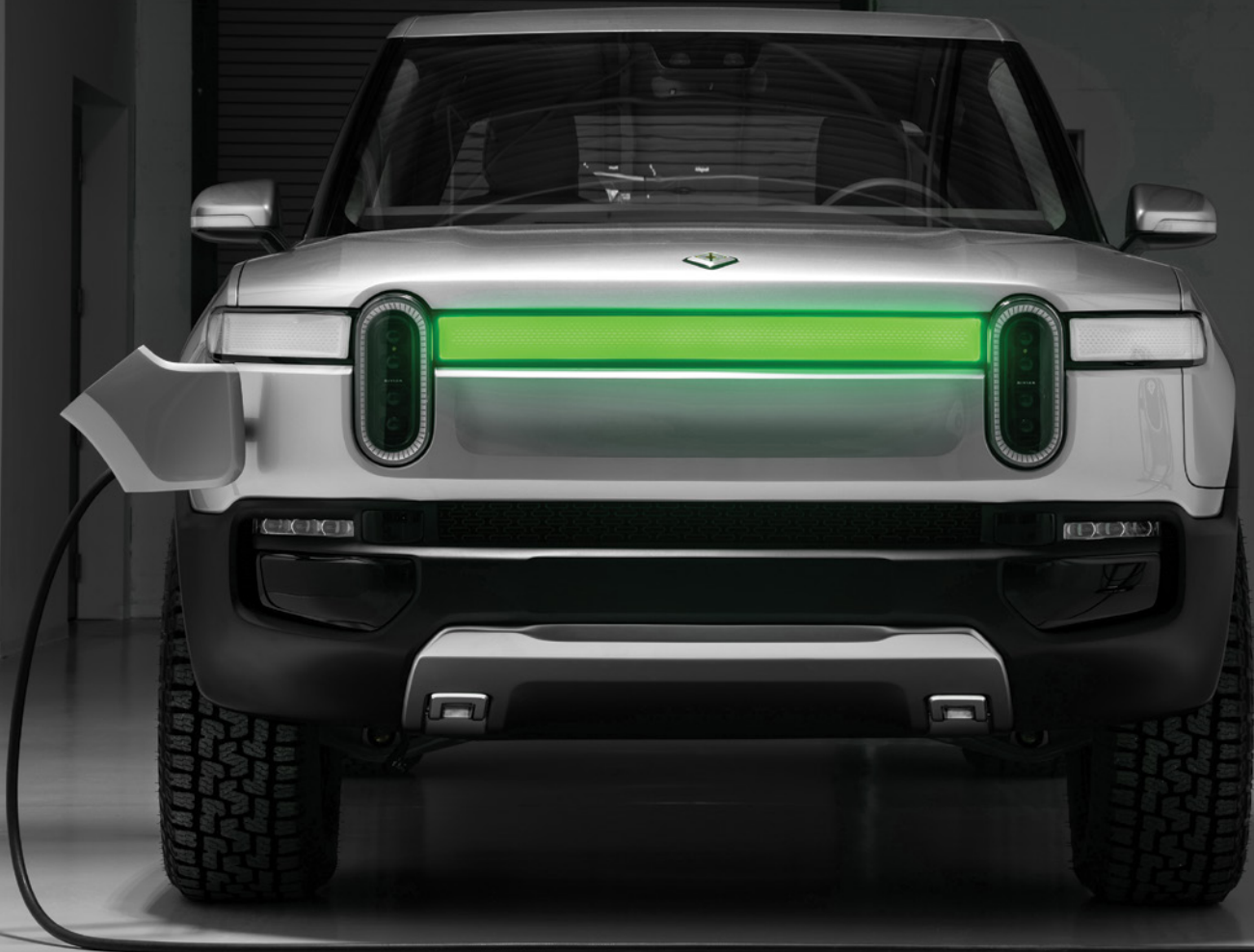
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## Pickup Shocker!

Startup Rivian Automotive aims to beat Detroit with the first electric full-size pickup

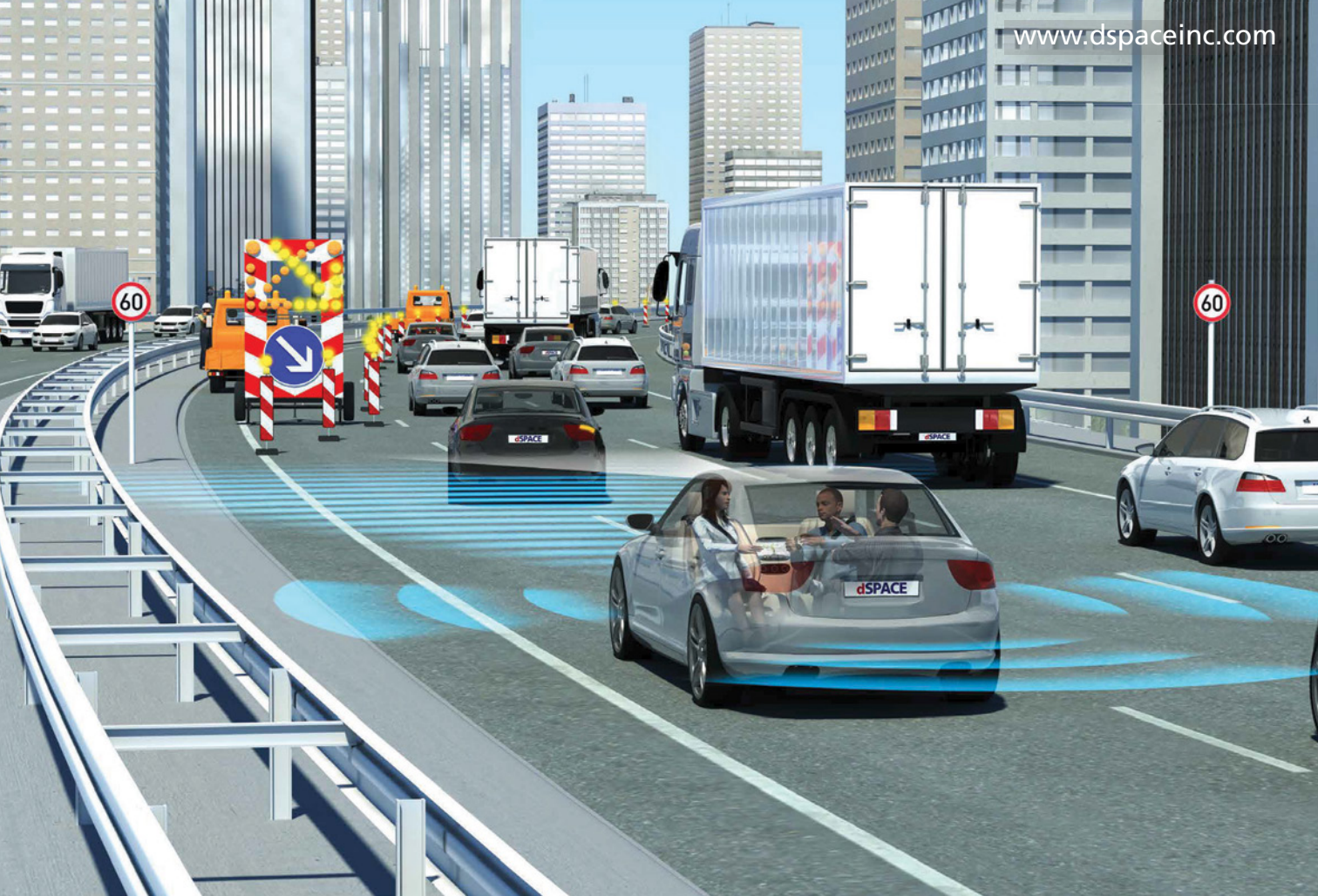


**New simulation solutions**

**Innovations in Plastics**

**Heat pump tech for EVs**



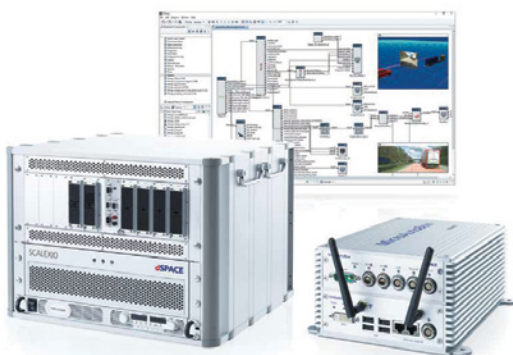


## Functions for Autonomous Driving – Faster Development with dSPACE

The idea of self-driving vehicles offers great potential for innovation. However, the development effort has to stay manageable despite increasing complexity. The solution is to use a well-coordinated tool chain for function development, virtual validation, hardware-in-the-loop simulation and data logging in the vehicle.

Whether you are developing software functions, modeling vehicles, environment sensors and traffic scenarios, or running virtual test drives on PC clusters, these activities can be managed efficiently with perfectly matched tools that interact smoothly throughout all development steps.

Get your functions for autonomous driving on the road – fast and safe!



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## ON THE COVER

Rivian's R1T battery-electric pickup truck isn't slated to be on sale until the fall of 2020, but it was the uncategorical hit of the 2018 Los Angeles show where it made its world debut. With a driving range of up to 400 miles and a raft of clever features enabled by its electric propulsion, many believe the R1T's unveiling gave the pickup-reliant Detroit-based automakers plenty to ponder. (Rivian)

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# EDITORIAL

## Rivian out-innovates the Detroit 3

The plugged-in vehicle that graces this month's cover answers the ongoing question: Who will be first to produce a battery-electric fullsize pickup truck? Because unless one of the pickup incumbents springs their own BEV surprise before 2020, that answer is most likely **Rivian**.

Skeptics snort that Rivian is yet another upstart OEM with outsized ambition. Read my colleague Bill Visnic's insightful reporting on p. 18 and judge the truck and its technologies for yourself. Regardless of whether the naysayers are right or not, Rivian's R1T electric pickup is a milestone. I'm betting that five years from now, other OEMs will have followed suit.

Of course, automotive history is littered with milestones that failed in the marketplace. Is the R1T more akin to the 1934 **Chrysler** Airflow, itself a commercial flop despite pioneering a unibody structure and forward-looking aerodynamics? Or is it the pickup analog of the **Tesla** Model S—a disruptor whose success spurred an entire industry toward BEVs?

My first chance to inspect the R1T was at its official L.A. show debut. The truck and its development team, led by ex-**McLaren** program director Mark Vinnels, were mobbed all day—but no more so than the **Jeep** Gladiator, which serves as the R1T's counterpoint. While on the Rivian show stand, I ran into operatives I know from the Detroit 3. They were examining the new entry with their competitor's steely eye—and a few measuring devices.

"Did you notice that the electric bed cover is production-ready?" asked one.

"What do you think of the cab's integral cargo tunnel?" another queried.

I noted that these features—along with the R1T's "skateboard" chassis/battery pack, unit-construction traction modules and robust suspension system—appear to be impressively engineered. The bed cover and unique cargo tunnel have immediate show-room appeal.

Thus, my response to my OEM friends: *Rivian beat you!*

Why haven't your companies, I asked, bothered to show an electric-

pickup feasibility exercise—at least to inform the public that you're on the case? Why not **Ford**, which built electric Rangers back in the 1990s for ZEV compliance. Why not **GM**, the skateboard pioneer whose EV engineering "bench" is among the industry's deepest. Why not **FCA**, now breaking ground with 48-volt hybrid trucks and Jeeps?

Shaking his head, one replied: "Many of us internally are asking the same question."

As happened with the Model S, the OEM pickup kings allowed themselves to be out-innovated by a scrappy start-up. Its engineering chief hails from a British supercar boutique. Much of its design talent was recruited from the kings' own studios.

Rivian still needs to prove basic pickup durability—how waterproof is the battery pack? How does payload and trailer towing affect battery range? But its real challenge is bringing the R1T and its SUV spinoff to sustained volume production, with high quality. They have much to prove before 2020. But Rivian's historical milestone is established. ■

**Why haven't the Detroit 3 bothered to show an e-pickup—at least to inform the public that they're on the case?**

## EDITORIAL

**Bill Visnic**  
Editorial Director  
Bill.Visnic@sae.org

**Lindsay Brooke**  
Editor-in-Chief  
Lindsay.Brooke@sae.org

**Paul Seredynski**  
Senior Editor  
Paul.Seredynski@sae.org

**Ryan Gehm**  
Associate Editor  
Ryan.Gehm@sae.org

**Jennifer Shuttleworth**  
Associate Editor  
Jennifer.Shuttleworth@sae.org

**Lisa Arrigo**  
Custom Electronic Products Editor  
Lisa.Arrigo@sae.org

### Contributors

**Kami Buchholz**  
Detroit Editor

**Stuart Birch**  
European Editor

**Terry Costlow**  
Electronic Technologies Editor

**Ian Adcock, Steven Ashley, Matthew Borst, Dan Carney, Bruce Morey, Don Sherman, Paul Weissler**

## DESIGN

**Lois Erlacher**  
Creative Director

**Ray Carlson**  
Associate Art Director

## SALES & MARKETING

**Joe Pramberger**  
Publisher  
joe@techbriefs.com

**Debbie Rothwell**  
Marketing Director  
drothwell@techbriefs.com

**Martha Tress**  
Recruitment Sales Manager  
+1.724.772.7155  
Martha.Tress@sae.org

## REGIONAL SALES

### North America

**New England/Eastern Canada:**  
ME, VT, NH, MA, RI, QC  
**Ed Marecki**  
+1.401.351.0274  
emarecki@techbriefs.com

**CT:**  
**Stan Greenfield**  
+1.203.938.2418  
greenco@optonline.net

**Mid-Atlantic/Southeast/TX:**  
MD, DC, VA, WV, TN, NC, SC, GA, FL, AL, MS, LA, AR, OK, TX  
**Ray Tompkins**  
+1.281.315.1004  
rayt@techbriefs.com

**NY, NJ, OH:**  
**Ryan Beckman**  
+1.973.409.4687  
rbeckman@techbriefs.com

**PA/DE:**  
**Desiree Stygar**  
+1.908.300.2539  
dstygar@techbriefs.com

**Midwest/Great Lakes:**  
IN, MI, WI, IA, IL, MN  
**Chris Kennedy**  
+1.847.498.4520, x3008  
ckennedy@techbriefs.com

**Midwest/Central Canada:**  
KS, KY, MO, NE, ND, SD, ON, MB  
**Bob Casey**  
+1.847.223.5225  
bobc@techbriefs.com

**Southern CA, AZ, NM, Rocky Mountain States:**  
**Tim Powers**  
+1.424.247.9207  
tpowers@techbriefs.com

**Northern CA, WA, OR, Western Canada:**  
**Craig Pitcher**  
+1.408.778.0300  
cpitcher@techbriefs.com

## International

**Europe – Central & Eastern:**  
**Sven Anacker**  
**Britta Steinberg**  
+49.202.27169.11  
sa@intermediapartners.de  
steinberg@intermediapartners.de

**Europe – Western:**  
**Chris Shaw**  
+44.1270.522130  
chris.shaw@chrisshawmedia.co.uk

**China:**  
**Alan Ao**  
+86.21.6140.8920  
alan.ao@sae.org

**Japan:**  
**Shigenori Nagatomo**  
+81.3.3661.6138  
Nagatomo-pbi@gol.com

**South Korea:**  
**Eun-Tae Kim**  
+82-2-564-3971/2  
ksael@ksae.org

## Integrated Media Consultants

**Angelo Danza**  
+1.973.874.0271  
adanza@techbriefs.com

**Christian DeLalla**  
+1.973.841.6035  
christiand@techbriefs.com

**Casey Hanson**  
+1.973.841.6040  
chanson@techbriefs.com

**Patrick Harvey**  
+1.973.409.4686  
pharvey@techbriefs.com

**Todd Holtz**  
+1.973.545.2566  
tholtz@techbriefs.com

**Rick Rosenberg**  
+1.973.545.2565  
rrosenberg@techbriefs.com

**Scott Williams**  
+1.973.545.2464  
swilliams@techbriefs.com

## SUBSCRIPTIONS

+1.800.869.6882  
AEI@kmpsgroup.com

## REPRINTS

**Jill Kaletha**  
+1.574.347.4211  
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## SAE updates J3016 automated-driving graphic

**S**AE International recently unveiled a new visual chart that is designed to clarify and simplify its J3016 “Levels of Driving Automation” standard for consumers.

The J3016 standard defines six levels of driving automation, from SAE Level Zero (no automation) to SAE Level 5 (full vehicle autonomy). It serves as the industry’s most-cited reference for automated-vehicle (AV) capabilities.

The update is the latest iteration of the J3016 graphic first deployed in 2016. As the industry gets closer to producing AVs in volume, the SAE J3016 Technical Standards Committee saw the need to more clearly explain the features in each of the six driving levels, and how they relate to consumers’ increased safety and convenience, noted Jack Pokrzywa, SAE’s Ground Vehicle Standards Director.



**Jennifer Shuttleworth**  
Associate Editor  
*Jennifer.Shuttleworth@sae.org*

External parties, including insurance companies, the **American Automobile Assoc.**, and the **Transportation Research Board**, provided input for the new chart while it was under development. SAE’s marketing group worked with the committee on the graphic’s text and design to ensure it is technically faithful to the J3016 standard, said Keith Rigby, Marketing Communications Director. They collected information at the inaugural “SAE Demo Day” in May 2018 that informed the design of the new chart. Feedback was also gathered from AV riders during the SAE Demo Day held in December 2018 at Babcock Ranch in Florida.

The latest J3016 graphic is a living document. It will continue to evolve gradually as the industry and the technical standard J3016 itself evolves, Pokrzywa explained. ■



## SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver’s seat have to do?	You <b>are</b> driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You <b>are not</b> driving when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance	These features provide steering <b>OR</b> brake/acceleration support to the driver	These features provide steering <b>AND</b> brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering <b>OR</b></li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering <b>AND</b></li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>

For a more complete description, please download a free copy of SAE J3016: [https://www.sae.org/standards/content/j3016\\_201806/](https://www.sae.org/standards/content/j3016_201806/)

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## Suppliers shift focus to rising costs

**W**elcome to 2019, a new year that's already brimming with challenges for mobility-industry suppliers. As they deal with escalating technology investments, unpredictable product-launch cadences, an influx of non-traditional competitors, extreme U.S. import tariffs, and other factors, most suppliers (and their OEM customers) are in a reactive mode to stabilize the bottom line.

The tariffs—25% on steel and 10% on aluminum—have been a thorny issue since March 2018. According to IHS Markit, the Steel Producer Price Index in September 2018 was up over 22% year over year, significantly impacting material economics for this metals-intensive industry. Exposure to such unplanned economic price hikes depends upon who is the importer of record, as well as whether or not they're participating in OEM material resale programs.

Some tools and automotive components sourced from China are already subject to U.S. tariffs, ranging from 10% to 25% depending upon the situation. When the China tariffs were imposed last July, several suppliers and OEMs scrambled to airlift molds back from China before the deadline. In doing this they incurred premium freight charges. Paying an unanticipated \$25,000 at the border for a \$100,000 mold landed after the deadline will upset any income statement. Capturing these additional costs after the fact with your customer is a difficult balancing act indeed.

Downstream, increasing material prices and the impact of tariffs are having an impact on vehicle costs. Despite the positive impact of recently moderating oil prices (allowing some relief on resin), the Federal Reserve Automotive Producer Price Index has been rising year over year since December 2017. Over the past few months this index has been up an average of 2-3%.

The tight labor market plays a role: While U.S. unemployment is at a healthy 3.7% (as of late November '18), the industry continues its struggle to find skilled and semi-skilled workers. Non-farm payroll wages rose almost 3% in 2018



**Michael Robinet**  
Managing Director  
IHS Markit  
*michael.robinet*  
*@ihsmarkit.com*

**Welcome to a new era of cost avoidance and risk containment.**

and are forecast to continue rising in 2019, according to IHS Markit. Suppliers used to employ factory automation to substitute for tight labor markets, but this has slowed due to shortages in machine build and construction trades.

Moving finished products is also getting expensive. Beyond the well-publicized driver shortages in the logistics industry, costs are rising. Last year, the IHS Markit Transport and Storage index outlined a jump of 7% as the economy sustained its strong pace. Though more modest, the forecast calls for costs to rise over 3% on average over the next three to four years.

If that's not enough of an alarming outlook for you, there's more: Expect an increase in the cost of borrowing money. A handful of U.S. Fed Fund Rate increases are forecast for 2019; these may well carry over into 2020. Other factors such as erratic exchange rates will impact suppliers' overall costs unless an organization is 'currency neutral.'

And no less critical will be the cost of compliance. Though still to be ratified by all parties, there is little doubt that suppliers and OEMs will bear the cost of additional reporting for the U.S.-Mexico-Canada Agreement—the trade pact formerly known as NAFTA. Another concern is warranty exposure, to which OEMs have shown a heightened awareness and swiftness to respond.

Of course, the vehicle buyer is the final arbiter regarding the industry's rising costs. According to Autodata, overall U.S. new-vehicle incentive spending was up over 3% for 2018 through October. OEMs will likely pull back on incentives to raise transaction values and achieve moderate economic relief. Eventually, production volume will suffer as consumers start to feel the impact of higher new-vehicle transaction prices—averaging nearly \$36,000 as of 3Q2018.

The next few years will be an era of cost avoidance and risk containment for suppliers. Being flexible and innovative to aggressively attack issues, re-source problem components and guard against over-exposure to any one segment, supplier or customer will be paramount for survival. ■



## The not-so-hidden cost of “free”

**T**here is no such thing as a free lunch, as the old truism goes. For more than a century, the auto industry business model has been to sell it and forget it. Once you drove off the lot in that shiny new machine, you were on your own, aside from warranty repairs for defects or compliance recalls.

If you wanted to upgrade the functionality of your vehicle or even put fuel in to operate it, you paid out of pocket. Then **Tesla** seemed to turn that model on its head with free battery charging via its Supercharger network, and over-the-air (OTA) software updates.

But there was a problem with this new approach. Tesla has been notoriously bad at operating profitably and “free” energy and functional updates cost money. When you are trying to grow a self-sustaining business, giving stuff away on cars at lower price points quickly becomes incompatible. Thus, free electrons and connections are going away at Tesla.

The company is shifting away from some of the costly offerings that were more easily absorbed in higher-priced cars and a smaller fleet. Prior to the Model 3 launch, Tesla offered all customers free access to its high-speed Supercharger network for the life of the vehicle. As the number of drivers wanting access to Superchargers has swelled, the company has adopted a pay model for charging, similar to the more limited plans offered by **Nissan** and **Audi**.

OTA updates have seemed like a great way to save money by avoiding costly dealer visits for non-hardware fixes. But they too have costs. Tesla formerly pushed new software to all vehicles by whatever connectivity was available, either cellular or WiFi. Every Tesla built since the Model S launched has had a built-in data modem.

For six years, Tesla didn't charge for this connectivity. And the company still provides basic low-bandwidth connectivity for functions such as battery management as part of the purchase price, as most automakers do. However, data-intensive functions like downloading firmware or



**Sam Abuelsamid**  
Senior Analyst  
Navigant Research  
Sam@  
abuelsamid.com

**Not surprisingly, Tesla has shifted to a pay model for formerly free charging and OTA updates. The industry is taking note.**

map updates now require \$100 per year premium connectivity or else either a WiFi connection or service visit.

As a result, some customers have been finding they haven't received the latest AutoPilot enhancements because they may not have access to a good wireless connection if they park on the street or in an apartment garage.

This doesn't even factor in the cost of the ongoing development of the software, maps and even hardware upgrades that Tesla has promised its customers. Those customers will increasingly find themselves having to pay out of pocket to maintain or improve functionality in their vehicles.

This is a sign of things to come, as the industry moves toward greater reliance on connectivity and automation. Automated driving will require fresh high-definition maps on an ongoing basis in order to function properly. As the technology matures, the overall system will need functional updates as well as fixes for security vulnerabilities that may put these vehicles at risk.

Ongoing development of vehicles that are already in service will no longer be a nice-to-have option. This will be a mandatory process that has significant costs associated with it and customers will have to pay. Affordability of new vehicles is increasingly a thorny problem. It will only get worse if automakers try to bundle in the cost of updates upfront. Customers also won't be happy if they incur a mandatory subscription fee when they buy a car.

The other option is to not sell these vehicles at all, but only make them available through mobility services where the support costs can be hidden in the fare charged for those services. This, perhaps more than anything else including liability concerns, is why only very expensive premium vehicles are likely to be sold with fully automated driving capability.

The rest of us will be using automated vehicles owned and operated by a fleet somewhere on demand. ■

## Mercedes-AMG E 53 4Matic+

Select “Sport+”, floor the gas pedal, listen to the engine and exhaust notes, and the essence of **Mercedes-AMG**’s latest E 53 sedan is sensationally clear. But shouldn’t this combo be V8 sourced from AMG’s impressive repertoire rather than a 3.0-L in-line modular six, aided by an electrically-driven auxiliary compressor?



“There are different reasons why we decided to use the six-cylinder inline for the E 53, but particularly because it is very compact,” said Christian Enderle, Director of Drive System Development, Mercedes-AMG. “Also, the six-cylinder inline runs more smoothly, as the primary and secondary inertia forces and torque are balanced.”

It does indeed. But in the E 53, with a dual personality ranging from almost quiescence to practically race car assertiveness from its Performance Exhaust and Dynamic Select Sport+ mode, that solution makes it a huge delight to drive.

The car starts with a very subdued growl that won’t wake the neighbors, yet within a few hundred meters it becomes very clear that it isn’t a “mere” E-Class. AMG Ride Control air-based suspension, snappy AMG 9-speed auto transmission and 48-V inline EQ Boost starter/generator positioned between engine and gearbox add 250 N·m (184 lb-ft) to deliver complementary response to the ICE, together make the car’s raison d’être clear.

With 4Matic+ all-wheel drive, the E 53 is a delight to drive; it does feel firm, it isn’t a limo-like smoothie (although the engine is also available in the S500 L AMG line, which certainly is) but journeys long or short would always be enthusiastically anticipated. Welcome back the straight six.

Stuart Birch

## 2019 Toyota Avalon Hybrid

After ample time behind the wheel of the all-new Avalon, this one hybrid-powered, I’m beginning to think that I’ve finally become my father.

My late dad loved solid, dependable, comfortable sedans. Cars with seamless gearchanges, low-revving quiet engines, and plenty of shoulder, leg, and trunk room. And styling that verges on the sporty. Our family’s beloved **Plymouth** Fury fit that criteria in the 1960s. Likewise the new Avalon, **Toyota**’s most “American” car. This is a car that feels larger inside than it is. It’s stable and feels planted on the road. It’s a great highway cruiser. Not a hint of buzz, squeaks or rattles.



As my dad would say, “Man, I could drive this baby to Alaska and back!”

Recently I ran into Randy Stevens, the Avalon’s veteran chief engineer. I gushed over how much I like the latest Hybrid model. He reminded me that it’s literally a clean-sheet program. Virtually no carryover. Randy asked if my test car was delivering the EPA-estimated 43-mpg-combined fuel economy. No, only 42 mpg, I replied. But it delivers that like clockwork. Maybe the secret’s in Toyota’s “old school” battery chemistry—204 nickel-metal hydride cells still crank out the electrons reliably—and efficiently for this nearly 3,700-lb (1,678-kg) vehicle.

Avalon should have been a finalist for the 2019 North American Car of the Year award. I voted for it, among my three top car picks. Unfortunately, the other 56 jurors thought differently. I apologized to Randy for them, but he and I both know this car is a winner.

Lindsay Brooke

## 2018 Lexus LS500

I was dubious when this new-generation 2018 LS—on the freshly-launched GA-L rear-drive platform—dispensed with V8 power in favor of a twin-turbocharged V6 of just 3.5 liters. This is the first-ever LS to forego a V8, but damned if the all-new V35A-FTS isn’t sufficiently bombastic to all but make you forget the sweet V8s of Lexi past. There might be a smidge of lag in the first ten feet from standstill, but otherwise this twin-turbo setup just plain pumps: three-figure speeds blitz the monstrous 24-in (607-mm) optional (\$1,220!) head-up display with startling frequency.



For those who think any **Lexus**, but particularly the big sedan, is the default “soft” choice in the segment, the 416 hp generated by the LS500’s 3.5-L V6 handily whips the 6-cylinder choices in **BMW** and **Mercedes-Benz**’s flagships and isn’t that far in arrears of the Germans’ optional V8s.

Lexus and transmission supplier **Aisin** still have some fettle to do, though, with the new 10-speed automatic that collaborates with the LS500’s thrifty V6. The transmission is reluctant to reach deeply for lower gears and seems confused by other throttle inputs that seemingly run counter to foundation algorithms. And Lexus needs to throw in the towel on its Remote Touch computer mouse-style driver interface, which despite ongoing refinement and tweaking remains too fussy and imprecise to use effectively while driving.

The brand’s F SPORT treatment over the years has been executed with arguable degrees of effectiveness and value, but for the LS500, even at the package’s roaring \$9,700 price, it’s little short of transformative.

Bill Visnic



## FUELS/LUBRICANTS

### BP's Nexcel sealed-cell oil system an alternative for controlling GHG emissions



Extraction of the Nexcel module in the Toyota Prius demonstration vehicle.

The automotive industry is broadening its spectrum of technology to support the reduction of global greenhouse gases not just via electric drivetrains and downsized ICEs but by exploring more non-mainstream solutions. One of those is BP's Nexcel sealed-cell oil-management system, which is being further developed to work in tandem with hybrid drivetrains. The innovation business claims it can deliver a cost benefit able to compete on a \$/g CO<sub>2</sub>-saved basis with more conventional environmentally-focused technologies.

Nexcel claims its system is markedly less costly compared to mild hybridization, and instead of becoming a competitor, it sees a combination of the two delivering a significant environmental benefit. Nexcel is now focusing its development work on linking its system with hybrid drivetrains to achieve significant environmental gains. To make the point, it has developed a Toyota Prius demonstrator (above) using its oil management system as a genre-representative vehicle (it is not in partnership with Toyota) to support the results.

#### Targeting greenhouse gases

In volume production with economies of scale attained, Nexcel claims its self-contained system's unit cost would be about half that of electric power steering (EPAS). As previously reported, the system provides a sealed cell

containing the correct grade of oil and specification of filter for a particular engine type, an integrated pump and electronic control unit that communicates with the vehicle.

"Testing of the system has confirmed its potential to reduce CO<sub>2</sub> by 2g/km," claimed Nexcel's Sustainability Director John Ward-Zinski. "The reduction is delivered by ensuring a precise oil-engine match, helping the oil to warm up more quickly and boosting its active components between oil changes."

Nexcel expects initial applications of its technology to reduce CO<sub>2</sub> emissions for a cost of around \$50/g. Ward-Zinski said he believes active oil management technology's potential will see it taking a similar development trajectory to that which led to EPAS, initially also an outside-the-envelope solution to emissions reduction but now almost ubiquitous.

Ward-Zinski stated that the EC's "own impact study and indications from U.S. observers such as FEV" point to a prediction that mild hybridization will be significantly more costly than the latest Nexcel system for each gram of CO<sub>2</sub> saved, while full hybridization carries a cost over twice that of the Nexcel system. Nexcel expects the cost of its systems' CO<sub>2</sub> reduction to potentially lower to around \$25/g in fully-integrated, high-volume applications.

Nexcel's \$50/g estimate for an initial high-volume application is based on a combination

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of bill of materials and manufacturing costs. \$25/g is Nexcel's indicative target for a high-volume application with further economies achieved through increased levels of integration with the vehicle early in the design.

### Warming up to it

As engine efficiency improves, the warm-up period becomes proportionately more significant for emissions, said Steven Goodier, Program Director and founder of Nexcel. Even in the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) test cycle, a significant proportion of the measurement is conducted with the engine at less than optimum operating temperature, which means it is producing more CO<sub>2</sub> and more pollutants.

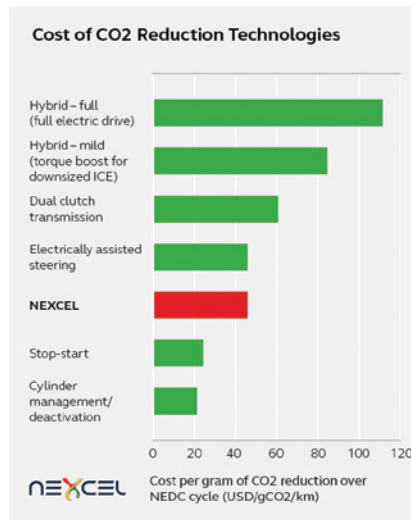
"By reducing the volume of oil in the engine sump during cold start, the Nexcel system enables faster warm up," Goodier explained. "Every liter of oil removed has a heat capacity equivalent to around 2 kg of aluminum or 4 kg of cast iron, so transferring oil to the cell when it isn't needed helps bring engines up to their optimum temperature more quickly."

Although the viscosity of engine oils is being reduced to minimize energy losses and cut CO<sub>2</sub> emissions, the biggest contribution to viscosity often comes from the additives in the oil, which are present in sufficient amounts to permit the longest extended service intervals, explained Ward-Zinski. He said an aim of the Nexcel system is to "change the rules by boosting the oils' additive content between services", so preserving its effectiveness.

### Motivations vary

Nexcel examined hybrid-vehicle-buyer motivations in seven countries (U.S., U.K., France, Germany, Japan, China, South Korea), where researchers found environmental concerns were a top motivation in the U.S., while fuel economy and government incentives were key European factors. Japanese and South Korean attitudes were similar to those of Europeans. In China, government purchase incentives were the main reason for the purchase of hybrid-electric vehicles.

"Hybrid-buyer motivations around



the world vary, but all are concerned about the whole life impact of their vehicle choice, both environmentally and economically," Ward-Zinski noted. "Because this resonates with Nexcel's benefits, it encouraged us to produce a research paper on development and market context regarding projected hybrid EV development over the next two decades and where Nexcel technology would be relevant."

One of these is packaging. The sealed oil cell allows for a reduced ICE sump capacity to facilitate a shorter engine with no requirement for sump drain access. This would provide benefits including battery storage under the engine, or lower engine mounting that could lead to aerodynamic and pedestrian safety improvements. With the oil filter now housed in the Nexcel cell, designers would no longer be required to provide space around the engine block for conventional oil filter replacement.

Ward-Zinski also cited benefits for ICE range extenders, stating that because they are not mechanically coupled to the wheels, the use of the Nexcel system, combined with other established technologies such as an electric water pump and remote induction, could allow the placement of the ICE in relatively inaccessible but efficient locations, but said "don't expect the ICE in the glovebox any time soon!"

Stuart Birch

### PROPULSION

## BorgWarner demos next-step electrification components

Anyone questioning whether a substantial portion of the light-vehicle market will imminently feature some form of powertrain electrification need look no further than the product portfolios of the major powertrain suppliers. At a recent event at its Propulsion Technical Center in Auburn Hills, Michigan, **BorgWarner** provided access to a range of demonstration vehicles—from full EVs to hybrid Ford F-150s—featuring technology engineered for OEM's seeking swift electrified integration.

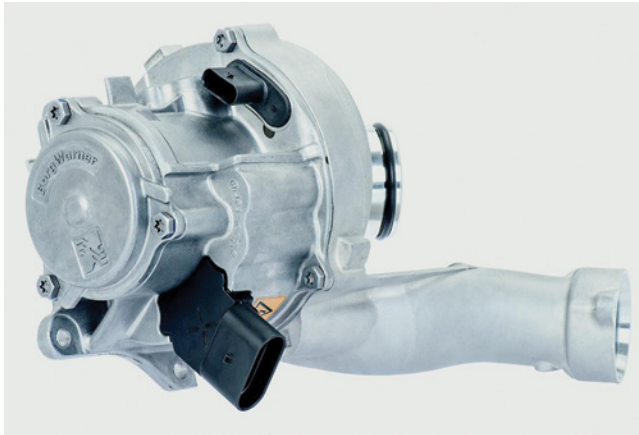
### eBoosting: The next big thing?

The engine-downsizing program has been in full swing for the better part of a decade and has meant big business for BorgWarner as one of the industry's most prolific developers of turbochargers. Though a crucial downsizing component, even BorgWarner will admit to the limitations of turbocharging, including turbo lag and the higher-rpm choke effect it can have when sized for low-end response. With the electrification trend providing more onboard energy capacity, it also creates an opportunity for electrically-powered compressors, an innovation that addresses several turbo shortcomings.

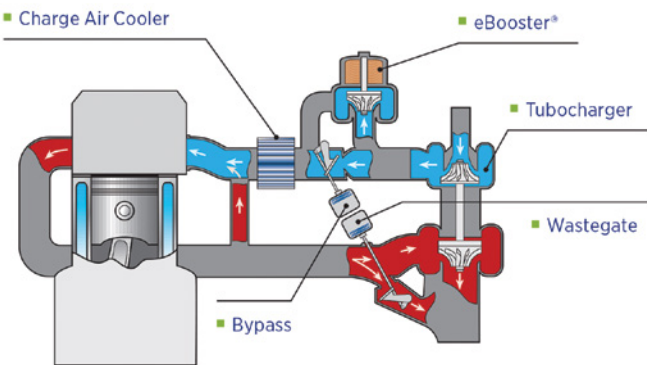
In a demonstration **Ford F-150** powered by the twin-turbocharged 2.7-L V-6, BorgWarner had installed its eBooster centrifugal-flow compressor (below). Essentially an electrically driven cold side of a traditional turbo, the eBooster can be fitted either pre- or post-turbocharger within an intake tract, and markedly reduces turbo lag. The F-150 demo vehicle was also fitted with a 48-volt architecture using BorgWarner's 48V BAS (belt alternator/starter) MGU (motor-generator unit) that can capture energy from regenerative braking to resupply the 48-V battery, smooth engine restarts and also provide a low-end torque assist.

Applicable to both gasoline/diesel





The BorgWarner eBooster features integrated power electronics and permanently lubricated bearings for the 70,000-rpm compressor shaft. For 48-V applications, spool time is just 250ms.



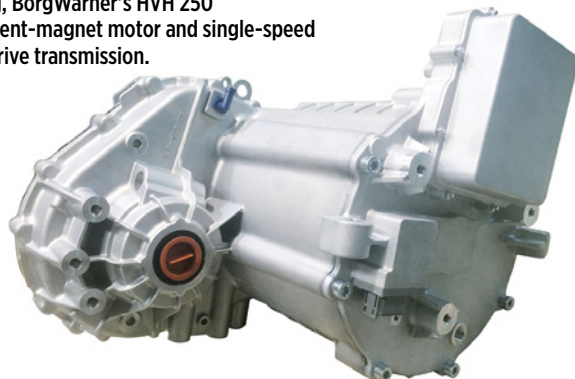
A diagram of potential intake tract position for the BorgWarner eBooster.

engines and 12- (2-2.5 kW)/48-V (5-7 kW) architectures, the eBooster is quite compact considering its power electronics are integrated into its housing, and permanently lubricated bearings for the 70,000-rpm compressor shaft should help ensure a long service life. When energized by a 48-volt architecture, BorgWarner claims “spool time” for the eBooster—driven by its permanent-magnet motor—is just 250 ms.

In the demonstration Ford pickup, the eBooster shaved more than a half-second off 0-40 km/h (0-25 mph) acceleration—an 18% improvement—while consuming less than half the electric energy of the BAS-MGU unit requires to provide a 3% acceleration gain. Since the system’s peak boost remains unchanged, Borg Warner claims eBooster integration does not require a full drivetrain revamp, and after several tire- evaporating launches in the demonstration truck, we’d concur on the turbo-lag elimination claim.

Apart from its impact on turbo lag, acceleration and transient performance, BorgWarner engineers are equally enthusiastic about the eBooster’s potential to enable more drastic engine downsizing, particularly when engineered with a

The BorgWarner electric drive module (eDM) features a water-cooled aluminum housing, BorgWarner’s HVH 250 permanent-magnet motor and single-speed eGearDrive transmission.



larger turbocharger designed for complimentary and less-restrictive boosting.

## Full EV componentry

On the fully electrified front, BorgWarner had a 2018 C30 from **Great Wall Motors’** new entry-EV brand ORA on hand for demo loops. The C30 compact sedan is the first EV model in China equipped with BorgWarner’s electric drive module (eDM, above) technology, which integrates the design of the electric motor and transmission. BorgWarner claims its integrated eDM enables weight, cost and space savings in addition to easy installation and improved efficiency.

With the April 2018 launch in China of the credit-score system that encourages the shift to “new-energy vehicles,” BorgWarner is anticipating significant growth for China’s already roiling EV market. BorgWarner also is providing localized production, which in the case of the C30’s eDM application, is via a manufacturing facility in Beijing.

Installed in the C30, within the eDM’s water-cooled aluminum housing is BorgWarner’s HVH 250 permanent-magnet motor featuring its patented, flat-wire high-voltage-hairpin (HVH) technology that helps it achieve a better peak-to-nominal power rating, along with more than 95% efficiency. The HVH 250 is coupled to BorgWarner’s compact, single-speed eGearDrive transmission that’s rated more than 97% efficient and features an electrically actuated parking lock.

Coupled to the C30’s 380-volt system, the eDM delivers a claimed 90 kW (120 hp) and 240 N·m (177 lb-ft) and provides a claimed 5.5 second 0-50 km/h time for the 1,385kg (3,053lb) sedan. On a surface-street drive with four well-fed adults on board, the C30 managed perfectly adequate acceleration and demonstrated surprising drivetrain refinement for an entry-level product. Throttle response was linear and torque ramp-up was smooth and predictable.

A new BorgWarner integrated Drive Module (iDM) currently in development, which adds dedicated power electronics to the eDM for even greater optimization and efficiency, is expected to see a production application by MY2021.

**Bill Visnic and Paul Seredynski**

MANUFACTURING

## Ford Advanced Manufacturing Center investment to speed production innovations



Harry Kekedjian (left) and Frank Maslar, Ford technical specialists, work with a collaborative robot, a smaller robot that can work safely alongside people without a protective cage.

Ford Motor Company is investing \$45 million in its new Advanced Manufacturing Center (AMC) in Redford Township, Michigan, to help quickly innovate and deploy scalable new manufacturing technologies. The new AMC co-locates approximately 100 manufacturing technology experts and their specialized equipment in one 100,000-ft<sup>2</sup> space just east of Detroit.

“One of the advantages of the Advanced Manufacturing Center and the people that are here,” said Michael Mikula, Ford’s global chief engineer for advanced manufacturing, “is to create a place where we can collaborate across technical disciplines and develop comprehensive, innovative solutions that can be immediately deployed into our plants with a high level of confidence and success.”

“Certainly we want to reduce the cost to deliver vehicles to our consumers,” Mikula explained when asked what that success looks like. “We want to reduce the amount of time it takes to

do the manufacturing, engineering and product realization so that we can be faster to market. And then we want to make sure that the people that are working in our processes are working efficiently and safely.”

### Additive manufacturing

Ford purchased the third 3D printer ever made in 1988, and currently has 90 3D printers at 30 locations globally producing parts and tools. The AMC features 23 3D printing (aka “additive manufacturing”) machines and Ford is working with 10 3D manufacturing companies including **Stratasys, Carbon, HP and Desktop Metal** (in which Ford has taken a minority stake), many which have their latest 3D printers on-site on a consignment basis. Printing materials include steel (left), nylon powder, carbon and sand.

Ford uses its 3D printers to produce “tens of thousands” of parts annually, most for product-development prototypes, but they also create production parts. The upcoming Shelby Mustang

GT500 has two 3D-printed brake-bracket parts and the F-150 Raptor features a logoed, instrument-panel spotlight-switch blanking plug specific to the Chinese market.

### Collaborative robots

Another key aspect of the AMC is Ford’s work with collaborative robots or “cobots.” These robots are smaller than typical assembly-line machines and operate at lower speeds and torque levels so they can operate without protective cages alongside people. The AMC’s role is to prove out the more complex cobot deployment tasks and to identify potential issues before installation in an assembly plant.

Cobot applications are often for tasks such as part picking or otherwise ergonomically taxing, such as one at Ford’s Livonia Transmission Plant that was so difficult for employees that they could only be on that station for one hour at a time.

**Paul Seredynski**



## TESTING/SIMULATION

### JLR uses predictive technology to reduce motion-sickness risk



Jaguar Land Rover (JLR) has revealed that a specialist “wellness research” team has created an algorithm to help reduce vehicle motion sickness by up to 60%. The algorithm generates a “wellness score” for each passenger. When it detects changes in the score it can automatically initialize personalization of both vehicle dynamics and cabin settings to reduce the effects of motion sickness.

Dr. Steve Iley, JLR’s Chief Medical Officer, described the research’s “solid scientific foundation” as having created a solution regardless of an individual’s susceptibility to travel sickness. Young children are most likely to suffer symptoms: “I am particularly excited by the benefits this research can have in making long journeys comfortable and stress-free for families.”

#### Linking systems

A key member of the research team is Spencer Salter, a JLR engineer who uses comprehensive modeling specifically to achieve pre-emptive solutions within dynamic systems. A further link embraces satellite navigation systems that can support “optimum wellness routes” that take into consideration speed, journey time and distance.

JLR’s wellness score is compiled using biometric sensors to

record physiological signals together with motion and dynamics data which together are designed to signal a potential motion sickness event, even before the vehicle occupant will be aware of it. The research work has so far involved some 15,000 miles, enabling the JLR team to establish a baseline driving style as a target for autonomous applications. A particular aim is to minimize steering corrections and unnecessary inputs.

#### Information correlation

Salter said that little had previously been known about causes of motion sickness and how to prevent or reduce it, despite the fact that up to 70% of vehicle occupants are estimated to be affected. What is known is that the problem may occur when a vehicle’s occupant’s eyes observe information that does not correlate with information sent to the brain via the inner ear, skin, and forces on the body. This happens particularly when reading – something that autonomous-vehicle travel will increasingly allow.

The first phase of the anti-motion sickness research program is scheduled to be completed by late November and JLR states that the findings to date are already being implemented into further research projects.

Stuart Birch

JLR

## Jeep's Gladiator takes up arms in midsize-pickup battle

Maybe the only thing more surprising than the fact it's been more than a quarter-century since FiatChrysler's Jeep brand sold a pickup truck is that it's taken so long to pull the trigger in a U.S. auto market that's been truck-crazed for the better part of a decade.

Blame Jeep planners. Or more-charitably attribute the glaring tardiness in launching a Jeep pickup to the reality that FiatChrysler had to navigate a recession and a couple of ownership changes before and during the market's transition to pickup mania. But the 2020 Jeep Gladiator is here, unveiled at the 2018 Los Angeles auto show looking like one of the surest things the auto business can conjure.

First, by all appearances it's a pickup truck; right now, that's a can't-lose proposition with the midsize segment likely to touch around a half-million sales for 2018. But more directly, its body-on-frame structure and most of its major components are borrowed from Jeep's silly-successful new JL-series Wrangler, the main cog in the money-making machine that is Jeep.

At a media briefing for the 2020 Gladiator prior to the Los Angeles auto show, Tim Kiniskis, head of the Jeep Brand—North America, said of the Wrangler, "This thing is absolutely on fire," but Jeep nonetheless decided it needed to return to the segment with a



Based on the Wrangler SUV, but to accommodate a 5-ft cargo bed the Gladiator is some 31 in longer.

real truck, "not a Wrangler with a bed on the back"—alluding to the old CJ8 Scrambler.

Gladiator's aluminum doors and hood are shared with the Wrangler (the tailgate is aluminum, too), but Jeep claims less than 50% parts commonality. The Gladiator is approximately 400 lb (181 kg) heavier than a 4-door Wrangler and uses its own high-strength steel frame.

### 'Real truck' reality

The quickly-expanding midsize-pickup segment is dominated by "real" trucks

such as Toyota's best-selling Tacoma and the similarly body-on-frame Chevrolet Colorado. The showroom appearance of Ford's new-generation Ranger—also painfully late to the market—is imminent. To succeed in the segment, it seems the safe play is to be a real truck—even above plying on the Wrangler connection.

"We wanted it to be a truck first, said Chief engineer Pete Milosavljević. "But we set a stretch goal to have best-in-class ride quality."

Although judgement about the Gladiator's refinement (it retains Dana-supplied solid axles, after all) will come when test drives are available, there's little question its size should help in that regard. The Gladiator's wheelbase is 18.9 in (480 mm) longer than the 4-door Wrangler's 118.4-in (3008-mm) wheelbase and it is 31 in (787-mm) longer overall. This also would underscore the Gladiator's primary brief to be a truck, as all that added length will win no praise from the hardcore elements of the Jeep camp—although Milosavljević said the Gladiator has been validated as capable of traversing the offroad-benchmark Rubicon Trail.

The Gladiator's high-strength steel bed is 5 ft (1524 mm) long, about 6 in



The 2020 Gladiator can tow up to 7650 lb and has a maximum 1600-lb payload rating.





The Gladiator's cargo bed is steel; tailgate incorporates a partially-lowered function to handle longer cargo.

(152 mm) shorter than the class' standard bed length.

Final evidence that Jeep intends the Gladiator to fulfill the mission of a truck: engineers are declaring the pickup's maximum payload of 1600 lb (726 kg) and maximum tow rating of 7650 lb (3470 kg) to be best-in-class. However, it appears Ford's new Ranger may hit showrooms with a higher payload rating and as can be expected in the pickup market, disputes about best-in-class are likely to issue from other competitors.

## Many flavors

As with the Wrangler, there is a wide variety of ways to configure the 2020 Gladiator, starting with four trim levels: Sport, Sport S, Overland and the offroad-focused Rubicon.

When the Gladiator goes on sale in the second quarter of 2019, the only available engine is the corporate 3.6-L V6, generating 285 hp and 260 lb-ft (353 N-m). The standard transmission is a 6-speed manual, optional is FCA's 8-speed automatic.

Engineers confirmed that in 2020, the Gladiator will be available with a 3.0-L V6 turbodiesel good for 260 hp and 442 lb-ft (599 N-m). The 8-speed automatic will be the only transmission paired with the diesel. Unsaid but probably inevitable is fitment of the 2.0-L turbocharged 4-cyl. currently serving in the Wrangler and other Jeep models.

Meantime, there is a choice of two distinct four-wheel-drive transfer cases, Command-Trac and Rock-Trac (each a part-time unit), depending on trim level. Gearing and features are unique to each.

There is all manner of ways to configure the doors and roof, including body-color panels for the 3-piece hardtop on some trims; as with Wrangler, the windshield of the Gladiator can be folded down onto the hood.

The Gladiator is manufactured at FCA's Toledo, Ohio assembly plant that also builds the Wrangler, with the "South" portion of the plant dedicated to Gladiator production.

Bill Visnic

## Porsche reveals eighth-generation of fabled 911



Porsche's new 911 updated as usual with more power, more performance-oriented features—and the expected refinement of the time-honored design.

Regularly updating and evolving the Porsche 911's aesthetic signature might seem an impossible task. But more than half a century after its birth, the unveiling of the eighth-generation at the 2018 L.A. Auto Show demonstrated that it is in fact still a totally possible art—with design boss Michael Mauer the chief artist.

Designated in-house as the 992 series and slightly larger than the outgoing 991, it is launched in rear-wheel-drive and all-wheel-drive forms—Carrera S and Carrera 4S—and now only in the wide-body width previously used for the Carrera 4 GT3 and GTS, instead of two body widths. Across the nose, the new 911 is 45 mm (1.8 in) wider than the outgoing version, a figure some 911 purists may look at askance, as growth in recent years has already been considerable.

Transmission for either 911 variant is a choice of 7-speed manual or new 8-speed PDK dual-clutch automated manual. The engine is, of course, a rear mounted flat-six (to change that position and cylinder configuration would see those purists suffering mental and physical agony), turbocharged and now delivering 331 kW (443 hp), upped by 23 hp (17 kW).

Claimed top speed now is 308 km/h (191mph) for the S and a more-modest 306 km/h (190mph) for the AWD 4S. The extra power is attributed to some fresh fuel-injection technology and a "new arrangement" for the twin turbochargers and charge-air cooling system. There is yet no plug-in hybrid-electric (PHEV) variant—but Porsche promises it will come.

## Homage styling

While the general signature of the 992 harks back to Ferdinand "Butzi" Porsche's original styling, the latest iteration has distinctive aspects that delineate it from Generation 7. These include three large frontal air intakes, wider wheel housings (20 in wheels front, 21 in rear), LED matrix headlights and a front hood with a more pronounced recess, very much an early 911 feature. Side elevation changes include flush-mounted, electrically-operated door handles to achieve a small aerodynamic benefit. There is yet no overall Cd figure for the car.

Stuart Birch

FROM LEFT: FCA; PORSCHE



## Ford engineers a tech barrage with 2020 Lincoln Aviator

Ford Motor Co. officially launched its 2020 Lincoln Aviator at the 2018 Los Angeles auto show, with the all-new three-row midsize luxury SUV featuring a barrage of equally new and significant technologies. Production is slated for 3Q 2019 at Ford's Chicago assembly complex.

Aviator debuts Ford's first RWD/AWD vehicle platform, coded CD6, that was engineered from a clean sheet to support both conventional gasoline-ICE and plug-in hybrid models. It also features the much-anticipated electrified variant of Ford's 10R 10-speed automatic transmission, which will also be used to "hybridize" the F-Series pickup. Known internally as MHT (modular hybrid transmission), the electrified 10R packages the e-motor on the input side, between the engine and gears. It re-

tains its torque converter. Non-hybrid Aviators will use the conventional 10R60 unit.

The AWD system features electric disconnect on the front axle.

### Electrification and twin turbos

A liquid-cooled lithium-ion battery pack is mounted horizontally in the Aviator's underfloor structure. At the L.A. Show launch, Lincoln engineers did not provide details of the lithium-ion battery pack. The PHEV (only offered with AWD) can be fully recharged in three to four hours using the Level 2 (240-V) component of its SAE J1772 charging setup. With two pure-EV driving modes, Aviator will offer about 50-km (30 mi) EV driving range, veteran program engineering chief John Davis said.

Rather than specify a boosted 4-cyl-

inder engine, the Aviator development team opted for a twin-turbocharged 3.0-L V6 to pair with either 10R gearbox. "The V6 was the standard engine from the start of this program," Davis told *Automotive Engineering*. He said a 48-V system was debated as well. While the V6 had not yet (as of mid-December 2018) received its SAE certification, Davis is confident its rating will meet 400 hp (298 kW) and 400 lb-ft (542 N·m) targets.

The new hybrid propulsion system will be in Aviator's optional Grand Touring package, where it is expected to deliver 450 hp (335 kW) and 600 lb-ft (813 N·m) when full SAE power and EPA certifications are completed.

The Aviator development team set a new standard within Ford (in the author's opinion) in terms of applying sensing technologies to where they can be best appreciated by the end customer. Aviator features speed-dependent "active pixel" LED headlamps and a new "air glide" suspension option. The latter automatically lowers the body to improve ingress/egress and cargo loading. The system also has an adaptive feature that uses road-surface imagery data from the vehicle's forward-facing camera to adjust damping prior to the vehicle impacting potholes and gnarly pavement. This seems an ideal technology application for the luxury-vehicle market. The camera software also recognizes traffic signs and adjusts vehicle speed when in 'Intelligent' driving mode, one of seven driver-selectable operating modes.

The new CD6 architecture was finalized in 2014. It's a mixed-materials approach, with extensive use of aluminum alloys in the front structure, suspension knuckles and hood. The steel roof outer panel is stamped with longitudinal blisters for added strength. Acoustic glazing is used in the windshield and front- and second-row side windows. Also keeping the cabin quiet are active noise cancellation and active sound-enhancement systems.



Aviator debuts Ford's new CD6 rear-drive/all-wheel-drive architecture that will underpin multiple Ford and Lincoln crossover and SUV models.



Centerpiece of Aviator's cockpit is 12.3-in. LCD screen.

Lindsay Brooke

## Palisade SUV new Hyundai flagship



The 2020 Palisade effectively replaces the brand's Santa Fe XL and can seat up to eight.

The three-row 2020 **Hyundai** Palisade is the brand's biggest SUV yet, providing more passenger room and more thermal-management performance to handle towing load.

Palisade replaces the three-row, 7-passenger Santa Fe XL, the long-wheelbase version of the Santa Fe midsize SUV. Like the Santa Fe XL, the Palisade is capable of towing 5000 lb (2268 kg).

Palisade is powered by Hyundai's Lambda-series 3.8-L gasoline direct-injection (GDI) V6 that produces 291 hp at 6000 rpm and 262 lb-ft (355 N·m) at 5200 rpm and Atkinson-cycle operation. "That's plenty of torque for towing and for moving a vehicle of this size and there's a fuel economy benefit with the Atkinson cycle," said Phil Zoldak, Manager of Engine Development and Testing at HATCI.

The only transmission offered for the Palisade is an 8-speed automatic. The company said EPA-certified fuel economy will be released at a later date; the 2020 Palisade goes on sale in summer 2019.

As Hyundai's largest SUV, the Palisade's dimensions outside the Santa Fe XL in wheelbase (114.2 in/2900 mm vs. 110.2 in/2799 mm); length (196.1 in/4981 mm vs. 193.1 in/4904 mm); height (68.9 in/1750 mm vs. 66.5 in/1689 mm) and width (77.8 in/1976 mm vs. 74.2 in/1885 mm).

"Palisade is an 8-passenger SUV. The outgoing model was too narrow for three occupants across the third-row seat and it was too narrow to have easy ingress and egress to the third row," said Michael O'Brien, Vice President of Product, Corporate and Digital Planning for Hyundai Motor America.

**Kami Buchholz**

## Hyundai Nexo out-spaces Toyota and Honda FCVs

The 2019 **Hyundai** Nexo is a distinctively-styled and luxurious compact SUV based upon Hyundai's first fully dedicated fuel-cell electric vehicle (FCEV) platform. A technological flagship for Hyundai, the front-wheel-drive Nexo is the most refined fuel-cell (FC) offering to date and also trumps the **Toyota** Mirai and **Honda** Clarity via a trendier and more practical SUV format.

Like its two Japanese competitors, the Korean offering will face the same geographically limited availability until hydrogen refueling infrastructures catch up with these long-range electrified platforms.

Hyundai claims the Nexo (in base "Blue" trim) is the world's longest-range EV at 380 miles (Honda claims a 366-mile range for the Clarity FCEV) and unlike a battery-electric vehicle (BEV), it can be refueled in five minutes. *Automotive Engineering* spent a day in the Los Angeles area piloting the Nexo in normal workday traffic and couldn't escape the feeling of driving around in (a very quiet) future.

### Rolling power plant

The 2019 Hyundai Nexo is Hyundai's second-generation FCEV and also its second SUV, the first being the Tucson FCEV introduced in 2013. Compared to the Tucson FCEV, the Nexo's revamped FC powertrain is 14% lighter and takes up 18% less volume thanks to better module integration. Packaging is also improved, with FC stack hardware contained beneath the Nexo's hood and the high-voltage battery (along with a separate 12-volt lithium-ion battery for accessory power) shuttled back below the rear load floor.

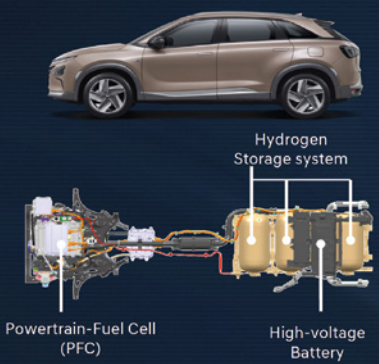
Total system power is 135 kW, of which 95 kW emanates from the FC stack and 40 kW from the 1.56-kW-h, 240-volt lithium-ion polymer battery. Hyundai claims a system efficiency of 60.4%, a 5.1% improvement from the Tucson FCEV, with power density improved 50% to 3.1 kW/L. The stack powers a 120 kW (161 hp) permanent-magnet motor (the Tucson's motor was AC induction) that produces 395 N·m (291 lb-ft) routed to the front wheels through a single-speed reduction gear (7.981:1).

The dedicated vehicle architecture and bespoke independent rear suspension permits the Nexo to use three 52-L (13.7 gal) hydrogen storage tanks (right) compared to the torsion-



Hyundai said the 2019 Nexo FCV holds claim to being the world's longest-range fully-electric vehicle.





Powertrain-Fuel Cell (PFC)      High-voltage Battery

Hydrogen Storage system

Comparing the new Nexo FCV to its Tucson-based predecessor.

	NEXO	Tucson FCEV
Fuel Cell Stack	95kW (127hp)	100kW (134hp)
Battery	40kW (54hp)	24kW (32hp)
Max. Power	161hp / 5,000rpm	134hp / 5,000rpm
Max. Torque	291 lb. - ft. / 1,000rpm	221 lb. - ft. / 1,000rpm
Motor System	Permanent magnet 120kW (161hp)	AC Induction/ 100kW (134hp)
H <sub>2</sub> Container	13,96lb. (@10,000psi)	12.4lb. (@10,000psi)
Fuel Economy (mpge)	61 (Blue) (65/58) 57 (Limited) (59/54)	50 (Combined)
Driving Range	380 miles (Blue) 354 miles (Limited)	265 miles
Max. Speed	110 mph	100 mph

In terms of FC development, Dr. Hong said that he felt the industry has reached a third distinctive hurdle, with the first having been getting enough power from the FC stacks (10 kW was a challenge when development first began two decades ago he noted, but now they're netting 10 times that amount). The second challenge was packaging, but he said he felt that has been solved with FC components housed beneath a conventional vehicle's hood.

Where the Tucson FCEV was lease only, the Nexo will be leased and sold, and available

beam Tucson FCEV's two alternate-sized tanks, netting a total capacity of 156 L (41.2 gal).

### Conventional but dedicated platform

The 2019 Hyundai Nexo uses a new, dedicated platform designed around a fuel-cell architecture, and employs the latest advanced high-strength steels to improve rigidity and reduce weight. Hyundai claims a base curb weight of 3,990 lb (1,810 kg) for the base Blue trim on a 109.8-in wheelbase, which is almost 6 inches longer than the Tucson FCEV.

The Nexo features a fully independent suspension (McPherson strut front; multi-link rear), electric-motor-driven power steering, four-wheel disc brakes, and alloy wheels in standard 17-inch or optional 19-inch diameters.

As a tech flagship, the Nexo is loaded with driver assist/warning features from the Hyundai portfolio, including forward collision, lane following and rear cross-traffic assists, combined with blind-spot and surround-view monitors. A remote parking system will autonomously park or retrieve the Nexo from either a parallel or perpendicular parking space with or without a driver in the vehicle and also can back the Nexo into a parking spot.

### First drive with a FC fellow

AE's time driving the Nexo at the launch event was exceedingly fortunate to include Dr. Bo Ki Hong as a passenger. Based at the Mabuk Technical Center in Korea, Dr. Hong is the fuel-cell research fellow for Hyundai Motor's R&D division.

According to Dr. Hong, the key engineering challenge with the Nexo was finding the proper balance between the fuel-cell stack and the high-voltage battery in terms of performance, efficiency and drivability. These are new knobs to turn from an engineering perspective, and Dr. Hong noted it's the recent improvements in high-voltage battery technology that makes FC vehicles viable—with the battery acting as a crucial, on-demand storage device for energy produced by the stack and (more commonly) regenerative braking.

wherever there are "enough" hydrogen refueling stations. The Nexo will be built on Hyundai's dedicated FCEV production line in Ulsan, Korea, and pricing had yet to be announced as of early November. Hyundai said the Nexo would be available in Southern California before the end of 2018, with Northern California availability planned for early 2019.

Paul Seredynski


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# PICKUP SHOCKER!



With the R1T, Rivian emerges as the startup most likely to build the electric vehicle all of America will want to own.

by Bill Visnic

Rivian's R1T is sized between Detroit's midsize and fullsize pickups and promises credible towing, hauling and off-road capabilities.

**R**ivian founder and CEO R.J. Scaringe isn't claiming he's developed the formula for cold fusion, but it's possible he's cracked a code of similar import to the automotive world: the formula to make electric vehicles truly resonate with mainstream America.

It seems simple, really. Develop a fresh-looking and cleverly designed pickup truck—and make it electric.

If it's so obvious, why hasn't anybody done it yet? And can this company that's made nothing pull it off, expecting the world's pickup-truck experts in Detroit to remain indefinitely focused on their profit-pumping, combustion-driven dinosaurs?

## Not your garden-variety startup

The answers come from multiple angles: the confluence of technologies suddenly available and ever less costly, for one. The hysteresis of the "traditional" auto industry, certainly. But also because Scaringe, with an almost spookily infectious optimism and calm, leads a start-up company unlike just about any borne from Silicon Valley.

**Rivian**, started in Scaringe's home state of Florida, has existed for almost a decade under a couple other prior names and has headquartered in suburban Detroit since 2015.

Rivian is comfortably—if not lavishly, avers the CEO—funded by patient investors led by Saudi Arabian automotive distributor Abdul Latif Jameel (ALJ), which has close ties to MIT, where Scaringe earned a Master's and Ph.D in mechanical engineering. The company currently has a reasonably modest 560-odd employees spread between three U.S. facilities and an office in the United Kingdom.

"We're very well capitalized," Scaringe told a small group of journalists visiting the company's Plymouth, Michigan, headquarters last November for a look at the R1T pickup prior to its world debut at the 2018 Los Angeles auto show.

Unlike virtually all its contemporaries, Rivian already owns a viable manufacturing facility, having bought the former **Mitsubishi**-owned 2.6-million sq-ft assembly plant in Normal, Illinois, for the reported price of just \$16 million. The company has a workforce of about 65 revitalizing the plant, last used in 2015, for the start of R1T sales that Scaringe said are about two years away.

"For these first two vehicles (the R1T pickup and the R1S SUV), we're talking about tens of thousands of units (annually)," Scaringe said, with an annual global-sales target of approximately 45,000 after the first five years.

"Rivian's challenge, like **Tesla**, **Karma** and **Lucid**, won't be attractive product," asserted Eric Noble, president of the CARLAB automotive consultancy, after seeing the confidently hip R1T at its unveiling in L.A. "It'll be every other aspect of the world's most difficult business. Being a profitable carmaker is not a trivial task, even if your models are cool."

## Zig while the incumbents zag

Scaringe took early notice of the U.S. market's swing towards pickups and crossovers, calling it a "market space that's massively underserved," by alternatives to the current combustion-engine configurations.

Because of the well-known profitability of conventional body-on-frame pickup trucks, "The formula hasn't changed much," said Scaringe. He added that today's pickups are inefficient, ride terribly and just "aren't very good at what they do. But in large part, (it's because) they're being used like cars."

Noting all this, Rivian did a wholesale shift and began to develop its modular platform for the R1T pickup and the R1S SUV. It is not overstatement to say Rivian's redirection to the truck market was prescient—and little short of enlightened.

"I'm thumbs-up on the direction Rivian has taken," said Tony Posawatz, P.E., a 30-year-plus industry veteran with **General Motors** who oversaw some of the company's most significant electrification programs as Vehicle Line Director. He's now CEO of Invictus iCAR, as well as serving as a Board Director and advisor for many auto-tech firms.

"And it's not just about North America," Posawatz



As with many contemporary electric vehicles, Rivian's basic battery/chassis structure is a "skateboard" layout that enables multiple body styles to use the same modular platform.

added, saying China and even Europe are displaying a consumer-preference shift towards trucks and SUVs.

## Land Rover used to be here

The more one looks at the R1T, it's easier to understand Scaringe's plan for Rivian: to create a pickup for the upscale adventure market, to "focus in this Patagonia-like space" that he described on a clothing-brand spectrum of tough and utilitarian yet still being premium and aspirational.

"**Land Rover**, as a brand, used to be here," Scaringe said. Now, however, Land Rovers are "not products you really feel comfortable getting dirty."

The R1T will start at \$69,000 before the existing federal tax credit of \$7,500, the company said, with the top model starting somewhere around \$90,000. Heavy money, to be sure, but these are not prices that will shock anyone shopping today's high-end fullsize pickup, Invictus iCar's Posawatz asserted to *Automotive Engineering*.

Fullsize truck devotees may scoff at the Rivian R1T's 55-in (1397-mm) bed length, for example—although it's a longstanding industry axiom that few who own pickups put much of anything in the bed.

Posawatz was a leader in GM's fullsize-truck product development when the company designed the first Avalanche. He said the Avalanche was one of the first models to acknowledge the changing use case of the pickup, saying the Avalanche was a response to the growing understanding that pickup buyers "didn't really need or use the bed that often."

Thus Rivian's rationale for its 55-in bed. Enough-but-not-too-much also could be the analysis for the truck's hardly-skimping 11,023-lb (5000-kg) tow rating and 1764-lb (800-kg) payload capacity. These are figures that place the R1T ahead of conventional midsize pickups that mostly have all the utility casual buyers need.

## The hard parts

Rivian's R1T and R1S share a modular "skateboard" platform that sees the battery pack placed between the high-strength-steel (HSS) frame rails; some parts of the chassis are aluminum. The R1T has a 135.8-in (3450-mm) wheelbase and overall length of about 216 in (5475 mm). Overall width is 79.3 in (2015 mm). Maximum ground clearance: 14.2 in (360 mm) when jacked to the utmost of the standard air suspension. The front suspension is a double-wishbone layout, the independent rear suspension is a 5-link design.

The pickup's body is mostly aluminum, with HSS and composites in key areas, said Mark Vinnels, Rivian's executive director of engineering & programs. Vinnels spent more than a dozen years at **McLaren**, leading the engineering programs for the company's highly-regarded line of supercars. Many other engineers and Rivian employees also worked at McLaren prior to joining Rivian.

The R1T is all about "utilizing the elegance of electric drive," Vinnels said, although he won't say much about the batteries that provide the power. Exact battery chemistries and suppliers are the ongoing secret-du-jour for most vehicle startups and Rivian is no different. Vinnels would confirm Rivian's lithium-ion battery form factor is the well-known 2170 cylindrical configuration, and indicated they will come from a proven manufacturer. Vinnels said Rivian's battery pack is 30% more energy-dense compared with "the current best in the market."

For the largest battery pack, there are 800 cells grouped into nine modules. The battery modules stack two cells atop one another, making for a thick battery pack. As with most EVs that remains an advantage because their placement imparts a deliciously low center of gravity.

Vinnels said great care has been taken to optimize thermal management of the pack—coolant passages run between the two-high cell stacks, for example—crucial to maximizing efficiency and driving range. There are three coolant circuits for the vehicle and engineers say the R1T has successfully completed towing runs on the gruelling Davis Dam climb in Arizona.

The battery-size "walk" is where it gets intriguing. Most of the initial hype focused on the R1T's largest battery-pack capacity, 180 kW-h, which the company said should be good for a plump maximum driving range of 400 mi (644 km) "eliminating any chance of range anxiety," said Vinnels. But Invictus iCar's Posawatz said the volume sellers could be the pickups with the 135-kW-h pack delivering 300 mi (483 km) of range or the 105-kW-h entry-level pack good for 230 mi (370 km), as many buyers may choose to optimize the balance of price and driving range.

As charging infrastructure expands, he said, buyers will begin to





Rivian promises a degree of premium look and feel for the R1T cabin, but also durable and easily-cleaned surfaces owners won't have to be afraid to get dirty.

gravitate toward buying only as much battery capacity as they anticipate requiring. Assuming there's a 400-amp DC fast charger around, the 180-kWh pack can be charged to 80% capacity in 50 minutes.

## 4wd and clever touches

The R1T's propulsion system appears exquisitely simple and promises immense capability. There is an electric propulsion motor for each wheel; Rivian has varied slightly in its specifications for the motors' output, but Vinnels said at the truck's media preview each motor develops 137 kW (186 hp) for a total of 743 hp and total torque of 811 lb-ft (1100 N-m). All this purportedly is good for a 0-60 mph dash of 3 seconds and highly precise and controllable torque vectoring at any speed.

The individual motors, each with a single-speed transmission, are combined into an integral sealed casing for each axle.

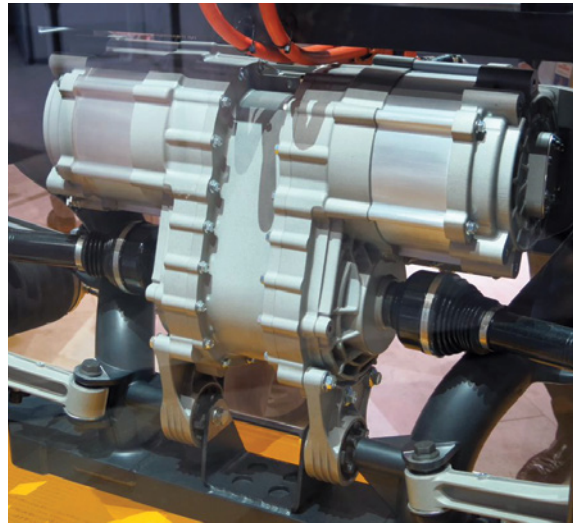
The R1T's electrified platform allows a variety of useful features not necessarily available to conventional-pickup developers, although nobody should be surprised if some of Rivian's innovations show up elsewhere.

One feature that won't: the R1T's front trunk, located where the engine resides in a conventional pickup; it holds up to 330 liters and is deep enough to hold many kinds of items. There's a wonderful built-in rigid tonneau cover for the cargo bed that retracts, accordion style, at the push of a button, to disappear into a holding area at the forward edge of the bed.

The feature with the most "wow factor," though, must be the "gear tunnel" that runs transversely across the vehicle just under and behind the rear seats. The gear tunnel is envisioned for long or unwieldy items such as baby strollers, snowboards and the like. A small door on either side of the truck that accesses the gear tunnel opens downward to double as a handy bed-access step or seat.

## The vaporware factor

All these promises are made for vehicles that are nearly two years from showrooms and from a company that's never made a vehicle. It's impossible not to lump in Rivian with the troubled startups that



The unitized drive for the R1T's front axle integrates two propulsion motors and their respective transmissions into a single case. The same arrangement is used at the rear.

have dotted the landscape in the past few years. But Scaringe said the Rivian story is as much about addressing the aberrations in today's vehicle market as it is about introducing "radical" new technology.

The OEMs "have a lot of incredibly smart people," he said, but "they have structural disadvantages" such as embedded scale and processes and legacy costs that make it difficult for them to be agile.

Product-development expert Posawatz, who after GM served as CEO for **Fisker Automotive** and has consulted to numerous start-ups and technology companies, likes Rivian's modular-platform approach, which he believes is an immense asset.

He calls Rivian "in the top couple (of vehicle-manufacturer startups) that have a chance," adding that one significant advantage has been Rivian's "long time in incubation" that enabled the company's principals to assess the moves and mistakes of others.

Nor does he think there's much good in comparing Rivian to Tesla, as has been done exhaustively since Rivian broke cover. "They've carved out something unique—and done something very different from what Tesla has done," Posawatz asserts.

The CARLAB's Eric Noble agrees that Rivian's trump card is having the right product at the right time. And a bit of emotion, too.

"First, they're an acknowledgement that fullsize trucks and SUVs are never going away—and that if we want to 'green' the [U.S. vehicle] fleet, we've gotta green these behemoths. Second, Rivian borrowed a page from **FCA**, with unapologetically masculine styling. Like the Wrangler, they'll be either loved or hated. As long as there are enough lovers, who cares?" ■



# PLASTICS spur tech innovations

MATERIALS FEATURE

The SPE Innovation Awards recognize vehicle OEMs and their supply chains for novel material developments and applications.

by Ryan Gehm



Grand Award and Powertrain winner: 2017 Ford F-150 vacuum generation system for brake assist.

**F**ord Motor Co. took home top honors at the 48th SPE Automotive Innovation Awards Competition, winning the Grand Award for its Powertrain nomination, and claiming four other categories along with its suppliers. **Fiat Chrysler Automobiles** (FCA) topped three categories and **Hyundai Motor Co.** nabbed the Materials prize at the largest recognition event in the automotive and plastics industries, held annually by the Automotive Division of the **Society of Plastics Engineers** (SPE).

*Automotive Engineering* was again honored to participate on the Blue Ribbon Judges panel that reviews the finalists in nine major materials-technology categories and votes on the winners in each.

## Grand Award and Powertrain Award—2017 Ford F-150 vacuum generation system for brake assist

**Tier Supplier / Processor:** Dayco Products / MacLean-Fogg, Engineered Plastics Co.

**Material Supplier / Toolmaker:** DuPont Automotive / Kaid Tool & Die

**Material / Process:** Delrin 73M30 POM+PTFE, Minion 520MP PA6 / injection molding  
Airtight to 200 psi (13.8 bar) and leakproof following infrared welding, the all-plastic vacuum generation system (VGS) consists of 10 components that work together to provide 20% better performance at higher elevations. The open/close valve actuation is accomplished via two complementary resin systems acting in concert to allow no “stick-slip” and no measurable wear after 2.5 million hot/cold test cycles. Injection molding allows for very close tolerances of critical details necessary for total system performance. The design achieved a 40%

weight savings and a 25% cost savings compared to current pump systems. Tunable to various engine requirements, the VGS is already employed on four other Ford programs including the Taurus and Explorer, according to a program engineer.

## Additive Manufacturing Award—2017 Ford Mustang Convertible window alignment fixture

**Tier Supplier / Processor:** Stratasys / Stratasys

**Material Supplier / Toolmaker:** Stratasys / Stratasys Direct Manufacturing

**Material / Process:** PA 12 35% short carbon fiber / fused deposition modeling (FDM)

The 3D-printed fixture for the production floor is 30% lighter and cheaper to produce compared to a traditional welded fixture. It took only 50 hours to build the integrated fixture with handles and mounting brackets. Line of sight and ergonomics were improved significantly with the design, which allows for easier handling and precludes the need for a lift assist. The printed fixture also integrates pneumatic control, eyelets for a stowage rack, trigger switch housing, gage protector/deflector and pneumatic tubing retainers and switch mounts. “Complexity doesn’t cost you anything” in 3D printing, said George Russell, Automotive Segment Leader at Stratasys.

## Body Exterior Award—2019 Jeep Cherokee thermoplastic liftgate

**Tier Supplier / Processor:** Magna International Inc. / Magna Exteriors Belvidere

**Material Supplier / Toolmaker:** Trinseo & LyondellBasell / Tycos Tool & Die

**Material / Process:** DLGF 9411 & Hifax TYC TPO / injection molding  
By replacing a steel liftgate with a new thermoplastic design, the engineering team enabled a 28% mass reduction and a 50% tooling and capital investment savings through part integration and manufacturing efficiency. The accelerated 18-month program, from sourcing to Job 1, also resulted in NVH levels that exceeded target. A claimed industry-first use of conformal infrared welding behind the molded-in-color



grain class-A surface increased structural and dimensional performance and enabled quicker processing. Bonded-in brackets enabled patent-pending tethering attachments without fasteners, improved metal reinforcement efficiency and maintained styling surface wrap in D-pillars without sacrificing daylight opening.

### Body Interior Award—2018 Lincoln Navigator integrated modular pelvic bolster

**Tier Supplier / Processor:** Faurecia Interior Systems / Faurecia Interior Systems

**Material Supplier / Toolmaker:** LyondellBassell / Roush Tooling

**Material / Process:** Profax SG702 PP / injection molding

This application combines two unique side-impact bolster designs to meet the requirements for 5th and 50th percentile occupants while achieving an approximate 10% weight savings. Integrating them into the door-trim map pocket resulted in tooling-cost savings estimated at \$100K. There was an additional \$100K indirect savings in testing time and \$8-per-vehicle cost avoidance if add-on bolsters were used. The modular mold-in design's energy-absorbing characteristic can be

tuned to accommodate vehicle-specific loading distribution and stiffness requirements. The Lincoln Aviator and Ford Explorer and Escape all incorporate this design now, according to the nomination presenter.

### Chassis/Hardware Award—2016 Chrysler Pacifica self-tapping composite nut

**Tier Supplier / Processor:** ITW Deltar Fasteners / ITW Deltar Fasteners

**Material Supplier / Toolmaker:** Asahi Kasei Plastics / Maple Mold

**Material / Process:** Leona 90G55 PA66 / injection molding

The high-strength composite nut has "self-healing" properties enabling it to maintain sufficient torque and clamp load even after it's been stripped, unlike the conventional metal nut that it replaces. A mass reduction of 8 g per joint location, times 121 joints on the Pacifica, results in a total vehicle mass savings of 2.1 lb (0.95 kg). The estimated cost savings per vehicle is \$3.25. Install drive time was reduced by 400%, with no MAT point or proprietary thread forms required for drawn arc stud. The composite nut can be translated across all OEMs and in many additional applications.

### Environmental Award—2018 Lincoln Continental sustainable hybrid composites

**Tier Supplier / Processor:** Summit Polymers / Summit Polymers

**Material Supplier / Toolmaker:** Celanese & International Paper / Summit Polymers

**Material / Process:** THRIVE & Celstran PP+HC (CF/LGF) PP/RPP / melt compounding followed by injection molding

Claiming an industry-first application of composites combining tree (cellulose) fiber with long glass fiber (LGF) in a polypropylene (PP) matrix, which replaces 35% short glass-mineral filled PP for the console retainer, the program realized a 24% weight savings and 13% cost savings. A total \$2 million cost savings resulted by reducing weight and reducing cycle times by 20 to 40%. A lifecycle assessment improvement was also attained. The material is being tested for other "near future" interior and underhood applications such as instrument-panel substrate, door panels, battery trays and fan shrouds.

### Materials Award—2019 Hyundai Nexu EMI shielding compounds for high-voltage cover

**Tier Supplier / Processor:** Yura Corp. / Yura Corp.

**Material Supplier / Toolmaker:** Hanwha Compound / Hyundai Motor Co.

**Material / Process:** Hanwha Compound ESM-204B PA6 / injection molding

New conductive plastic compound materials for EMI (electromagnetic interference) shielding were developed for high-voltage junction box upper covers.





2019 Hyundai Nexo high-voltage cover with EMI shielding compounds.

The material replaces conventional die-cast aluminum covers for reduced weight and manufacturing costs, and it satisfies the 40-dB EMI shielding effectiveness. The materials are polyamide 6/PPO compounds with hybrid conductive carbon filler (carbon fiber, carbon nanotubes, carbon black) not containing metal powder or metal-coated fiber. Weight savings is estimated at 30% (0.3 kg) and the estimated cost savings is 70%, or \$50 per vehicle, compared to aluminum.

**Process/Assembly/Enabling Technologies Award—2018 Jeep Wrangler integrated tire carrier, rear camera & brake light assembly**

**Tier Supplier / Processor:** TMD-Grammer AG Group / Leggera Technologies

**Material Supplier / Toolmaker:** DuPont / Leggera Technologies

**Material / Process:** Zytel ST 801 AW PA66 / injection molding

The tire carrier assembly utilizes magnesium injection molding for higher structural strength with reduced weight and polymer over-molding for improved impact and corrosion resistance. A 60% weight savings is achieved compared to metal stamping and a 20% weight savings compared to die-casting processing

methods. A cost savings of 20% is realized with an improved load rating from 85 lb to 115 lb (38 kg to 52 kg). The Thixo-molded Mg inner carrier with 1.9-mm over-mold eliminates the need for a steel bracket for an indirect cost savings.

**Safety Award—2019 Ford Transit Connect interlocking mechanism for side impact**

**Tier Supplier / Processor:** Faurecia Interior Systems / Thermolympic SL  
**Material Supplier / Toolmaker:** Trinseo / Meymol SL

**Material / Process:** Magnum 3325MT ABS / injection molding

The interlocking mechanism improves door-trim performance during side impacts by preventing fracture or separation of components that could cause sharp edges. This patent-pending design provides strong attachment, force absorption and high impact resistance between two components during side impact. It replaces the need for metal bracket reinforcement solutions, saving 3.70 kg (8.16 lb) in weight per vehicle. The component enables a cost-avoidance savings of \$30.60 per vehicle and a tooling investment saving of \$9.88 million. ■

**For more on the annual SPE Automotive Awards program, see [www.speautomotive.com](http://www.speautomotive.com).**

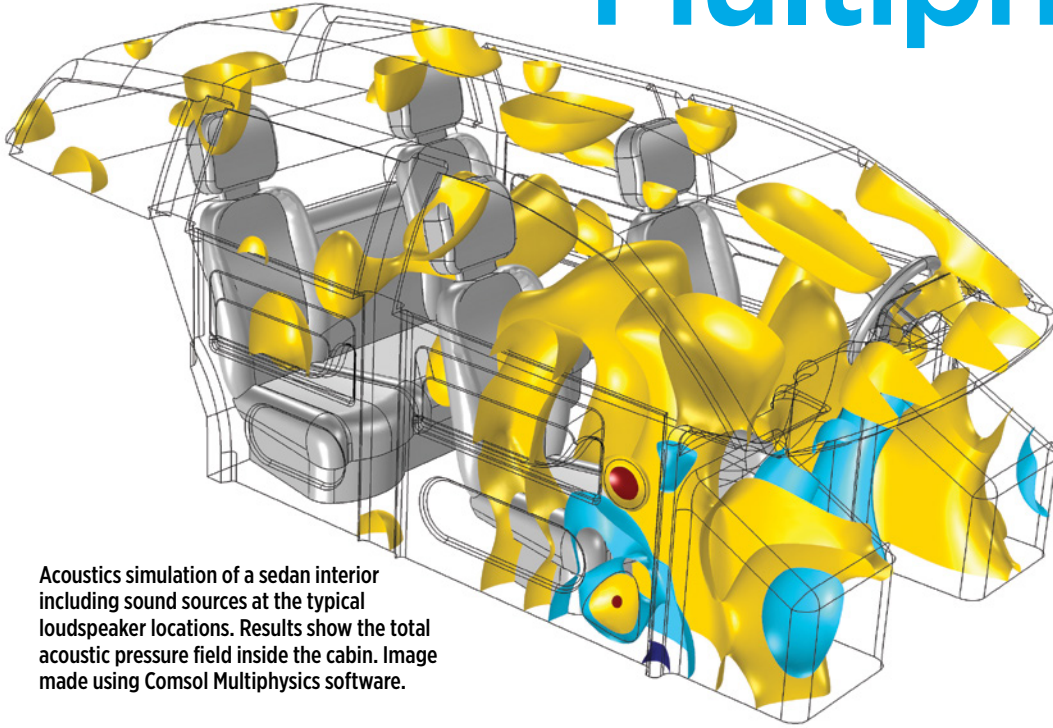


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# A LESSON IN Multiphysics



Acoustics simulation of a sedan interior including sound sources at the typical loudspeaker locations. Results show the total acoustic pressure field inside the cabin. Image made using Comsol Multiphysics software.

OEM engineers reveal how new software from Comsol improved their modeling and analysis of EV battery performance and audio-system sound quality.

by Terry Costlow

**M**odeling and simulation are becoming a more critical factor in automotive design, particularly in subjective areas like passenger-cabin sound quality and complex newer technologies like battery management. Design tool suppliers are increasing the power of those tools while also making them easier to use.

Tools that handle multiple physics categories are becoming more important as engineers need to understand how complex interactions change when various parameters are adjusted. At the recent **Comsol Users Conference**, technologists from **General Motors** and **Nissan** detailed their efforts to understand nuances in audio systems and electrified-vehicle battery packs.

Patrick Dennis, Principal Engineer at Nissan, told attendees how the company migrated to virtual sound rooms because physical tests for analyzing audio speaker quality and configuration proved problematic. After the analysis of the sound room tests showed problems at certain frequencies, Nissan engineers ran simulations that predicted those issues, giving the team the confidence to change the roles of physical and virtual tests.

“We went into a sound room and made a binaural recording that seemed to be perfect,” Dennis said. “When we brought it back and put it in a car, it didn’t sound that good. We created a reference room using Comsol tools that gave us recordings that sound better than what we did in the expensive room. That’s our primary tool now.”

At the conference, Comsol unveiled Multiphysics Version 5.4, which the company claims offers improved performance and ease of use. The latest version provides a number of modules that make it easier and faster for users to understand how changes to one parameter ripple out to many other elements of the overall system.

“Version 5.4 is several times faster for rendering large 3D models; depending on the geometries, it can be an order-of-magnitude faster,” claimed Bjorn Sjodin, Comsol’s VP of product management. “There’s also a new comparison tool that lets you change the settings in a model and

compare the new one with the model saved on file. We also added a more sophisticated module for batteries.”

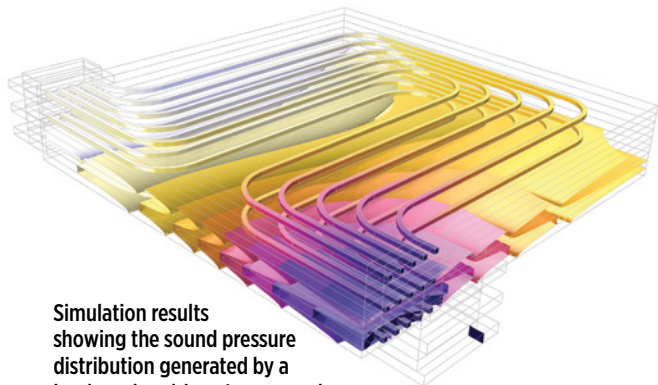
That’s a helpful move for automakers and Tier 1s that are striving to meet regulatory mandates for fuel economy and emissions. Battery charging/discharging and overall lifetimes involve myriad factors that span several types of physics. The updated tools and modules can give developers deeper insight into areas that haven’t previously been examined.

“We need to supplement the information suppliers give us, so we end up with huge data sets,” reported Taylor Garrick of General Motors Global Propulsion Systems. “I deal with 40 to 50 parameters I need to model; the suppliers usually only give us 20 to 30. We need to understand all these parameters to answer questions about the size, performance, and output of battery packs, and to see when we need to cool every cell or when we should selectively cool cells.”

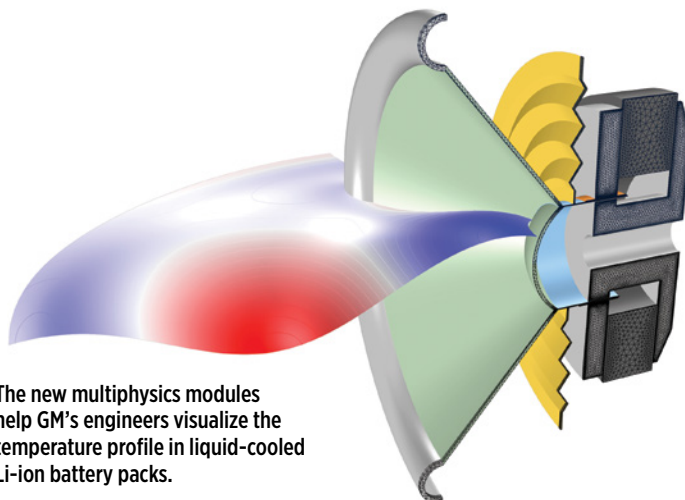
Multiphysics tools are becoming more important as engineers attempt to eke out more performance, since minor changes in one area can cause often-unexpected changes elsewhere.

“In battery packs, you’ve got a lot of factors to examine,” noted Sjodin. “You need to know how the ions inside the battery are reacting to heat, and you need to know how temperature changes are impacting the cooling liquids. Both factors have a big impact on performance and [battery] lifetime.”

The addition of dedicated modules is part of a corporate focus on making the multiphysics software easier to use. The battery module includes 1D, 2D and 3D options, so users can work with different fidelity levels depending on the task at hand.



Simulation results showing the sound pressure distribution generated by a loudspeaker driver. Image made using Comsol Multiphysics software.



The new multiphysics modules help GM's engineers visualize the temperature profile in liquid-cooled Li-ion battery packs.

“When we want to put the battery pack together with inverters and other components, a 1D model gives us the quickest results,” Garrick said. “If we’re trying to work out some aspects of battery pack design, 3D models give us the best results. 3D has the highest fidelity.”

Comsol also unveiled a compiler program that makes it easier to share apps. It even lets users who don’t have the company’s software view models and simulations. Version 5.4 attempts to balance the need

to provide more ways to analyze the subtleties of each design with the need to offer tools that don’t take a long time to learn. Modules dedicated to specific fields are among the company’s ease-of-use techniques.

That approach also helps specialists in these fields delve into the subtle factors that determine end performance.

“We have more modules for specific applications,” noted Valerio Marra, the company’s marketing director. “They make it easier to do the work in those fields, since many advanced factors are tailored to the application.” ■

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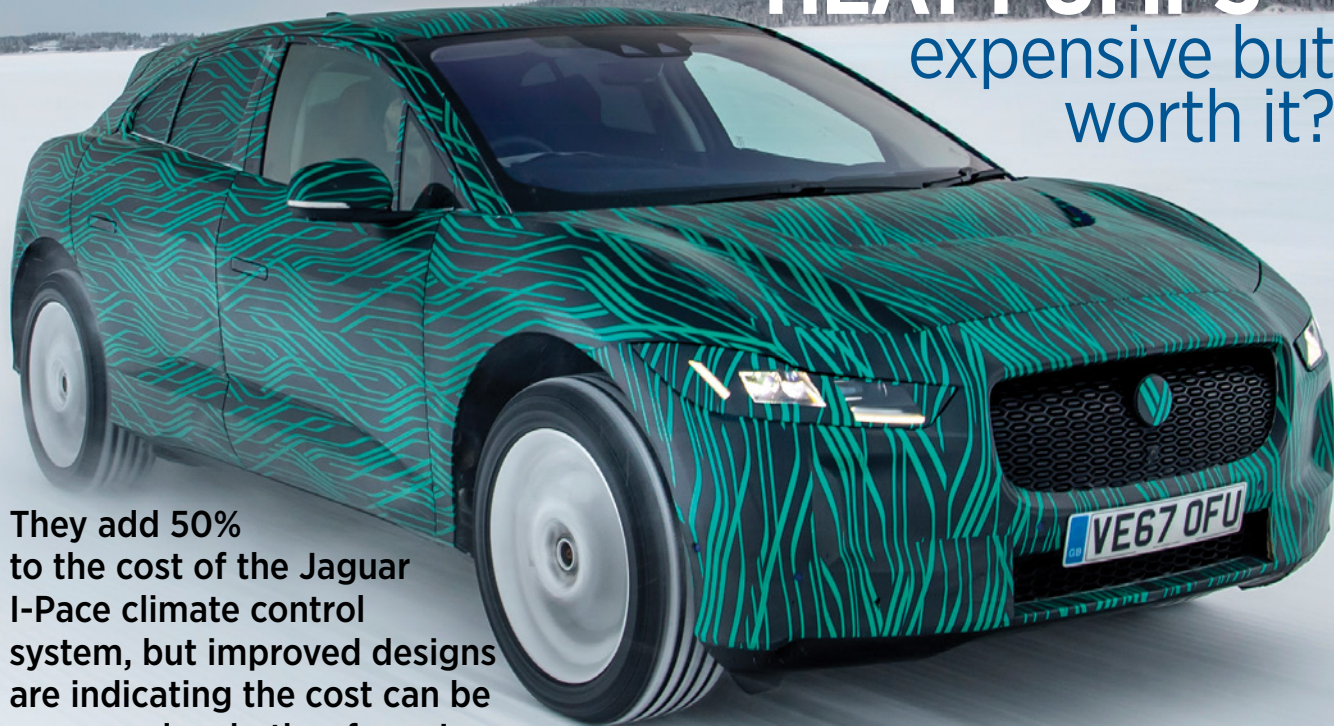
HV Connector



HV Charging Coupler



# HEAT PUMPS— expensive but worth it?



They add 50% to the cost of the Jaguar I-Pace climate control system, but improved designs are indicating the cost can be recovered—whether for a Jag or an electric school bus.

by Paul Weissler

Jaguar's new electric I-Pace (shown under winter testing in Arjeplog, Sweden) joins the Toyota Prius Prime as pioneers of the Denso-designed heat pump HVAC system.

**C**an a heat pump-equipped battery electric vehicle (BEV) overcome major energy losses for cabin heating comfort in cold ambient conditions—and at reasonable system cost?

These questions were addressed at the 2018 SAE Thermal Management Systems Symposium, and although definitive answers may not all be production ready, promising work has been done.

The industry recognizes as unacceptable the BEV battery pack range losses of up to 40%+ from winter operation with PTC (positive temperature coefficient) heating, which is the conventional approach.

Testing by **Hanon Systems** in 2017 showed simple, coolant-circulating waste heat-gleaning circuits from power electronics, electric motor and battery pack would produce sufficient thermal storage during a commute-length drive (50 km/30 mi) in a pre-conditioned cabin (as part of a battery pack charge). And the Hanon research indicated this approach is far more cost-effective and efficient than a heat pump. However, as BEVs with greater range enter the market, the heat pump comes back into play. It also is being considered for such other uses as school buses, now typically diesel-powered, but being evaluated for electrification.

## Vapor-injection approach

Jaguar's new 2019 I-Pace AWD model features a 90 kW-h battery pack and up-to-240-mi/384-km rated

range. It's a premium-market vehicle with surely more flexibility in its cost/pricing structure than a **Nissan Leaf**, for example. The electric Jag also is expected to deliver near its rated range in very cold weather. And although it includes a heat pump, there is much more to the system.

In his SAE TMSS presentation, Nilabza Dutta, a **Jaguar Land Rover** thermal-management engineer, cited "30% to 50%" as the extra cost of the I-Pace's HVAC system. However, he said, there would be added cost of 150-450% for covering the range shortfall of using PTC by increasing the size of the battery pack. There would be an additional cost over that of the battery pack: recharging it from the grid, which Dutta said was in the range of 80-300%.

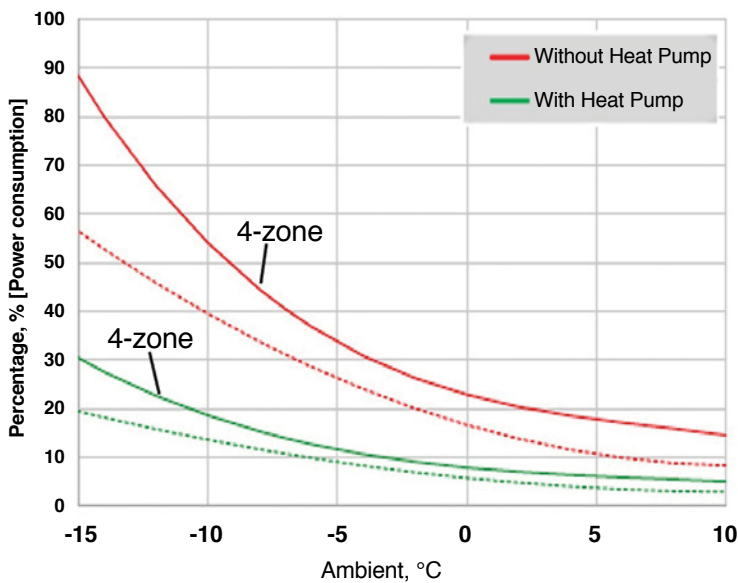
The Jaguar approach, therefore, was "do whatever is necessary" within the alternative cost framework. First, the HVAC air distribution is three-zone: driver only, driver and a front passenger and both front and rear.

Next, there is a heat-gleaning coolant circuit for the electronics. It is integrated with a vapor-injection HVAC heat pump system, for maximum heating season performance. It does not cover the regenerative braking—a "one-pedal" control system that is based off the accelerator and similar to those used on various BEVs.

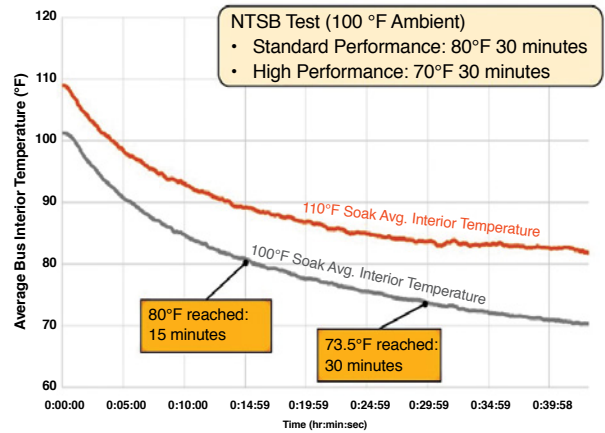
The vapor-injection heat pump design, introduced on motor vehicles last year by **Denso** on the **Toyota Prius Prime** plug-in hybrid, incorporates a liquid-gas separator. This approach, adapted from commercial heat pump systems, injects the hot vapor into the compressor to produce system heat at low ambient temperatures. In this arrangement the heat pump, which normally is ineffective at 0°C/32°F because of the slowdown in refrigerant mass flow in low temperatures, remains operational.

Toyota cites +14°F/-10°C as the lower end for the Prime. The





I-Pace graph shows advantage in heat pump cooling operation, both in four-zone and two-zone (dotted line just below).



Emerson graph shows school bus heat pumps would meet standard cooling need, come within 3.5°F in high-performance test.

the battery control module, to optimize range. It works with any Alexa voice communication device, and at this time also can update the infotainment system.

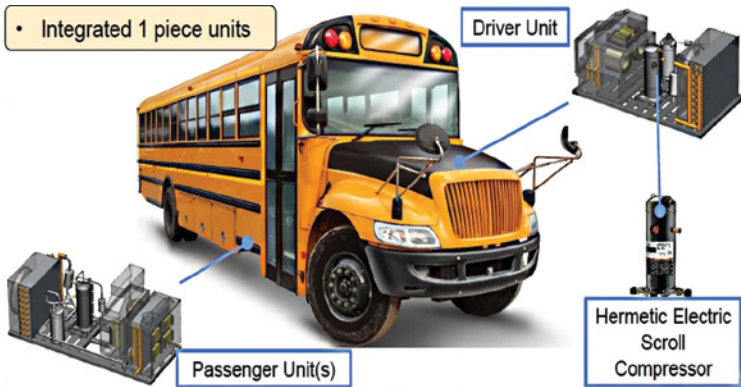
### School bus heat pump project

Schools typically are closed for vacation during the hottest weather months, so bus cabin comfort typically focuses on heat in cold weather, with under-seat and driver/stairwell units. There are geographical exceptions, however, and A/C is used in perhaps 25% of school buses, according to a TMSS presentation by Shawn Vehr of Emerson Climate Technologies. But the need for long refrigerant lines to the rear of the vehicle has been a deterrent to A/C installations. Although diesel-powered school buses are predominant, work is under way to develop electrically-powered buses.

Emerson's proposal is for an all-electric bus using two electric-powered self-contained heat pump assemblies with vapor injection. This would permit year-round use.

According to Vehr, off-vehicle testing indicated a severe loss with PTC heating alone, for an electric bus with a 600-volt, 440 kW-h battery pack, with a projected range of 305 mi/488 km, diminishing to 177 mi/283 km. With a vapor-injected heat pump system, however, the range would be 230-257 mi/368-411 km, he said.

The heat pump was demonstrated to be capable of pulling cabin temperature from a cold soak at 0°F up to 68°F (-18°C to +20°C). It also would meet the NTSB (National Traffic Safety Bureau) standard for hot soak pull-down to 80°F from 100°F (27°C from 38°C) in 30 minutes, though falling slightly short of high-performance cooling standards. ■



Proposed electric school bus by Emerson would use two self-contained heat pump systems, providing cabin comfort year-round.

I-Pace system, with its integrated heat gleaning, can pull up to 4.5 kW, Dutta said. At 0°C (32°F), it can draw 2.5 kW from the electronics/motor system with a collection loss of 0.3 kW, for a net gain of 2.2; and 1.9 kW with a loss of 0.3, for a total of 3.8 kW, he told the TMSS session. Even at -8°C (+18°F), the system can pull a total of 3.5 kW, he added.

The effect of cabin preconditioning, as demonstrated by the Hanon research, is enormous even for the Jaguar I-Pace. Without it, the heat pump saves only 17%; with it, the saving jumps to 83%. And even with the heat pump turned off, the preconditioned car saves 49%.

Range extension on the I-Pace as equipped is an impressive 30-45 km (18-27 mi), in operation from -10°C to 0°C (+14°F to +32°F). Additionally, the I-Pace has an over-the-air software update feature for

CLOCKWISE FROM TOP LEFT: JAGUAR LAND ROVER; EMERSON CLIMATE TECHNOLOGIES; EMERSON CLIMATE TECHNOLOGIES

## SPOTLIGHT: ELECTRONICS

### LED matrix manager



Designers of high-performance automotive matrix lighting and adaptive driving-beam light-emitting diode (LED) applications can now mi-

grate to higher current devices while reducing design size and improving flexibility. The MAX20092 12-switch matrix manager from **Maxim Integrated Products**, Inc. (San Jose, Calif.) provides flexible current management for matrix and pixel lighting. The integrated circuit (IC) minimizes thermal issues associated with LED matrix lighting applications by offering what the company claims is the industry's lowest internal MOSFET drain-source resistance (RDS\_ON). The MAX20092's Low RDS\_ON of 70 mohm safely enables LED current of up to 1.5A. Twelve integrated switches control LEDs in string voltages up to 56 V. The MAX20092 features advanced fault protection and management for open, short and open-trace LED detection. It also offers continued operation through fail-safe mode.

For more information, visit <http://info.hotims.com/73001-400>

### Transceiver series

**Analog Devices**, Inc.'s (Norwood, Mass.) transceiver series enables high-definition (HD) video over existing unshielded twisted-pair cables and unshielded connectors, allowing OEMs to upgrade from standard-definition cam-



eras to HD cameras and provide the resolution and image quality required for today's automotive camera applications. The ADV7990 and ADV7991 transmitters and ADV7380 and ADV7381 receivers use ADI's car camera bus (C2B) technology to enable savings in weight, bulk and cost and reduce cable-routing constraints when compared to other automotive link solutions. The C2B transceivers are defined and designed specifically for automotive applications, which means that along with supporting visual quality over the unshielded infrastructure, care was also taken with on-chip EMC/EMI mitigation techniques enabling full compliance to the rigorous industry mandates for EMC, EMI, and ESD robustness.

For more information, visit <http://info.hotims.com/73001-401>

### Mapless platform

Developer of autonomous vehicle software **Imagry** (Scottsdale,

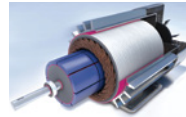


Ariz.) launched the latest version of its mapless platform, which works with commoditized sensors. The software provides an alternative for traditional autonomous-vehicle solutions. Instead of using technology that relies on HD-mapping, Imagry's solution uses a vision-based approach that doesn't require a cloud connection. Imagry's real-time software can identify the road, route, vehicles, obstructions and pedestrians. Its software is trained by a patent-pending simulator that's developed in-house, and it features a proprietary Aleph Zero algorithm that uses physics-based planning to compensate for perception errors in real-time.

For more information, visit <http://info.hotims.com/73001-402>

### Structural adhesive

**DELO**'s (Windach, Germany) DELO MONOPOX HT2860 structural adhesive offers increased



stability at high temperatures, achieving up to three times the strength at a temperature of 150°C (302°C) compared to previous product generations. Suitable for bonding magnets in electric motors used in cars, drilling, milling tools and washing machines, as well as in other applications, DELO MONOPOX HT2860 has a glass transition temperature (T<sub>g</sub>) of 168°C (334°F). As a result, the elasticity (Young's modulus) below T<sub>g</sub> does not change significantly, allowing the adhesive to achieve a very high temperature stability with flexibility only increasing if the temperature rises above 168°C. It is suitable for bonding under high static or dynamic loads.

For more information, visit <http://info.hotims.com/73001-403>

### Positive-displacement pump

The KPP05 Piston Pump from **Kinetics Automation** (Richmond,

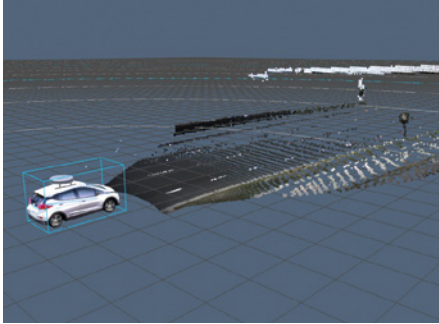


British Columbia, Canada) is a shape memory alloy-based positive displacement pump that uses proprietary Bundled Wire technology to deliver a precision stroke. Driven by the company's KLA05 Linear Actuator, the product requires only AC or DC electrical power to operate and allows for displacement or pressure control when additional sensors are used. This innovative fluid power product offers the functionality of a motor, pump, and proportional valve in a single compact unit. Compatible with a wide range of fluids, the KPP05 Piston Pump provides a high pressure-to-size ratio.

For more information, visit <http://info.hotims.com/73001-404>

SPOTLIGHT: LIDAR & RADAR

**Solid state lidar sensor**



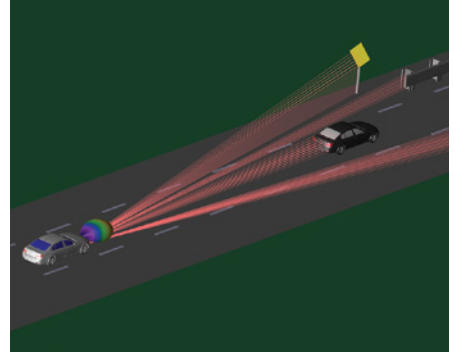
**AEye's** (Pleasanton, Calif.) 300m+ class solid-state lidar sensors achieve scan rates of 100Hz or greater, which the company says is a 10x improvement

over currently-deployed competitive systems which typically scan at 10Hz. The artificial perception platform, iDAR, is designed to mimic the performance of the human visual cortex. This biomimicry enables software-definable search patterns that can be optimized for specific driving situations. iDAR's biomimicry enables autonomous perception engineers to create these situationally-specific scan patterns that can search a scene four to five times faster than the human eye. This scanning speed is matched by spatial coverage that breaks down a scene into Dynamic Vixels, a data type unique to iDAR that combines X,Y,Z and R,G,B data. By finding and locating objects as fast or faster than a human, iDAR enables perception that can intelligently classify and track objects at what the company claims are "unprecedented" rates.

For more information, visit <http://info.hotims.com/73001-405>

**Radar simulation software**

WaveFarer automotive radar simulation software from **Remcom** (State College, Pa.) is used for automotive radar design and placement. It enables OEMs and Tier 1 suppliers to set up



virtual scenarios and refine sensor performance earlier in the design process. WaveFarer uses ray-tracing algorithms specifically adapted for radar applications to predict the scattered returns from a scene, with support for frequencies up to and beyond 79 GHz. Near-field propagation and scattering methods compute raw radar returns from target objects while considering multipath interactions from ground reflections and other structures. The company says drive scenarios and sensor placement locations can be iterated in WaveFarer, reducing the overhead required to build prototypes and improving installed sensor performance. WaveFarer is integrated into Remcom's electromagnetic simulation platform, enabling the program to work seamlessly with XFtd EM Simulation Software.

For more information, visit <http://info.hotims.com/73001-406>



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## e-bike rise, Alta Motors' fall

Thank you for your recent article on Alta Motors. As a NorCal electrical engineer who races MX (still with a combustion-engine bike), Alta was a rising star in our sport. The company was also an inspiration to engineers like me who dream of starting our own companies. It's a shame they couldn't sustain their business—and painful to me because I'd planned on buying one of their bikes for next season.

**Howard Nacato**  
Sunnyvale, Calif.

Just as it looks like electric motorcycles are an upward growth trend, Alta Motors' skid-plate goes upside down! I work at a Harley-Davidson dealer and we've had some techs from Milwaukee visit us about plans to set up e-bike charging, to prepare for the launch of the new Live Wire model(s). One of the visitors was an engineer formerly with an auto company. Please let us know why Alta failed, because there is no hard info about this on the various bike sites. Too bad!

**Jim Freeman**

## Electrify the U.S. Postal fleet!

Regarding your editorial in the Nov.-Dec. issue: From what I've ascertained—or perhaps envisioned to some extent—the idea with the new postal vehicles is to have a favorable spot for a “power module” of some sort, whether a full IC engine, a hybrid variation or a simple battery pack.

While a “city version” vehicle—for a short delivery route with many drop-offs (apartments units) at each actual stop might well be served by batteries as the vehicle might only travel a few miles each day, a “country version” where the stops might be the same in number but each one some distance apart is better served by an actual engine of some sort.

And I think that a more flexible variation of a vehicle that might readily continue to have a very long life is just a good idea. Who knows: Some new magical “power module” may yet come along that is better than anything else available today and could then be readily fitted into place.

**John Fischer**  
Palatine, Illinois

I agree with Lindsay Brooke that the U.S. government should be “walking the walk” to demonstrate to the public that EVs are a viable, everyday means of transportation. What better platform to kick this off than the U.S. Post Office's 100,000-plus fleet of local mail delivery trucks? Yes, there are challenges for heating the interior in winter and cooling it in summer with an EV platform. Okay, let's get to work on that as an industry!

**Manny Rosenfeld**  
South Bend, Indiana

Aside from some thermal-management challenges that would be unique to the postal-delivery duty cycle, the state of electric-vehicle technology has indeed reached the level of being ready to support a large mail-truck fleet operation. I'm glad the SAE editor has brought some much-needed visibility to this discussion.

**S. Khan**  
Toronto

## SAE's new Autonomous Vehicle Engineering

Will SAE please tell me why I am not receiving your new *Autonomous Vehicle Engineering* magazine, with my copy of *Automotive Engineering*? A friend who works at GM in body trim gets both magazines. I work at a supplier that develops autonomous systems for GM but I don't receive the new magazine. What gives?

**Robin Harrison**

*SAE's new Autonomous Vehicle Engineering launched in 2018 as a quarterly supplement to AE. It was sent to a targeted audience of about 25,000. For 2019, AVE moves to a bi-monthly schedule and becomes a stand-alone publication beginning in March. For subscription information, go to [www.SAE.org/publications/magazines/autonomous-vehicle-engineering](http://www.SAE.org/publications/magazines/autonomous-vehicle-engineering).*



**READERS:** Let us know what you think about *Automotive Engineering* magazine. Email the Editor at [Lindsay.Brooke@sae.org](mailto:Lindsay.Brooke@sae.org). We appreciate your comments and reserve the right to edit for brevity.

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**January 16:** Truck & Off-Highway Engineering Technology eNewsletter

**January 23:** Autonomous Vehicle Engineering Technology eNewsletter

**February:** Automotive Engineering Print Magazine

- Special coverage: NAIAS '19, CES'19
- 2019 Vehicle Top Technologies
- Propulsion: ICE, Hybrids, EVs
- Sensors
- Power Electronics & On-board processors spotlights

**February:** Truck & Off-Highway Engineering Print Magazine

- Over-the-Air (OTA) Software Updating
- The Work Truck Show Preview
- Engines & Subsystems: Power Generation/Gensets
- State-of-the-Art Vehicle Testing
- Data Acquisition, Imaging/Cameras, Simulation/Analysis Software spotlights

**February 6:** Automotive Engineering Technology eNewsletter

**February 11:** Truck & Off-Highway Engineering Technology eNewsletter

**February 14:** Vehicle Engineering Technology eNewsletter (all markets)

**February 20:** Automotive Engineering Technology eNewsletter

**February 25:** Autonomous Vehicle Engineering Technology eNewsletter

**March:** Automotive Engineering Print Magazine

- Vehicle Electrification Tech
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## Gearing up drive axle innovations

While electric and robotic cars tend to dominate the mainstream automotive news, **SAE** readers know the huge investments being made to improve “traditional” vehicle technologies—body structures, chassis and driveline systems, lightweight materials—for greater overall efficiencies, improved safety and reduced cost. Tier 1 driveline systems supplier **American Axle & Manufacturing** currently has Quantum, its all-new family of lightweight beam axles with aluminum center housing, in customer evaluations for future light trucks, crossovers and SUVs.

When *AE* learned there’s **NASA** technology inside the Quantum “pumpkin,” we asked Jeffrey Nichols, AAM’s executive director, advanced technology integration, to explain.

### It’s our understanding that the new Quantum drive axle contains some trick aerospace technology, correct?

Architecturally Quantum is different than previous drive axle designs, most of which haven’t changed in over 100 years. Our design makes the drive module much more power-dense and compact. We’re able to achieve these gains because we eliminated a number of components. The traditional tapered roller bearings that you’d see on the pinions and differential are gone. In fact, the bearing races are now integrated with the pinion shaft. The pinion shaft serves multiple purposes.

### Your company’s CTO, Phil Guys, told me in 2017 that Quantum axles have no shims.

That’s right—no shims. No spacers! It’s a net-build environment. The bearings are separated by ‘race dividers.’ We’re leveraging four-point bearing contact, and those bearings are rotating to meet the load requirements on demand. Some NASA bearing technology we studied inspired us to look at axle bearings a bit differently. That opened the space for our team to integrate the components that exist in that same space today.

### At the time AAM was claiming some pretty big efficiency gains for this product.

Quantum has hundreds of thousands of miles that validate our analytical work to prove the technology. We’re hitting our target of up to 1.5% efficiency improvements, versus conventional RDAs [rear

drive axles]. And the mass-reduction numbers—some exceeding 30%, or up to 100 pounds in a full-size pickup due to secondary-mass reductions that Quantum enables—are exciting our customers. The 1.5% improvement is quite significant in terms of vehicle fuel efficiency. And that is low-hanging fruit.

### Do the new bearing technologies also provide NVH benefits?

Yes, the unique bearing arrangement and its four-point contact performance gives us the improved NVH behavior that AAM and our customers are looking for as well. Our testing and customer evaluations have shown Quantum doesn’t have the gear-whine issues of traditional axle designs. Our NVH profile is improved, but the axle itself is ‘transparent.’ At Winter Test, customers got into the vehicles with Quantum and couldn’t hear anything—that’s exactly what we want!

### Can the aluminum center housing also be paired with aluminum tubes for live-axle applications? And does the Quantum design translate to an IRS?

Definitely steel tubes. And yes, the core architecture doesn’t change for independent rear suspensions. The application of split clutches for torque vectoring and biasing, we provide various ways to execute torque transfer. We can include axle-disconnect functionality, too. We’re also engaged with a customer for a Quantum front axle application.

### Thermal management is critical in drive axles. What is AAM’s lubricant for Quantum?

Great question (laughs), but I can’t really get into lube specifics. I can say that it’s very unique and there are additives. We have a strong collaboration with our lubricant partner **Lubrizol**, who have been with us since the beginning of this program. ■

*AAM’s new Quantum Driveline is the winner of the inaugural Lightweighting Innovation Award, sponsored by Ducker Worldwide and announced in late 2018 at the Society of Automotive Analysts (SAA) summit. Quantum’s combination of reduced mass with increased power density and improved NVH performance put it at the top of 15 finalists, according to the award judges.*



Jeffrey Nichols

**Some NASA bearing technology we studied inspired us to look at axle bearings a bit differently.**



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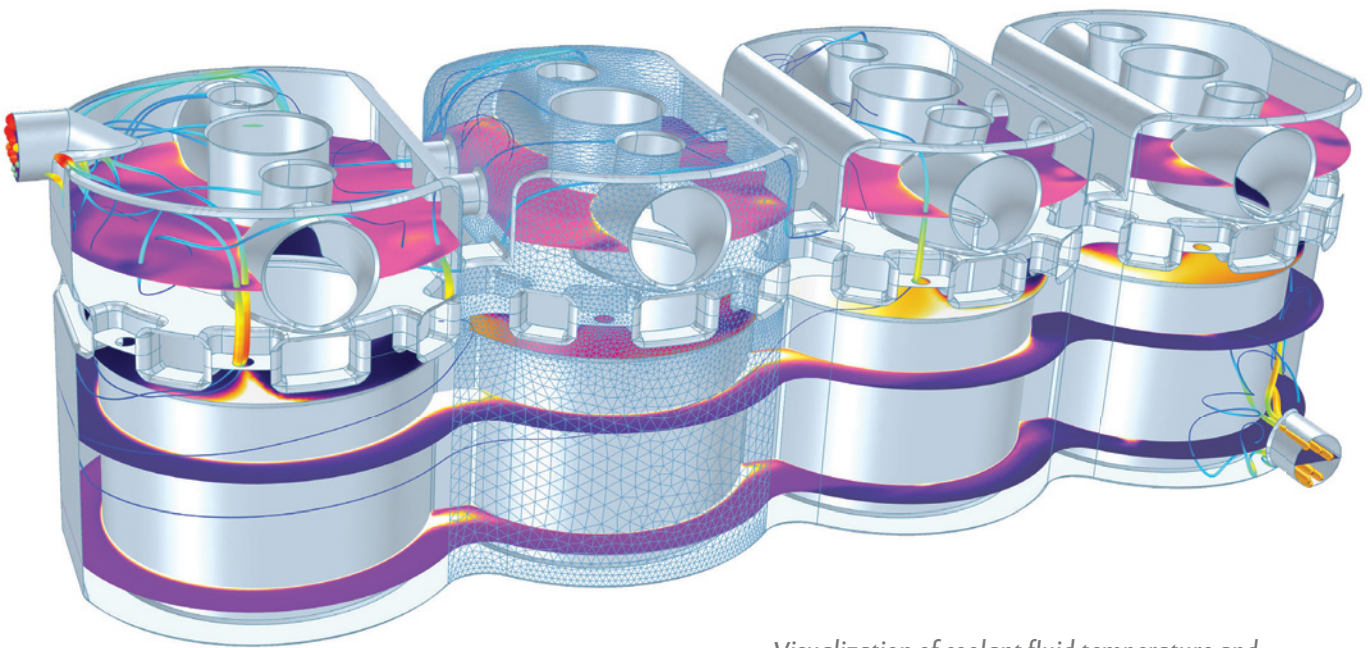
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