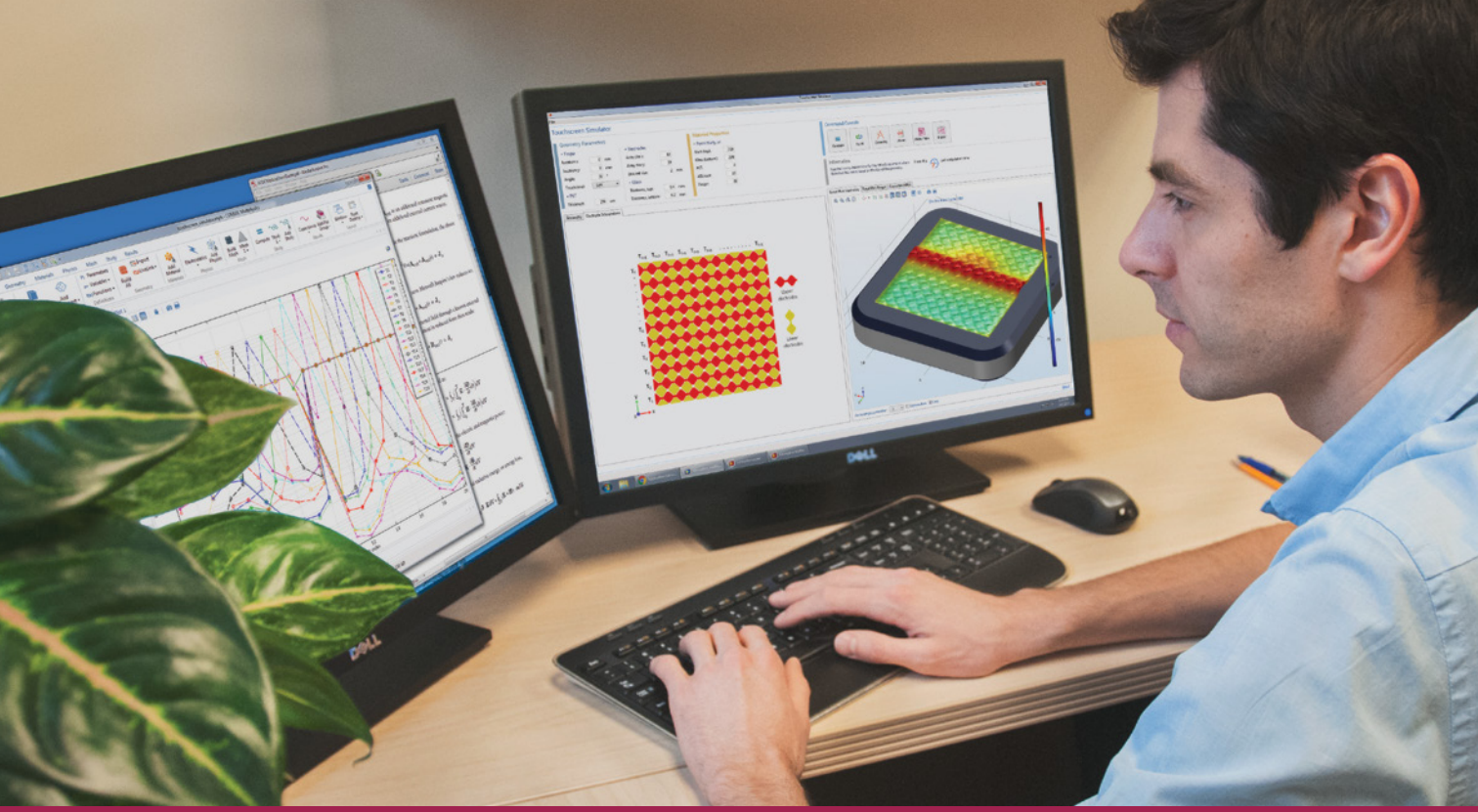

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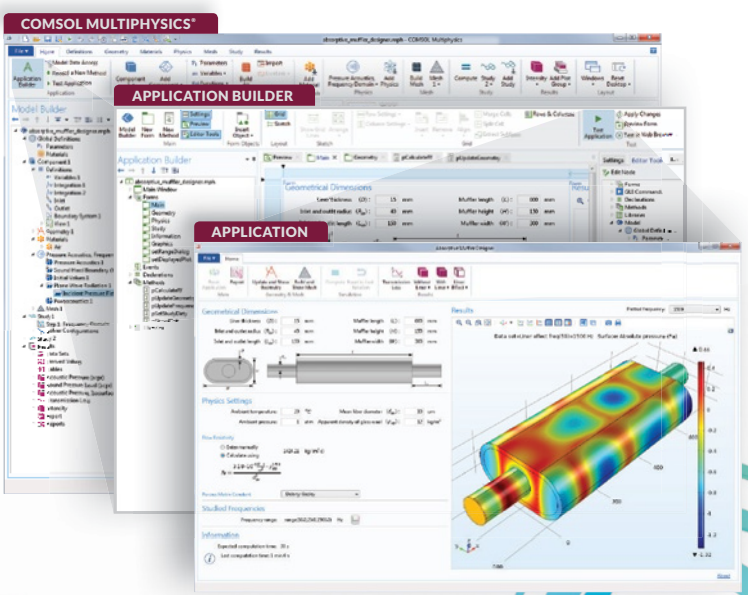

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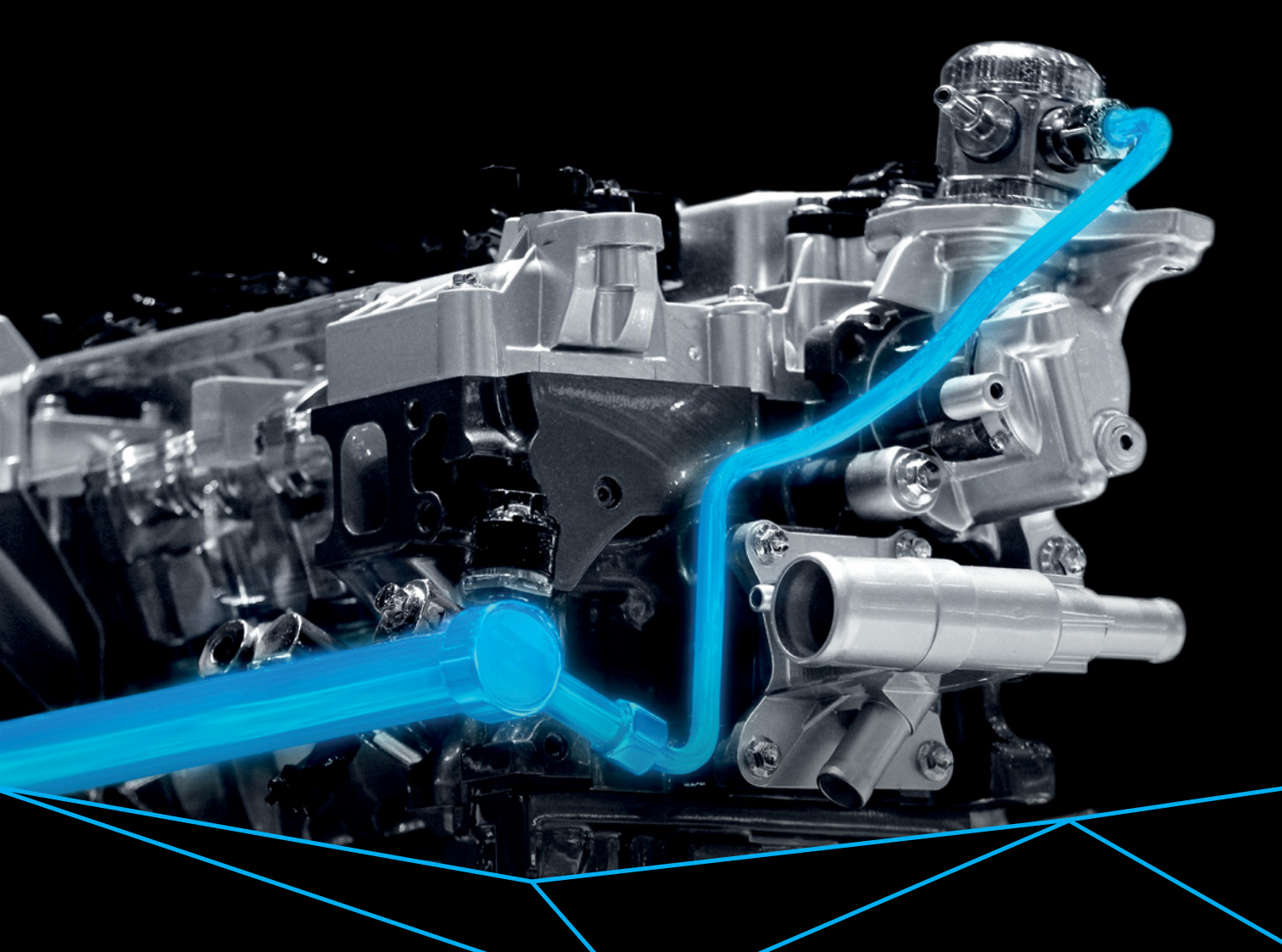

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ON THE COVER

The exquisitely engineered right-side body hinge pillar of the 2017 Cadillac CT6. The large, complex pillar is one of 13 aluminum high-pressure die castings on the car, all of them produced at Magna's Cosma Castings plant in Battle Creek, MI. The single casting replaces 35 parts in a traditional hinge-pillar application, according to GM engineers. Our Lightweighting feature begins on page 18. (Lindsay Brooke image)

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REGULARS

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WHAT'S ONLINE

WEBSITE REDESIGN

Automotive Engineering Website redesigned, upgraded

You'll find an enhanced look, improved functionality, and a host of new features from *Automotive Engineering*'s recently redesigned Website at http://autoengineering.sae.org/.

Automotive Engineering's upgraded Web presence reinforces **SAE International**'s century-old renown for providing highly technical automotive design-and-development content to a professional audience—but now does so regardless of platform. The revised site augments the content enjoyed by print subscribers and provides an engaging gateway to *Automotive Engineering* magazine for Web-only readers.

New Website features incorporate SAE video and podcasts with the magazine's authoritative long- and short-form articles to provide an involving mix of old and new. As always, readers are able to rate and share articles, but the new *Automotive Engineering* Website also sets the stage for planned future innovations to meet the information needs and preferences of an audience captivated by all things technical and automotive.

VIDEO

SAE Eye on Engineering: Connected car growth

24 million cars already have their own wireless connections. But now that most people have smart phones, why would anyone need wireless service in their car? In this episode of SAE Eye on Engineering, Editor-in-Chief Lindsay Brooke looks at three important features of the connected vehicle. The video can be viewed at https://youtu.be/nRzXjo1Gbxs. SAE Eye on Engineering airs in audio-only form Monday mornings on WJR 760 AM Detroit's Paul W. Smith Show. Access archived episodes at www.sae.org/magazines/podcasts.

Most-viewed articles

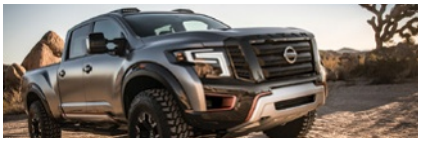
The following are the top 5 most-viewed automotive-related articles of the month as of mid-February. Additional articles across all transportation sectors can be read at http://articles.sae.org/.

1 **2016 Civic structure employs 'first' partial in-die soft zones**
http://articles.sae.org/14449/

2 **3D-printed high-temperature ceramics** http://articles.sae.org/14537/ or see page 16

3 **Plug-in vehicles await better power electronics**
http://articles.sae.org/14519/

4 **Nissan Titan Warrior concept previews a Raptor competitor**
http://articles.sae.org/14562/



5 **Brembo brake-by-wire will be production-ready before 2020**
http://articles.sae.org/14570/

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EDITORIAL

Mainstreaming hybrids and EVs

Will the inefficiency of the automobile ultimately doom the automobile? Big questions like this one, posed by **Ford** Technical Fellow Dr. Michael Tamor, hit February's **SAE** Hybrid & Electric Vehicle Symposium audience between the eyes.

Dr. Tamor's look at greenhouse-gas reduction opportunities beyond 2025 kept returning to a key point: affordability. It was an ideal kickoff to the next two days of insights from engineers and other industry experts who are charged with enhancing HEV, PHEV, and EV battery power density and driveline performance and efficiency—while driving down cost, of course.

During this 13th annual SAE event, I spoke with a number of the presenters about the future of vehicle electrification. Nearly all agreed that in order for their companies to meet the increasingly stringent global CO_2 emission requirements going forward, hybridization must become mainstream technology. Depending on vehicle application, experts see a mix of 12-V, 48-V, and high-voltage solutions. For plug-in vehicles, there must be ubiquitous deployment of SAE Level 2 fast chargers and continued development of wireless charging.

"CO_2 emissions can be reduced significantly if conventionally-powered vehicles are electrified," stated Shingo Kato, who directs electrified systems development at **Honda R&D**. And Mats Olof Andersson, **Volvo** Car Corp.'s Director, Electric Propulsion Systems, asserted that "Hybrids will eventually transform into a 'normal' competitive market."

Realistic or optimistic? Despite regulatory mandates in seven U.S. states requiring 15% of new vehicle sales to be zero-emitting by 2025, the SAE presenters are acutely aware of the headwinds facing the expansion of the market for electrified vehicles. Overall U.S. market penetration dropped from 3.8% to 2.8% during the last two years, according to a 2015 **Boston Consulting Group** study.

Nearly everyone appreciates the drop in U.S. gasoline prices to less than $2.00 per gallon, but the factors that created such a fuel-price windfall for consumers (and strong profits for full-line vehicle manufacturers) clearly impede greater adoption of advanced-propulsion solutions.

Cost-slashing progress has been made, but the industry still has a long way to go in order to mitigate the $3800 to $6000 price premiums currently burdening HEVs (and the $12,000 premium on EVs):

- Cell cost for a power battery has dropped from an average of $700/cell in 2009, to approximately $150 today. Experts estimate cell cost will drop to $100 by 2025.
- Battery cost at the pack level is expected to decline from approximately $250 per kW·h today to $180 per kW·h by 2025. Engineers say chopping price to less than $180 will be challenging—and markedly more scale is needed.
- At the retail level, there is a perceived misalignment of sales focus regarding HEV/EV and non-electrified products: many auto dealers still need deeper understanding of, and commitment to, electrified vehicle sales. Meanwhile, leasing has become vital to this segment—48% of **Chevrolet** Volts are leased, a hefty 79% of **Nissan** Leafs, 64% of Ford's C-Max Energi, and 88% of **BMW**'s i3. Experts expect this trend to continue.

Commonality of systems design and engineering is critical to cutting cost. As SAE presenter Tim Grewe explains in this month's Q&A (see page 44), his **General Motors** colleagues set out to make the drive systems of the 2016 Chevrolet Malibu Hybrid and second-gen Volt as common as possible. The two systems share all but five components.

Perhaps the strongest response to Dr. Tamor's opening question comes from the industry re-engineering its development approach for electrified products. GM's recent name change of its powertrain engineering group, now called **GM Global Propulsion** systems, reflects the rapid expansion beyond traditional drivetrains into alternative energy systems—and new business models.

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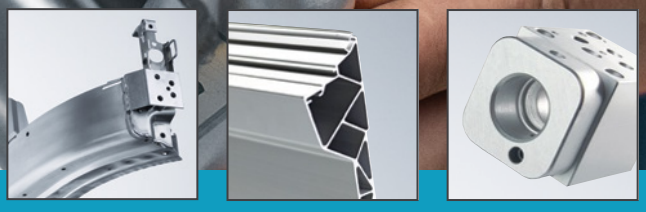

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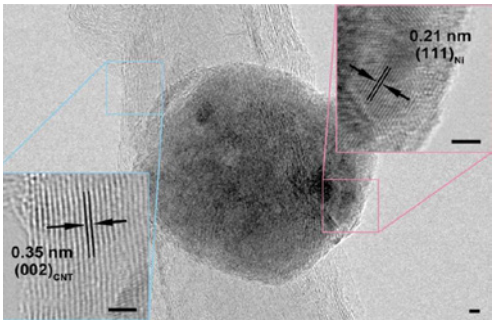
Rethinking the route to lower-cost fuel cells



This transmission electron microscope image shows a new platinum-free fuel cell catalyst that Yan's team developed.

New fuel cell-powered cars and SUVs from **Toyota**, **Honda**, **Hyundai**, and **Mercedes-Benz** are capturing plenty of publicity on this year's auto show circuit. But the first commercial models are expensive, in part because their fuel cell stacks use costly platinum catalysts to speed the key power-producing chemical reactions.

"The level of platinum use in fuel cells has come down ten-fold in the last 20 years," observed Yushan Yan, chemical engineering professor at the **University of Delaware** in Newark, "but I have a feeling that the platinum level will stay where it is for some time to come."

Yan is skeptical that current fuel cell technology can become truly affordable. About a decade ago he and his colleagues turned away from current proton exchange membrane (PEM) fuel cells in favor of a type that needs no platinum at all.

Acid versus base

When William Grove invented the principle of the fuel cell in 1839, he used sulfuric acid as the electrolyte. But it took another 100 years for the alternative—the alkaline, or basic, fuel cell—to be developed. The alkaline fuel cell used KOH, or potassium hydroxide, as its electrolyte. Yan noted that the reactions of both types are similar at a high level—oxygen reduces on the positive electrode, and the hydrogen oxidizes on the negative electrode.

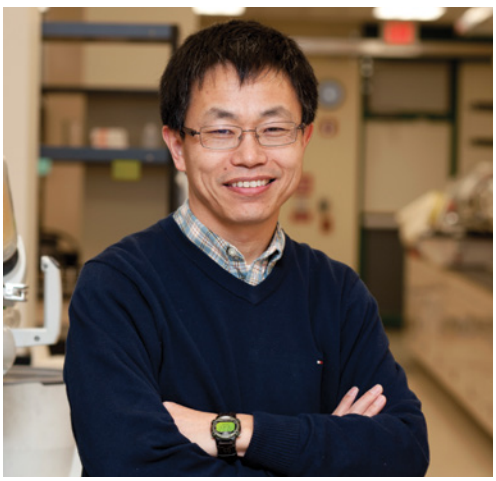
"But when you write down the chemical reaction with the charge-carrying ions, it's different because you use an OH- instead of an H+," he said.

In the 1990s when the auto industry focused development on PEM hydrogen fuel cells, there wasn't much concern about their extremely corrosive, acidic operating environment. The main issue was the other key component, the membrane that passes protons (H+) between the two electrodes.The ready availability of **DuPont**'s Nafion semi-permeable polymer film was the game-changer, despite it looking like ordinary plastic kitchen wrap.

Though the fluorinated polymer membrane was itself premium-priced, researchers "felt like that was it; they never wanted to work with other technologies," Yan recalled. Rather than settle on Nafion, he and his group at Delaware bet that their hydroxide (OH-) exchange membrane fuel cell concept can offer high performance at an unprecedented low cost.

Opting for the high end of the pH range has an advantage: it enables replacement of platinum catalysts with cheaper metals like nickel or silver, Yan explained. "A basic operating environment is better," he said, "because many catalytic metals are much more stable, while everything dissolves in acid, including platinum."

Yan's team recently published an account of their work on a hydroxide exchange membrane fuel cell that uses a prototype low-cost nickel-based catalyst for the hydrogen oxidation reaction at the anode. (See www.nature.com, January 14.) The composite catalyst, which features nickel nanoparticles that are supported on nitrogen-doped carbon nanotubes, exhibits levels of hydrogen oxidation activity similar to



Professsor Yushan Yan's research team at the University of Delaware has long worked to develop a lower-cost alternative to conventional PEM fuel cells for automotive use.

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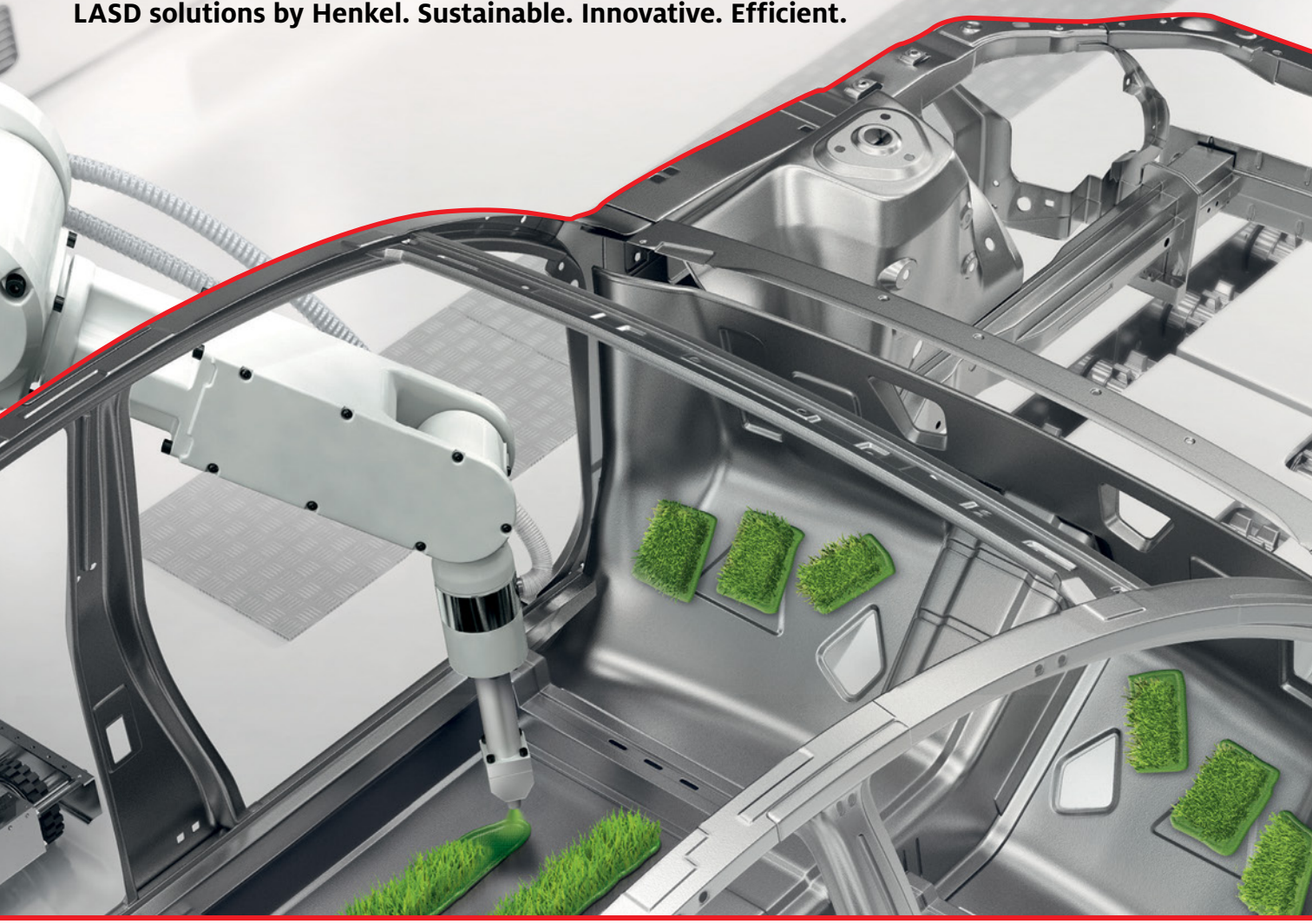

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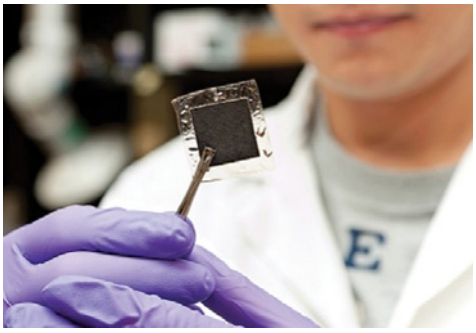


Several years ago Yan's University of Delaware team developed an efficient hydroxide exchange membrane for fuel cells.

those of platinum-group metals in an alkaline electrolyte.

The key remaining issue to address in the catalyst is the comparative slowness of the alkaline reaction compared to its acidic platinum counterpart. "It's a problem; the reaction occurs 100 times slower in basic conditions," Yan noted, "but we have our ideas about how we can get the catalyst to do what we want. Still, it's probably a couple of years away."

Basic membrane challenges Nafion

Several years ago the Delaware group developed a "Nafion-equivalent" membrane for its alkaline fuel cell, a thin polymer membrane that does for hydroxide ions what Nafion does for protons. "We have a good handle on the hydroxide exchange membrane," Yan asserted.

Technically, the prototype membrane is classified as "an efficient silver-phosphonium ionomer interface." Using a quaternary phosphonium-functionalized polymer yields a material that is less susceptible to swelling with water while providing excellent hydroxide exchange membrane fuel cell performance. According to Yan, the material is a nanoscale patchwork of hydrophobic domains abutting hydrophilic water channels; it is via these tiny passages that hydroxide ions come streaming through.

The new membrane technology would also be cheaper because it would replace the PEM's high-priced fluorinated polymer membrane with a cheaper hydrocarbon material, another boost to economic viability.

"Our real hope is that we can put hydroxide exchange membrane fuel cells into cars and make them truly affordable—maybe $23,000 for a Toyota Mirai," Yan speculated. "Once the cars themselves are more affordable, that will drive development of the infrastructure to support the hydrogen economy."

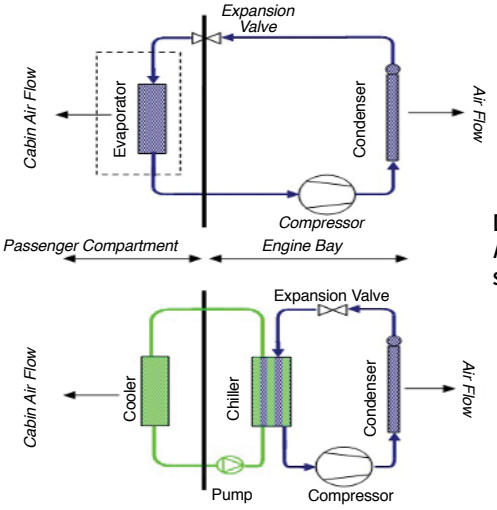
Yan recounted with amusement how he and his team's contrary R&D path somehow passed measure with Steven Chu, the **U.S. Department of Energy** Secretary and notorious fuel-cell skeptic, in 2009 and 2010. Despite a hard-eyed evaluation, Chu green-lighted Yan's group for funding.

If it wasn't the result of sheer spite on the part of the Nobel Prize-winning physicist, perhaps it was the sheer audacity of building a new kind of fuel cell that impressed the Secretary, because it was one of only a few grants that Chu ever provided for hydrogen fuel cell technology.

Steven Ashley

INTERIORS

Secondary loop and heat pump climate control under evaluation once more



Direct expansion A/C (top) vs. secondary loop.

Is secondary loop climate control about to make an engineering splash? It got a close look for A/C when the industry was considering low-global-warming alternatives to R-134a, because it permitted confining a system using a refrigerant with safety/environmental issues to a safe underhood area. But once R-1234yf was seen as a safe albeit mildly-flammable choice, usable with under-dash circulation in a direct expansion cycle with existing technology, secondary loop went into mothballs. However, at the recent **SAE** Thermal Management Systems Symposium (TMSS) it was once again identified as a promising alternative.

Direct expansion vaporizes the liquid refrigerant in the under-dash heat exchanger—the evaporator—a single heat exchange loop. A carefully packaged secondary loop allows safe use of R-152a, a low-cost, low-global-warming, modestly more flammable refrigerant.

However, secondary loop requires an additional heat exchange circuit—from the refrigerant to an underhood coolant chiller circulating water and antifreeze mixture into an under-dash heat exchanger for cabin climate control. The second circuit reduces overall system efficiency somewhat, of course. So why would it be worth a new look?

Heat pump, thermal storage

Essentially reversing the refrigeration cycle (using control valves) allows the compressor to operate as a heat pump, both for electric vehicles (EVs) and fuel-powered cars. If the system—A/C only or with heat pump circuitry—is a secondary loop, there are potential fuel-economy benefits with an idle stop system. The secondary loop is effectively "engine-off" liquid thermal storage and can provide long periods of cabin comfort.

According to a study presented at TMSS by the Department of Mechanical Engineering of the **University of Maryland**, the

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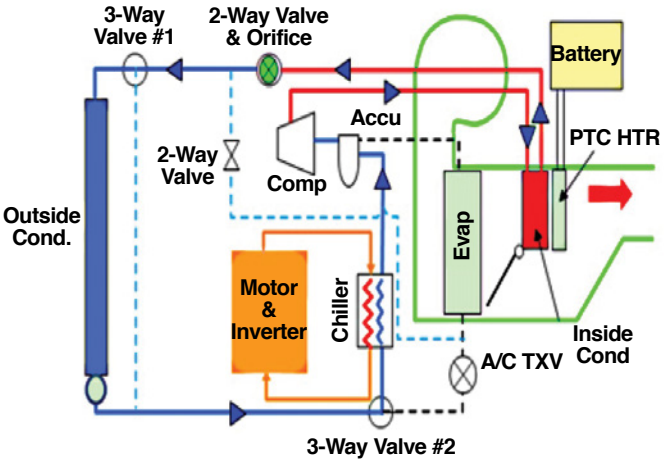

Kia Soul EV's switching valves bypass evaporator and direct hot liquid refrigerant through under-dash inside condenser.

engine-off A/C cooling storage from secondary loop can be sized to exceed 10 minutes. Developing a system for thermal storage of heat for an EV is an obvious area for study, and research in that area reportedly will begin when funding, perhaps from a UN agency, becomes available.

The use of a water-antifreeze secondary loop also simplifies the plumbing in vehicles with rear HVAC. Instead of high-pressure refrigerant lines, the system can use lower-cost heater-like lines and hoses.

Because the greatest gains are in A/C, a team of researchers looked at large population areas where the climate includes a long cooling season. India, the example chosen, has winter temperatures of 20-25°C (68-77°F) in the mainland southeast, and long hot and humid warm seasons. By taking this geographic example, it could be seen if an optimized secondary loop A/C system could match or exceed the efficiency of a direct expansion system.

The question and accompanying research was presented at TMSS by Sangeet Kapoor and Prasanna Nagarhalli of **Tata Motors**, and Timothy Craig and Mark Zima of **Mahle**'s **Delphi Thermal**. They worked with refrigerant scientist James Baker and Dr. Stephen Andersen, retired **EPA** climate issues executive and now research director of IGSD (Institute for Governance and Sustainable Development), a non-governmental organization.

Refrigerant savings

Secondary loop is tough to package, adding a refrigerant-to-coolant heat exchanger/chiller, the pump to circulate the coolant, and extra piping. However, there is a 20% reduction in refrigerant, which results in a significant cost saving if it's R-1234yf. Using R-152a, because it is very low in cost, saves even more. The coolant mixture used was 30% antifreeze, 70% purified water, chosen for heat transfer efficiency.

A dynamometer test program looked at COP (Coefficient of Performance) for the secondary loop, running it through a complete Federal Test Procedure (FTP) at 28°C (82°F), the New European Drive Cycle (NEDC) at 28°C and an SCO3 cycle, the supplemental EPA cycle for A/C operation, which is run at 33°C (91°F).

The tests were run with (1) no A/C, (2) continuous A/C with the cabin soaked to ambient temperature, (3) with the A/C compressor disengaged at idle, and (4) on acceleration. Although there was a modest improvement with the compressor stopped at idle, the combination with the disconnect-on-acceleration, taking greater advantage of the inherent thermal storage, produced dramatic fuel-economy improvements on all three cycles. The numbers: 6.5% on the FTP, 11.5% on the NEDC, and 12.5% on the SCO3.

R-152a has a global warming number below 150, so it is lower than international regulatory limits. Although this is higher than R-1234yf's under 10, unlike R-1234yf it does not produce TFA (trifluoroacetic acid, a plant growth inhibitor) as a degradation product, although currently not regulated.

The compressor with a circuit reversal to operate as a heat pump, providing heat for the passenger compartment, is superior in a secondary loop because it also provides engine/EV-off heat from the thermal storage. Even a half-way step—heat pump in a direct expansion system—has demonstrated value for an electric drive vehicle, where conventional electric heating (resistance or Positive Temperature Coefficient) can sharply reduce winter driving range. The heat pump is much more efficient than conventional heating.

Nissan, Kia EVs

Both the **Nissan** Leaf and **Kia** Soul EV offer direct expansion heat pump systems, presently using R-134a systems like the companies' gasoline-engine cars, but with R-1234yf on the horizon. There is a baby step into secondary loop: a water-antifreeze chiller circuit for cooling EV electronics, and Kia estimates a 27% improvement from the heat pump in electrical heating efficiency over the winter temperature range.

Conventional (resistance and Positive Temperature Coefficient) heating has a major effect on EV range in winter. A study with various sizes of cars, reported at TMSS by Dr. Gregor Homann of **Volkswagen** AG and Prof. Jurgen Kohler of the **University of Brunswick**, showed a loss of 20-50% with conventional electric heating. The greatest drop, not surprisingly, was suffered by the smallest vehicle, which has the smallest battery pack, in testing at -7°C (+19°F).

Heat pumps have a positive COP in ambient temperatures starting from above -15 to -18°C (0 to +5°F). They approach 2.8-3.5 at 10°C (50°F), the COP depending on refrigerant used and pump design. So although the heat pump makes a significantly positive contribution at moderately cold temperatures, in really cold weather conventional electric heating still is needed.

The heat pump might draw heat from warmer sources than ambient air, such as EV electronics, motor, and the battery pack. But these would require packaging a sophisticated ducting system and can make only minor contributions, if any, at low ambient temperatures. In many areas, however, the ambient temperatures during heating seasons are sufficiently high to make the heat pump a valuable addition for both EVs and even many fuel-powered vehicles.

Paul Weissler

www.dspace.com

Virtual Test Drives for Everyone

Test driver assistance functions on your own PC

The challenge: Test scenarios not available

Validating ECU functions in realistic test scenarios during the early stages of development is becoming a more common practice. Simple unit tests do not provide enough coverage anymore, especially for safety-critical driver assistance functions which, by nature, are networked with many other systems. In cases like this, function developers must test the functions' interaction with other control algorithms closed-loop with complex environment models.

The advantages: VEOS for virtual test drives

- Use your own PC for closed-loop tests of ADAS functions
- Reuse plant and environment models
- Use models and automated tests seamlessly throughout all development phases
- Support of Simulink® , TargetLink® , legacy C code, AUTOSAR, and FMI

The idea: Virtual test drives

The pragmatic approach takes the environment simulation models that already exist for ECU testing and reuses them on the developer PC. dSPACE VEOS® is the bridge between these two worlds. It lets function developers perform virtual tests of functions whenever they want to so that they can easily test many different environment scenarios. This holds the number of real test drives at an affordable level. It also makes reproducing virtual test drives much easier, which is useful for checking a corrected function. VEOS also includes established error analysis methods such as debugging and code coverage, which are not possible in real test drives. If function developers do not have access to the environment models, they can use the dSPACE models that cover many ADAS areas.

One example: Developing complex intersection assistant functions

Performing automated tests of intersection assistance functions on a hardware-in-the-loop simulator involves constructing many test scenarios that describe the exact traffic situations (the course of the road, how many traffic participants there are, what the roadside looks like, etc.) to test all the participating ECUs in detail. With VEOS, function developers can take the relevant function algorithms that were developed in Simulink or AUTOSAR and simulate them in interaction with these environment models. VEOS provides them the same features for visualization, simulation control, and automated tests as a HIL simulator.

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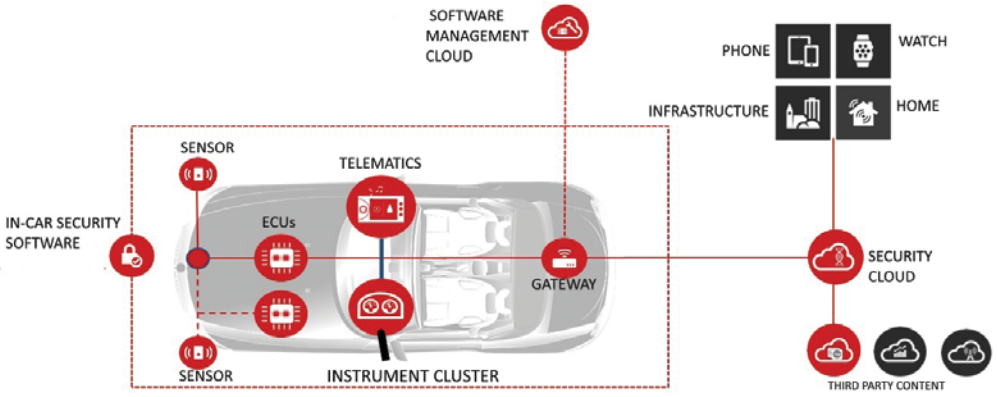
ELECTRONICS

OTA reflashing: the challenges and solutions



OTA reflashing for complex automotive computer systems requires software lifecycle management cloud, communication through secure cloud with a gateway and on-car electronics, plus smartphones and watches, smart home and infrastructure, and third party content.

Reprogrammable onboard modules have been in automotive use for more than a quarter century. But as electronic controls inhabit virtually every system today, anyone with a late-model vehicle knows that at some point, one or more of its electronic control systems will need to be "reflashed" with new software—often more than once.

In fact, even where the problem may be all-mechanical, including bearing knock, it can be ameliorated by new software for the engine computer.

While some of the reflashes are for customer satisfaction items, such as the air conditioning system that won't maintain set temperature, an increasing number are safety related. At best, perhaps 70% of the urgent notifications of a safety recall bring the customer into the dealership, and both government and industry are looking for ways to bring it as close to 100% as possible.

With autonomous driving on the horizon, the security and safety aspects create a new urgency for the ability to perform updates on a timeline that doesn't wait for the leisurely pace of a service appointment at the dealership.

Tesla success with OTA

Tesla's recent use of over-the-air (OTA) reprogramming has been successful, but this emergent OEM has a comparatively small owner base and that makes vehicle identification a simpler task. The typical Tesla reflash takes 45 minutes, but because the vehicles are electric drive, they can be reprogrammed during a recharge. Vehicles powered by gasoline and diesel engines face the more difficult issue of assessing battery state of charge to ensure it is high enough to complete the reflash.

Some automotive reflashes require so much time (perhaps more than a day) that presently the only way they can be made is with the car in a shop, using a proprietary factory tool or an SAE J2534 "Pass-Thru." Such reprogramming also includes use of a dedicated battery charger made for the specific purpose, so it produces a "clean" current flow that is free of electrical noise ("ripple") that could cause the operation to fail.

Because the carmakers are responsible for updates, they may start to install capacitors to smooth out the ripples from the charging system, making OTAs more feasible.

A related factor is available bandwidth, which could be subject to considerable change over a cellular network. That's why Tesla recommends its updates be performed with WiFi. Additionally, the OEM would have to design updates for piecemeal reflashing, so they can be installed incrementally as the system and needed battery capacity are available.

This issue goes beyond the need of a single module. Many updates are lengthy because of the design of the data bus in which it is installed. The update itself may apply for just the one module, but other modules on the bus may need to know about it, whether because there are new messages they must recognize, or know to ignore.

All suppliers of infotainment/onboard communications and WiFi are working with car makers to develop systems with OTA reprogramming function comparable to Tesla, but the larger and more diverse the vehicle base, the more complex the task. There have been reports that several makers will begin to do some OTA this year.

Security is No. 1 issue

Russ Christensen, Director of Automotive Solutions Architecture for **Wind River**, a systems supplier in this area, said the No. 1 issue has become security. It begins at each end (the source of the update at one, likely a cloud server, and the car's infotainment system at the other) so each is talking to a known authority. In the car that authority usually would be the telematics/gateway module.

The key to security is in the architecture, he said, telling *Automotive Engineering* that presently such appendages as the smartphone and watch, and keyless entry, hitherto not so considered, can be "threat vectors" into the car. He added that the CAN bus (Controller Area Network) was not designed for encryption, although there are some strategies for accomplishing that.

Also required is a way to get an authenticated payload (the updated software) to the car and having an electronic

"place" to hold it, Christensen said. A manifest comes down with all updates; the car says okay, a signature comes from the cloud and the car validates it. The first update is then discharged to the ECU. Which raises this issue: if the installation fails, the system needs to be able to activate a "restore" function to get the system back to original setting.

If there are three updates in the manifest, and the failure occurs during the third, there may need to be a removal function, so the system reflashes back to the original state.

"None of this is hard," Christensen noted. "We just need the vehicle design to be able to do it." He cited the example of an "atomic update," where all updates must be installed at once or none should be.

Bypassing owner OK

Christensen cited banking industry money transfers as an example of the way installations must be executed with secure protocols, where a scheduled data transfer must be completed instantaneously, or the entire transaction goes back to its previous state.

When there is an urgent safety update, the comparatively slow pace that includes owner evaluation and approval may need a work-around. There might have to be a provision for abrogating authorization, although that would be a last resort for an OEM.

Presently, reflashing is done in the auto repair shop, either with a proprietary factory tool or increasingly as shown, with an SAE J2534 "Pass-Thru" and a PC, using OE software.

A critical aspect of the entire challenge of OTA updating is identifying the vehicle configuration. Many OEMs right now do not have software configuration matrixes at a sufficient level of confidence to always be certain of the right software for all vehicles.

"The manufacturer can't even rely on the VIN once the car has left the assembly line," Christensen said, and certainly not if a module has been replaced.

Paul Weissler

MATERIALS

3D-printed high-temperature ceramics

Researchers fabricated a ceramic fuel cell microlattice using a novel additive manufacturing process that was developed at HRL.

Heat-resistant ceramics are useful for making components such as engine hot parts, rocket nozzles, and nose cones that have to contend with high temperatures or extreme environments. The trouble is it's not at all easy to cast or machine these heat-stable engineering ceramics into the necessary complex shapes.

In recent years, 3D-printing processes have been developed that enable much greater geometrical flexibility in fabricating ceramics. But whether the process deposits photosensitive resins that contain ceramic particles, jets binders onto ceramic particles, or fuses beds of ceramic powder with lasers, current additive manufacturing (AM) methods are limited by slow fabrication rates. Plus, they are often followed by a time-consuming binder-removal process. In any case, the physical properties of the final components are not optimal, yielding unreliable, low-strength parts that suffer from residual porosity, cracks, and/or inhomogeneities.

A new AM technique developed at **HRL Laboratories**, an R&D lab in Malibu, CA, that is jointly owned by **General Motors** and **Boeing**, has demonstrated the ability to make high-strength ceramic components featuring complex geometries more easily and rapidly. HRL's Senior Chemical Engineer Zak Eckel and Senior Chemist Chaoyin Zhou have invented a polymer resin formulation that can be 3D-printed into green parts with complex geometries and then fired in a furnace where they pyrolyze with uniform shrinkage into high-density ceramics.

"With our new 3D-printing process we can take full advantage of the many desirable properties of this silicon oxycarbide ceramic, including high hardness, strength, and temperature capability as well as resistance to abrasion and corrosion," said HRL program manager Tobias Schaedler when the new technology was unveiled. Such cellular ceramic materials are of interest for the core of lightweight, load-bearing ceramic sandwich panels for high-temperature applications—for example, in hypersonic vehicles and jet engines.

Printing preceramic monomers

"We go straight from printing the preceramic polymer to fully dense parts," Eckel said. "The first method is stereolithography, where we solidify, polymerize a special ultraviolet (UV) curable preceramic resin and a UV photo initiator with a laser to form complex shapes, but this still takes hours or even days."

That's why the HRL team focused as well on a home-grown technique that produces green parts much more quickly in larger volumes. As part of a decade-long **DARPA** contract to develop lightweight, high-strength materials, he explained, researchers had developed a way "to funnel the UV light all the way down to the bottom" of the precursor resin tank, allowing much faster builds.

The trick is to solidify material by shining a UV lamp simultaneously through the holes in a lithographic mask while at the same time collimating the light within the illuminated shafts to harden all the way to the bottom. In this "self-propagating photopolymer waveguide method" the light penetrates via a waveguide effect based on successive downward reflections off the internal surfaces of the resin column. This process has created uniquely lightweight but strong truss structures, for instance.

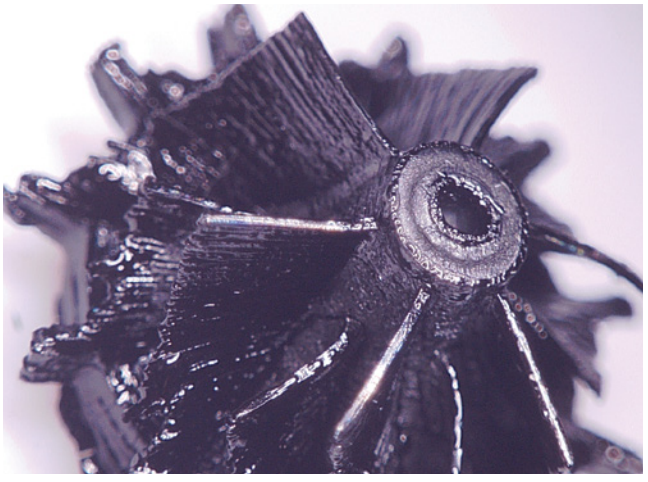
"We produced an ultralight nickel microlattice that for awhile was the world's lightest material; now it's the world's lightest metal material."

Multiple ceramic recipes

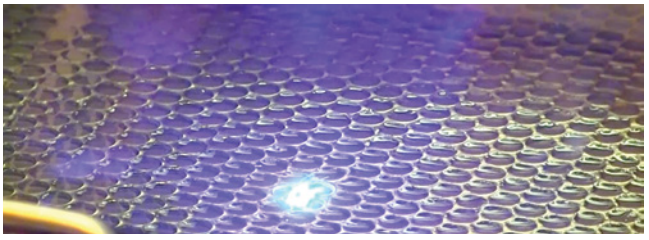
Today they're applying the alternative additive fabrication technique to high-temperature ceramic components.

Both UV hardening processes can ultimately produce many different ceramic materials, but for a start the team has demonstrated a silicon oxycarbide ceramic shaped into an intricately porous, lightweight structure that can withstand ultrahigh temperatures in excess of 1700°C (3092°F) and exhibits strength ten times higher than similar cellular ceramic materials, Eckel said.

"Technically, the amorphous glass microstructure is sort of



HRL researchers 3D-printed the precursor for a high-temperature ceramic impeller and then fired it to full density.



The ultraviolet laser of a stereolithography machine starts solidifying the photo-curable preceramic polymer liquid.

a hybrid of glass and carbides; at the nanoscale it's segregated into tiny silicon oxide regions surrounded by graphite layers," he explained.

"We're leveraging a certain special chemistry here," Eckel continued. "Preceramic polymers and polymer-derived ceramics are pretty common. This class of materials was first developed in the 1960s."

When heat treated to 1000°C (1832°F) under an inert atmosphere such as argon, they pyrolyze, forming many ceramic compounds including silicon carbide, silicon nitride, boron nitride, aluminum nitride, and various carbonitrides. At the same time, volatile chemical species such as methane, hydrogen, carbon dioxide, water, and hydrocarbons "cook off," leaving the mostly densified, shrunken-down ceramic shape behind.

By attaching various organic molecular groups to an inorganic silicon- or carbon-based backbone such as a siloxane, silazane, or carbosilane, the research team can formulate the UV-active pre-ceramic monomers that crosslink strongly when suitably illuminated.

Uniform shrinkage

In the test reported in their paper, "Additive Manufacturing of Polymer Derived Ceramics" in the January 1st issue of *Science* magazine, the silicon oxycarbide precursor pattern experienced a substantial 42% mass loss and 30% linear shrinkage during conversion in the furnace. But the team described the shrinkage as "remarkably uniform," almost like the storied shrunken heads of South Sea headhunters of yore, the relative proportions of the shrunken objects' features remain the same.

The NRL team has used the ceramic fab technology to produce thin-element truss structures—demoing multiple microstructures, honeycombs, re-entrant honeycombs—that exhibit surprising degrees of flexibility. They've also built everything from corkscrews to rocket nozzles, missile nose cones, gas turbine engine blades, and micro impellers.

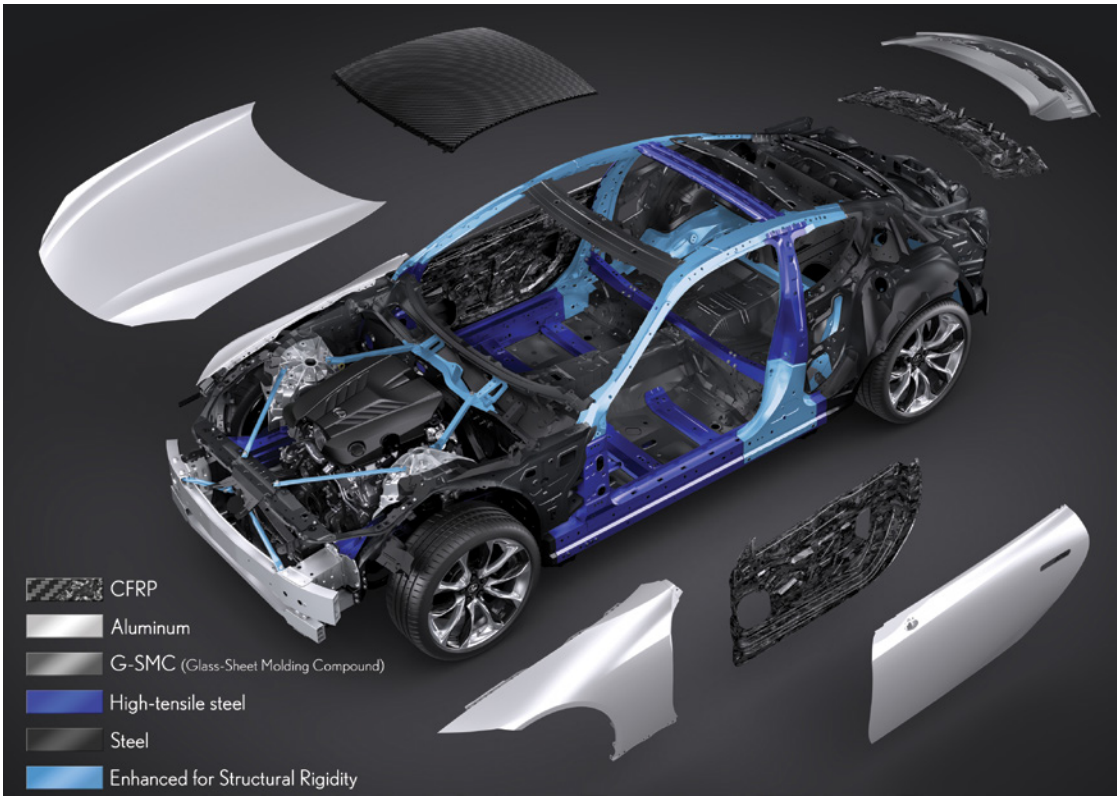
Additive manufacturing of such polymer-derived ceramic materials is not only of interest for propulsion components for jet engines and hypersonic vehicles, but thermal protection systems, porous burners, microelectromechanical systems, and electronic device packaging as well. HRL said that it is looking for a commercialization partner for this technology.

Steven Ashley

Multi-material structures move mpg upward

The quest to improve fuel economy is not waning, nor is the desire to achieve higher mpg through the use of just the right lightweight material for the right vehicle application.

by Ryan Gehm



Lexus opted for a multi-material approach for its 2018 LC 500 luxury coupe.

Multi-material vehicles are nothing new. Aluminum, plastics, and other "exotic" materials have long joined steel in the material mix of road-going cars and trucks, notably in powertrain and interior components as well as certain body applications like hoods and liftgates. But in recent years, application areas for so-called alternative lightweight materials have expanded as automakers and major suppliers look to gain even grams wherever they can.

Lexus offered a great example of this multi-material approach at the recent North American International Auto Show (NAIAS) in Detroit, with the reveal of its 2018 LC 500 luxury coupe. High-strength steels, aluminum, and carbon fiber converge to account for a mass reduction of 100 kg (220 lb), according to Chief Engineer Koji Sato.

"Mass management measures" include an available carbon fiber roof, aluminum door skins mounted to a carbon-fiber door inner structure, and a composite trunk floor. The LC 500 also represents the brand's most intensive use of high-strength steel to date. (Read more about the LC 500 at http://articles.sae.org/14565/.)

"Drivetrain technology alone cannot meet these [fuel economy] numbers. Lightweighting is really a dramatic lever our customers can pull with regard to meeting these standards," said John Thomas, Global Marketing Manager for **Alcoa**'s Automotive Rolled Products, during an Advanced Materials/Lightweighting session at the recent **SAE** Government/Industry Meeting.

"Engineers are pulling on aluminum very strongly, predominantly over other solutions with regard to lightweighting, along with other multi-material solutions," Thomas continued. "The days of a single type of material for an automotive product are gone; it's a multi-material world."

Alcoa claims its new "disruptive technology," called Micromill, will allow automotive parts to be twice as formable and 30% lighter than those made from high-strength steel. The continuous-rolling process "is the fastest, most productive system right now in the world for making aluminum in sheet form," Thomas claimed.

Several Micromill parts are featured on the **Ford** F-150, and its use on Ford vehicles is expected to double from 2016 to 2017. Alcoa has qualification agreements with 12 OEMs on three continents, he noted.

Parts already provided for stamping trials include hood outer and inner, tunnel pan, and a wheel well—products that customers have formed in their production dies with Micromill material.

"There's no limit on what you can make with it with regard to automotive structures," including Class A surfaces and high-formability areas like door inners, said Thomas. (Read more about Micromill in the April 2015 issue of *Automotive Engineering*.)

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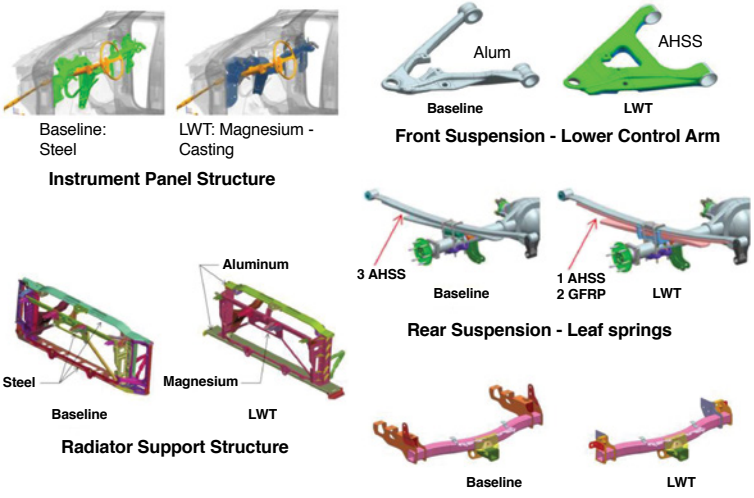


Many vehicle systems in the NHTSA-funded lightweighting project moved away from steel to aluminum or magnesium, but AHSS beat out aluminum for the front suspension's lower control arm.

"Steel can be considered its own multi-material solution because of its large range of performance capabilities," said Roger Newport, CEO of **AK Steel**.

Reinforcing that notion, AK Steel's Vice President of Research & Innovation Eric Petersen noted that in the year 2000 there were roughly 100 grades of steel, and now there are about 200. "Now [with third-generation steels] you can take something that's over 40% elongation with the strength of 1200 MPa, and it completely opens up the design perspective for automotive engineers," he said.

Third-generation steels combine the strength of advanced (AHSS) and ultra-high strength (UHSS) steels with enhanced formability. Gen3 grades are starting to appear in today's cars and trucks, and **Steel Market Development Institute** (SMDI) estimates indicate Gen3 steels will capture roughly 10% of the automotive market by 2020.

"If you want to say anywhere is more competitive [with alternative materials] it's the chassis and suspension area because of the very aggressive atmosphere and some of the durability requirements on a long-term basis," said David Anderson, Senior Director, Automotive Market Long Products Program, SMDI. "But we've recently provided three steel solutions that equaled the weight of a benchmark aluminum forged lower control arm, for example. In fact, **GM** is now using a steel clamshell design—the new Malibu went from an aluminum to steel lower control arm."

Bernhard Hoffmann, Vice President of Engineering and Product Development for Automotive Solutions at **United States Steel** Corp., said, "I do believe that [the industry] will be multi-material because some of the aluminum and magnesium in certain applications make more sense [due to a specific part's] functional objectives. But the primary body structure we think will remain very much steel-dominant."

Lightweight pickup for 2025

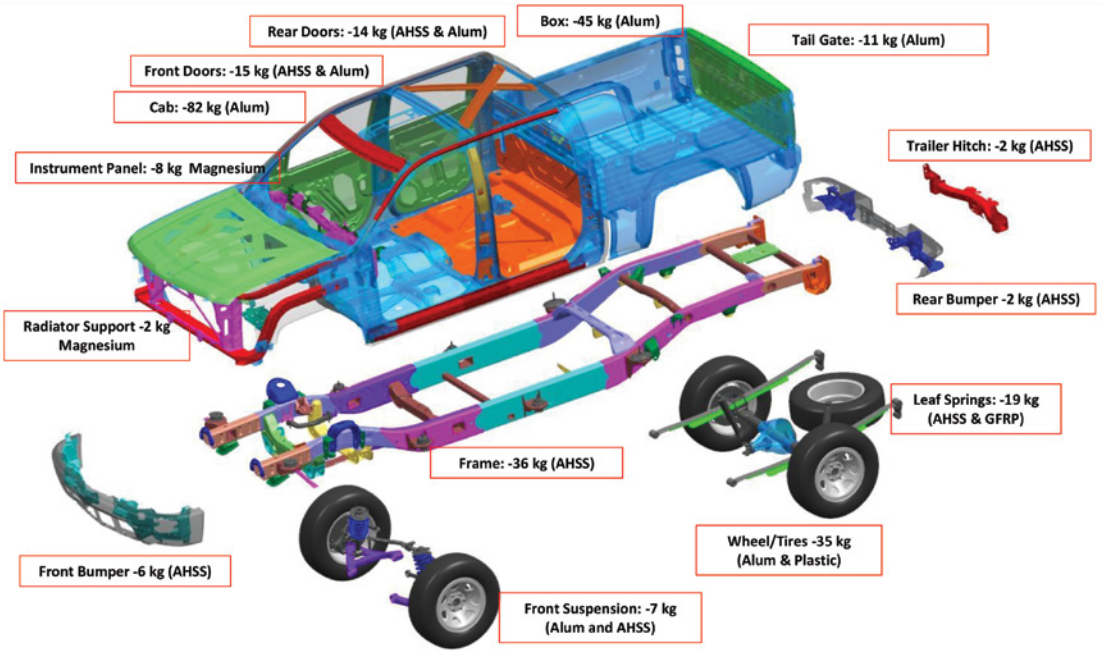
A recent **NHTSA**-funded (U.S. National Highway Traffic Safety Administration) lightweighting project set out to answer, "How much mass reduction is feasible for a 2025 model year light-duty truck? A multi-material approach was taken, with nearly every component of the baseline 2014 **Chevrolet** Silverado 1500 examined to determine the optimum material and design for that application. The 2014 Silverado makes extensive use of AHSS and was 150 lb (68 kg) lighter than the previous model.

Stipulations for the project were that cost could be no higher than 10% of current baseline's MSRP (i.e., $3,805 for 2014 Silverado, equivalent to $2,625 increase in manufacturing cost), vehicle performance and functionality had to be maintained, and all recommended technologies had to be suitable for 200,000 annual production by 2022.

During the materials and manufacturing technology assessment, researchers picked technologies that they classified as mature or mid-term—currently suitable for up to 50,000 units/year—for the lightweight design, said Harry Singh, Director for Lightweighting Vehicle Projects at **EDAG** Inc., who provided an update on the two-year-long NHTSA project at the SAE Government/Industry Meeting.

"We split the vehicle up into 36 systems, and we looked at each system [individually]," he said. For the cab structure, for example, four options were considered: AHSS, aluminum, AHSS + aluminum, and composites (carbon fiber). The team decided on aluminum, with some steel reinforcements, because of 100-kg (220-lb) mass savings with a cost increase of $7.44/kg saved. That compares to an estimated 53-kg (117-lb) mass savings for AHSS, with a cost increase of $2.37/kg. A carbon-fiber cab structure saved 122 kg (269 lb) but at a premium of $27.19/kg.

"For the frame, the design of the mounts and the cross members is a little bit different. The best choice was to stick with steel but use some more up-to-date, higher-strength steel grades," Singh shared. "For the doors, we thought the best option is to keep the steel on the inner panels where you get most of the



Mass savings for the lightweight truck design using new materials compared to the baseline 2014 Silverado 1500. (NHTSA)

strength from, but make the outer panels aluminum."

Composites find application in the rear suspension, with two glass-fiber-reinforced plastic (GFRP) leaf springs.

The engine could be downsized from 5.3-L to 5.0-L while maintaining performance as a result of the weight reduction—in turn allowing even more mass savings.

Preliminary findings (the report was still under peer review at time of presentation) show a mass savings of 17%, or 408 kg (900 lb), for the complete lightweight truck—2024 kg (4462 lb) vs. the baseline's 2432 kg (5362 lb). This was achieved at an incremental manufacturing cost increase of $1531, or $3.75/kg of mass saving.

Not considering the mass and cost reduction allowance for the powertrain, the mass savings for the "glider" is 20%, or 359 kg (791 lb), at a cost premium of $4.40/kg saved.

"If we apply these techniques to the fleet, we feel everything that we're recommending is doable," he concluded.

Multi-material decklid concept

Continental Structural Plastics (CSP) has developed a concept decklid that incorporates its TCA Ultra Lite material for the outer panel with a carbon fiber RTM (resin transfer molded) inner panel. The decklid weighs 12.11 lb (5.5 kg), a 13% weight savings compared to a similar decklid made from aluminum, according to the supplier.

The decklid concept is the result of a collaboration by the CSP R&D teams in Auburn Hills, MI, and Pouance, France. Contributing partners included **Owens Corning**, **Compose Tooling Expert**, **Altair Engineering**, **PPE**, **Hexion**, and **Brandolph**. It was developed as part of a study to compare the weight of decklids made from steel or aluminum versus a multi-material approach.

"This concept offers OEMs an affordable lightweight solution for body panels to help them achieve new CO_2 emissions regulations," said Philippe Bonte, President of CSP's European operations. How affordable? Bonte says the concept is "price competitive" with aluminum.

CSP's concept decklid uses TCA Ultra Lite for the outer panel with a carbon fiber RTM inner panel for a 13% weight savings vs. a similar decklid made of aluminum.

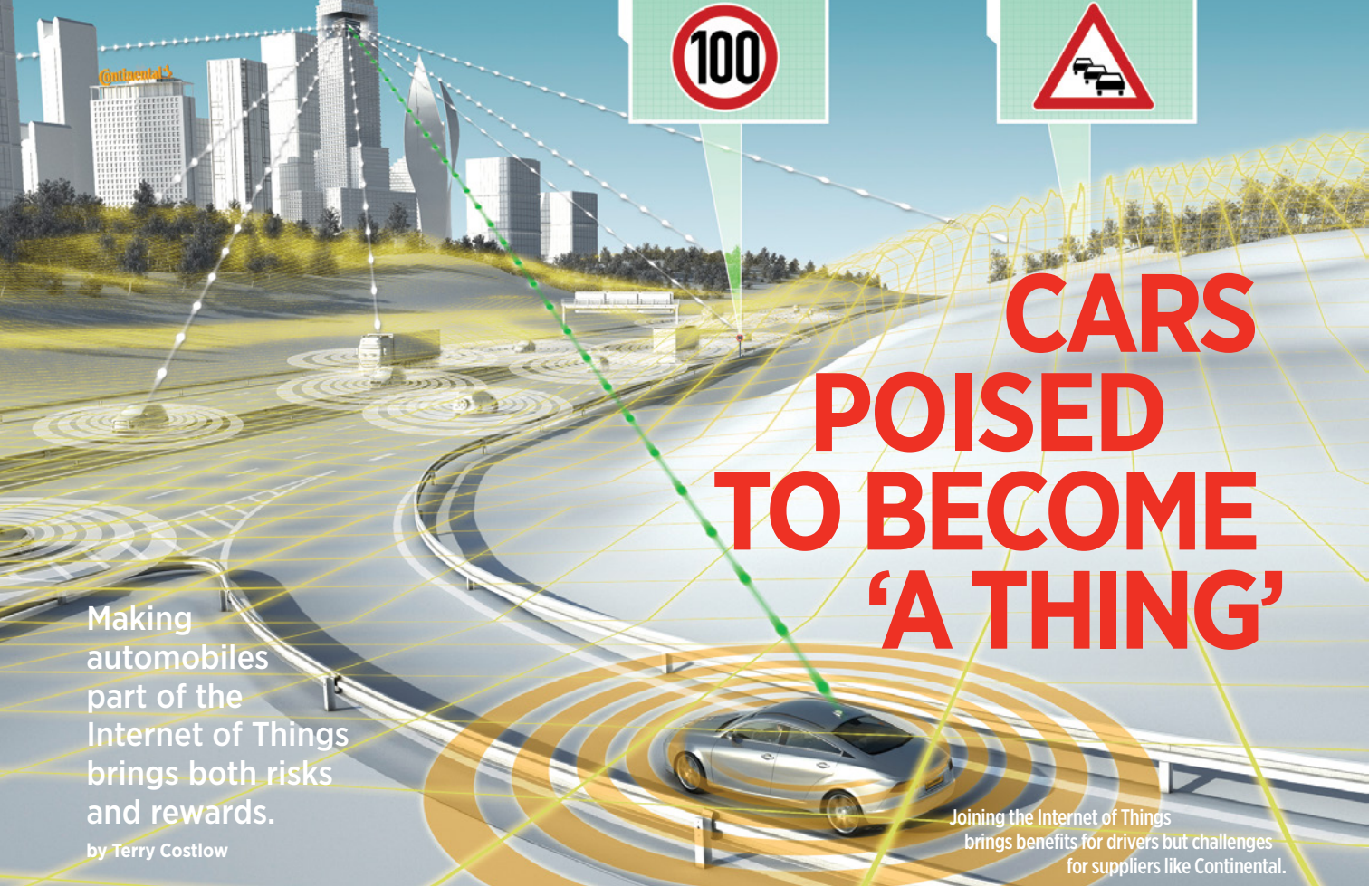
Simulation tools and advanced software allowed CSP to finalize this development in less than 16 months "from design to the first good part out of the production tool," Bonte told *Automotive Engineering*.

CSP claims "a number of breakthroughs" in the use of recycled carbon fiber materials for the structural inner component. Using preformed carbon fiber mats infused with a Hexion fast-cure, epoxy-based resin enabled the companies to reduce the cycle time associated with high carbon fiber content RTM. From injection time to cure to completion, the total cycle time for this component is 2.5 to 3 minutes. Traditional cycle time using the RTM process is 20 to 30 minutes, according to Bonte.

"We have now demonstrated the possibility to mold in less than 3 minutes a large part (decklid inner) that weighs just over 2 kg," Bonte shared. "Among many challenges [in the program], one has been to successfully impregnate a complex carbon-fiber preformed mat in less than 20 seconds. This was solved through the development of a high performance resin system, an intelligent part and tool engineering design, as well as significant process improvements using high pressure RTM technology (C-RTM)."

"The combination of our TCA Ultra Lite outer and CF RTM inner is suitable for most automotive closures applications—decklids, hoods, roofs, and doors," Bonte said. "The technology can also apply to structural applications such as load floors."

TCA (Tough Class A) Ultra Lite is currently used for 21 body panel assemblies on the Chevrolet C7 Corvette. It is a 1.2 specific gravity SMC formulation that can offer up to 40% weight savings compared to standard density composite materials. ■



CARS POISED TO BECOME 'A THING'

Making automobiles part of the Internet of Things brings both risks and rewards.

by Terry Costlow

Joining the Internet of Things brings benefits for drivers but challenges for suppliers like Continental.

The Internet of Things (IoT) will be the next transformational aspect of connectivity, enabling machines to communicate with each other without human intervention. Autos are becoming a major player in the IoT era, talking to cloud computers and potentially to other vehicles.

IoT connectivity requires automakers to adopt common standards and rely on independent service suppliers. This openness brings significant benefits—but also risks.

"While the benefits of the connected car are undeniable—enabling features like cloud-based services, downloadable apps, integration with personal devices of consumers, and vehicle data analytics—unwanted intrusions are becoming a growing concern as hackers have an increasing number of entry points into the car," said Alon Atsmon, Vice President of Technology Strategy at **Harman**.

The high bandwidth of 4G LTE has made it practical for cars to communicate even in rush-hour traffic when cell phone usage is high. Many information technology suppliers are gearing up to support vehicles and machines that will all have phone numbers or URLs. This trend's already well underway.

"At the end of 2014, in the US, there were 355 million wireless subscriptions with a population in the US of 320 million," said Joe Averkamp, Senior Director of Technology and Technical Strategy at **Xerox**. "There are more cell phones in use than people, meaning machines, including vehicles, are connected."

Monthly costs may be one gating factor for automotive's links to the Web. OEMs may not offer free connections for a vehicle's lifetime, and consumers won't pay for vehicle connections unless they perceive value. Cellular providers are already creating plans for machines, which typically don't send huge amounts of data.

"Machine-to-machine plans are typically used for smart-home power meters, home security systems, and other IoT types of functions," said Robert Gee, Head of Product Management, Software & Connected Solutions at **Continental** Automotive. "These plans are also suitable for remote vehicle services such as remote vehicle status like diagnostics, location tracking, or remote door unlock. The automotive industry would certainly benefit from low-cost plans."

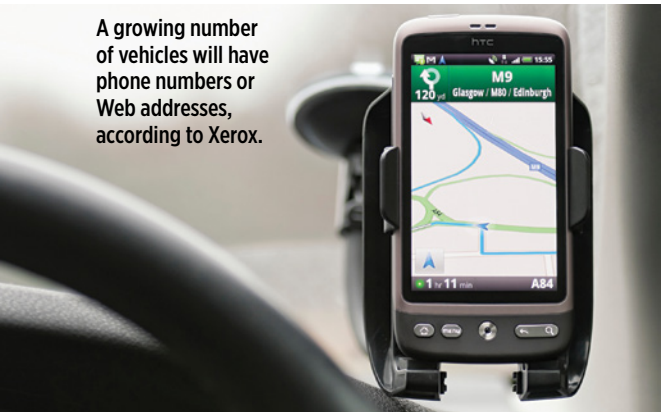
The connected-car era is still in its infancy, but the transportation industry is already a leader in machine-to-machine communications. Many commercial vehicles already utilize the Web.

"Automotive is at the forefront of IoT," said Scott Frank, Marketing Vice President at **Airbiquity**. "There's a high level of network connectivity for service delivery and increasingly to take data from the car. There's also a lot of activity in vehicle fleets."

Bright outlook

The cloud may eventually become a principal factor for many vehicle features and functions. Activities as diverse as voice control, infotainment and safety can be improved by leveraging the vast capabilities of remote servers.

"The cloud and connectivity can be leveraged to enable services that would not be possible on the vehicle systems standalone," said Michael O'Shea, CEO of **Abalta** Technologies. "Take natural language processing.



A growing number of vehicles will have phone numbers or Web addresses, according to Xerox.


Automakers are already working with Airbiquity and others to add functions and access the cloud.

This is much more effective when done on the cloud where vast computing resources can be leveraged. Similarly, we can take advantage of huge content databases to enable users to consume virtually unlimited content, such as music, on demand."

IoT connectivity will eventually play a major role in both the push to autonomous driving and the drive for more infotainment options. Cloud services can offload many functions so on-vehicle electronics can focus on real-time computing.

"The in-vehicle head unit cannot manage everything, it has limited capabilities," said Pradeep Seetharam, Director of Programs at **Excelfore**. "Non-latency sensitive decisions like slowing down the vehicle for an upcoming intersection can be made in the cloud. Moreover, for older vehicles with connectivity, more services can be added, like updating navigation and providing location-based services."

Many observers believe clouds and connectivity will reduce the need for dedicated vehicle-to-vehicle (V2V) communications. These links can provide many low-latency benefits, which can improve safety during the long startup cycle that will occur if or when regulators mandate V2V technology.

"V2V is a huge requirement," said Shrikant Acharya, Excelfore's CTO. "Consumers want safety that can be delivered through V2V. But V2V does not have a critical-mass of deployment. By integrating with web services, most V2V can be delivered now."

Seeking transformers

The Web's transformative nature will alter many aspects of vehicle design and usage. Human-machine interfaces (HMIs) will have to evolve, service providers will gain a major role and some business relationships will have to be revised.

Knocking back hacks

Automakers are hoping to accomplish something that's vexed leading corporations and government agencies: prevent hackers from breaking through their security walls. Some developers are going outside the vehicle to add more layers to defense schemes.

Design teams are attempting to bake security into every aspect of electronic controls, from concept stage through over-the-air updates that occur over the vehicle's lifetime, in order to prevent a seemingly endless list of potential troubles that could occur if hackers figured out how to take control of vehicle electronics.

The cloud and cellphones are being enabled with technologies like firewalls, secure operating systems and encryption. Some vendors want to communicate with the cloud to ensure that some instructions are from authorized sources.

"The vehicle should never act on an unexpected, unsolicited external request such as unlocking doors," said Robert Gee, Head of Product Management, Software & Connected Solutions at **Continental** Automotive. "Instead, the vehicle should receive a request for action, it should establish secure communication with a known server before identifying the requested action. Another safeguard is to store only necessary information in the vehicle. For example, credit card and other personal data may be stored on a secure server, not in the vehicle if it is not needed there."

Others propose using two steps to verify user identities. Cellphones could be used to reduce the chance of intrusions.

"When entering the vehicle, the vehicle will interrogate the user's cellphone to confirm who the user is and then allow access to the vehicle systems and the user data," said Joe Averkamp, Senior Director of Technology and Technical Strategy at **Xerox**. "In this way, a user's information cannot be compromised unless the hacker can get access and control of both the vehicle and the user's cellphone."

Cellphones can also be used to bring some level of connectivity to cars that don't have built-in modems. Tighter links between phones and cars can bring drivers a broad range of options.

"Abalta's SmartLink, which is used to enable vehicle connectivity via the cell phone for unconnected cars, can enable a completely secure encrypted data link from the vehicle to the cloud using industry-standard secure connections," said Michael O'Shea, CEO of **Abalta** Technologies. "A secure, unhackable link can be maintained between the vehicle and the head unit as long as the phone is used as a gateway. If however, the phone is used as a temporary repository for data to be later transferred to the cloud or to the vehicle, or if the phone controls the vehicle in some way, it can be compromised."

Terry Costlow

CARS POISED TO BECOME 'A THING'

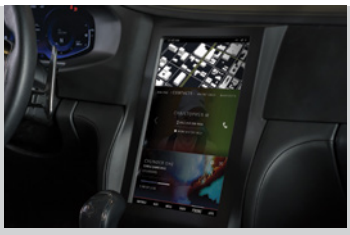
Keeping eyes on the road

Connectivity brings myriad benefits, but it also heightens concern about driver distraction. The challenges of minimizing driver distraction become more acute when smartphone screens are duplicated on center-stack displays.

When telematic links bring information into vehicles, drivers' attention can be diverted by information deemed helpful as well as by the many smartphone apps designed to entertain consumers. Automakers are using Android Auto, **Apple** CarPlay, MirrorLink and **Ford**'s SmartDeviceLink to duplicate phone displays on vehicle screens. That will make it difficult to prevent drivers from using apps that aren't designed for safe driving.

"There's always a risk that something will be distracting if it's projected from a portable device," said Andrew Poliak, Global Business Development Director for **QNX** Software Systems. "That raises the questions of who's responsible and who's liable. Some projection modes present big questions."

There are techniques that only allow approved apps to run on vehicle screens. Many proponents feel this will minimize distraction while giving passengers free rein.



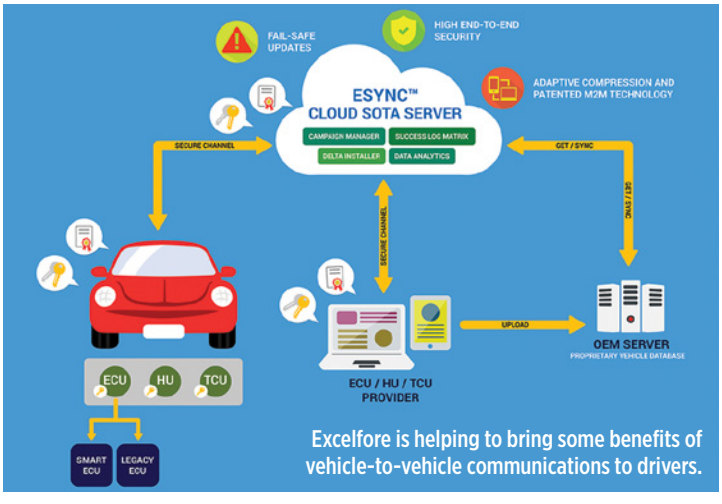
Duplicating cellphone screens on vehicle displays may distract drivers. (QNX)

"Technology exists both in vehicles and on other devices, for example programs on many office computers, that can be used to enable only approved functions," said Robert Gee, Head of Product Management, Software & Connected Solutions at **Continental** Automotive. "It will be important to allow unrestricted web surfing and application usage only for those vehicle occupants who are not involved in driving tasks."

Others feel that it will be difficult to prevent drivers and creative app writers from engaging in potentially distracting tasks. That may force the industry to alter human-machine interfaces to accommodate connectivity without sacrificing safety.

"It will not be possible to prevent drivers from conducting searches; at least on their smartphones, this will likely be unavoidable," said Joe Averkamp, Senior Director of Technology and Technical Strategy at **Xerox**. "For searches and other web-based work like seeking entertainment utilizing in-vehicle systems, the key is to provide larger displays, fewer icons, and less-complicated command structures. The system should rely on more audible information, for example e-mail using text-to-speech or speech-to-text."

Terry Costlow



Excelfore is helping to bring some benefits of vehicle-to-vehicle communications to drivers.

"Automakers used to put together a bill of materials, then when the vehicle was sold, responsibility transferred to the dealer," Frank said. "Now when a connected car is sold, the automaker can maintain a relationship with the customer without competing with the dealer. They can leverage that to enhance vehicle performance and service recalls and other software issues."

Data management will also become a major issue. Automakers will be able to gather volumes of information from vehicles, collecting usage data that can be mined for further research. Automakers and drivers alike will be able to use data that moves through the cloud.

"Connecting to the cloud lets you use data from a ginormous sensor," said Andrew Poliak, Global Business Development Director for **QNX** Software Systems. "It also makes it easy to send data back to the OEM and other services. Everything does need to be done with protections for privacy."

Privacy and security are critical aspects of any Web-related technology. In automotive, those factors are complicated by the need to provide HMIs that help drivers remain focused on safety.

"First, security over-the-air must be established via appropriate encryption and certification," Gee said. "Second, the server system itself must be secure in case the functions provided are driving-related. And third, the cloud-based service itself must be designed with all of the other HMI elements and functions in mind that will be in the vehicle, in order to reduce driver workload and enable safe usage."

Web-based standards are helping automakers alter display imagery so users can customize some aspects of the HMI. These standards make it easier for engineers to adjust visual elements, showing drivers information that suits driving conditions.

"With HTML5, you can easily change the look and feel; an older person who wants big buttons or only a couple radio stations can easily change things," Poliak said. "It's also easier to alter the HMI as speed changes, showing some things at low speeds and different things at higher speeds."

Showing this type of contextual information is also a key to reducing driver distraction. As more driving-related data comes from the cloud, user interfaces are being revamped to make sure information is easy to understand.

"Cognitive overload has a lot to do with how information is presented," Frank said. "As services get more data-intensive, you need to present data in a way that's digestible. That will require changes to the HMI. You don't want to give the driver three options, you want to offer the best one." ■

AGILITY TRAINING FOR CARS

The 2016 BMW 7 Series adjusts its Bilstein Damptronic dampers using information about upcoming road conditions from its GPS navigation system.

Chassis component suppliers refine vehicle dynamics at the high end and entry level with four-wheel steering and adaptive damping.

by Dan Carney

As personal mobility moves toward the perhaps inevitable singularity of automatically piloted pods able to totally isolate passengers from any sensation of the surrounding world, today's manually piloted cars are adding systems to aid with guidance and improve isolation from bumps in the road.

The 2016 **BMW** 7 Series not only features computer-steered rear wheels that assist the driver, but its GPS system uses data on road surfaces to tune the response of the car's air suspension system.

BMW calls this Active Comfort Drive with Road Preview. The system matches the driver's style with a database of the upcoming road surface to firm the suspension when necessary and soften it when possible.

"Exceptional driving dynamics has always been one of the main reasons customers buy this car," observed Klaus Fröhlich, BMW board of management member responsible for development. "That is why the new BMW 7 Series offers such a versatile driving experience, from absolute comfort to extremely sporty."

For 2016, the company switched to a faster-acting air suspension in place of the previous hydraulic active dampers to optimize the capability of Road Preview. It also added active anti-roll bars that disconnect when driving in a straight line for maximum compliance, then reconnect when the steering wheel turns. "Its sensitive control guarantees optimum road handling at all times," promised Fröhlich.

The 7 Series' air suspension system also contributes to the car's active ride height, which automatically lowers the car when driving in Sport mode. The driver can also manually raise the car 20 mm (0.8 in) when for example entering steep driveways. It automatically returns to normal height when the car reaches 22 mph (35 km/h).

BMW replaced the previous planetary variable steering device with a variable-ratio steering rack that now works with all-wheel-drive models, unlike the old system. The computer-controlled rear steering system helps by improving steering response when agility is called for and by slowing it down for stability at other times.

Performance applications

Of course, the goal of active suspension isn't always isolation. The **Porsche** 911 and **Nissan** GT-R Nismo use **Bilstein**'s Damptronic active dampers to give their cars maximum performance, contributing to the GT-R's achievement of a 7:08.69 lap time of the Nurburgring.

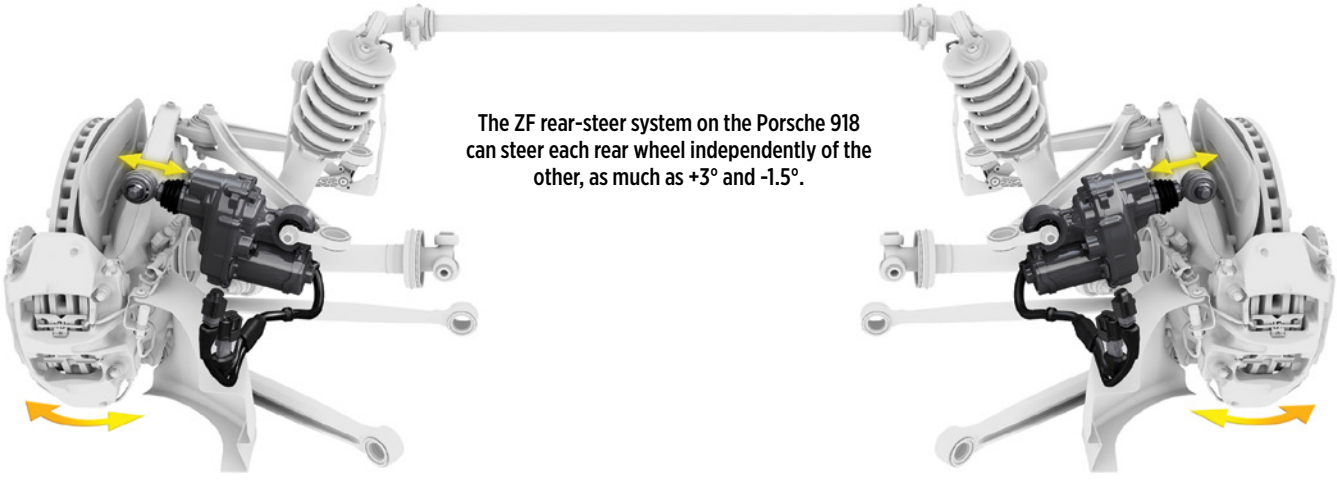
Porsche uses a **ZF**-supplied all-wheel steering system in addition to active suspension to optimize the dynamics of the 911. This is important, as the latest iteration of the car rolls on a wheelbase that is 100 mm (3.9 in) longer than before, which could reduce its nimbleness in turns. Porsche credits the rear-steer system with shaving three seconds off the Nurburgring lap time of the 911 Turbo.

A company technical paper describes the system's function in detail, explaining Porsche's rear-steer system controls each of the rear wheels individually, rather than steering them together in parallel, as with the front wheels.

It uses two electromechanical actuators installed where the toe control arms would normally go. The

AGILITY TRAINING FOR CARS

The Porsche 918's ride and handling benefit from both Bilstein active damping and ZF rear-wheel steering technology.



The ZF rear-steer system on the Porsche 918 can steer each rear wheel independently of the other, as much as +3° and -1.5°.

actuators use an electric motor to turn a spindle through a belt drive to a maximum of +2 or +3° (depending on the exact model) to -1.5°. For comparison, 2° of angle on the front wheels is the result of 30° of steering wheel rotation.

The rear-steer system points the rear wheels opposite the fronts at speeds below 50 km/h (31 mph), providing the equivalent response of a car with a wheelbase that is 250 mm (9.8 in) shorter than it really is. For practical parking purposes, the turning circle is reduced by 0.5 m (1.6 ft).

At higher speeds above 80 km/h (50 mph), the rear wheels steer in the same direction, parallel to the fronts, stabilizing the car with the effect of a wheelbase that is 500 mm (19.7 in) longer than it really is. Between the 50- and 80-km/h thresholds, the system continuously switches between steering opposite to the front and steering in parallel with the front, depending on the exact situation.

Another result of using the rear steering system is Porsche's ability to use a front steering rack with 10% quicker response for improved agility. This would make the car's handling potentially twitchy, but with the rear steering able to counteract the front to slow it down when necessary, the 911 and 918 are able to have lightning-quick front steering without making the cars unstable.

Budget future

It is no surprise that Porsche, BMW, and the Nissan GT-R feature advanced technology to improve their driving dynamics. But **Tenneco** aims to democratize active suspension technology by developing a simpler and less costly semi-active damper technology.

The company supplies its Continuously Variable Semi-Active (CVSA) suspension to cars like the BMW 1, 2, 3, and 4 Series, **Volkswagen** Golf, Scirocco, and Passat CC, **Ford** Focus RS, **Seat** Leon, **Volvo** XC90, and **Renault** Espace and Talisman.

But the company is aiming for still less expensive technology that has variable stages of damping it can switch among rather than a continuously variable range as with its CVSA product, explained Dan Keil, Chief Engineer of Advanced Engineering and Vehicle Dynamics.

The company's new DRIV technology targets light truck and compact car applications. "We wanted a simple and easy way to integrate a system with a significantly lower price than CVSA systems, so more customers can enjoy it on vehicles that typically wouldn't have variable damping," Keil said.

The company is testing hardware now that could be on pickup trucks for model year 2020, and it plans to start testing lighter-duty components for cars in the C-segment next year. The benefit of the DRIV adaptive damper system is that the shocks are independent modules that do not require specific systems be integrated into the host vehicle. The dampers carry their own processor circuitry and accelerometer, so there is no central control system.

Tenneco chief engineer for advanced engineering and vehicle dynamics, Dan Keil, says the goal for DRIV semi-active dampers is to achieve 75% of the benefit of more sophisticated systems at half the total cost.

Tenneco does use an electronic interface module that connects the dampers to the vehicle's CAN bus, but that is the only bit of hardware on the car, and it just connects to the bus to monitor information such as vehicle speed, steering wheel angle, and brake

AGILITY TRAINING FOR CARS

pressure, which it relays to the individual dampers' processors. The DRIV system does not monitor damper velocity, but rather estimates it from the accelerometer and other inputs.

The expectation is that the DRIV shocks will provide 75% of the benefit of a continuously variable CVSA system at half the cost. Some of this cost savings comes from reduced vehicle integration costs and the elimination of dedicated sensors in the car, so the dampers themselves will be more than half the cost of their CVSA counterparts, Keil noted.

Bilstein's Damptronic active damper has the appearance of a conventional passive damper.

Tenneco's DRIV semi-active dampers are a bit taller than a passive shock because of the self-contained electronics beneath its bumper cap, and a bit thicker in diameter because of the space needed inside for the solenoids.

Where CVSA is continuously variable, DRIV shocks have three solenoids that switch between two available damping valves to provide eight different levels of damping.

Compared to traditional inexpensive passive dampers, the DRIV shocks are taller, with the computer hardware mounted beneath the bumper cap atop the shock body, and that body is a bit fatter to incorporate the valve solenoids. However, the resulting damper is close enough to a regular one that manufacturers will have no difficulty accommodating its larger size, assured Keil. "I don't think that's going to be an issue," he said.

"It will show well on anything that needs improvement from a dynamic standpoint," Keil enthused. "We're very excited to get the first application going."

All drivers will appreciate the improvement to ride and handling available on the full range of vehicle segments too. At least, until we're relegated to automated transportation pods. ■

POWERING possibilities

Toyota's emphasis on creating a "hydrogen society" will be at the heart of its SAE Congress presence, with its 2016 Mirai hydrogen fuel-cell vehicle on display, along with a "Patent Bar" that will allow attendees to search Toyota's patents related to fuel cells.

That's the theme Toyota executives and other industry experts will explore in sessions devoted to advanced powertrains and connectivity, among other hot topics, at the SAE 2016 World Congress.

by Patrick Ponticel

The **SAE** 2016 World Congress (http://www.sae.org/congress/) will have a decidedly futuristic flavor, covering topics from fuel cells to flying cars. The event is slated for April 12-14 in Detroit and has as its theme, "Powering Possibilities."

Most responsible for adding the tasty technical ingredients is **Toyota**, which is providing Executive Leadership for the Congress with assistance from the event's Tier One Strategic Partner, **Aisin.** The two companies are closely aligned in the marketplace and will share booth space on the Congress show floor. One of the booth features will be a Patent Bar—computer screens that will allow attendees to search Toyota's patents related to fuel cells. The automaker has made those patents (about 2000 of them in English) available for free to the public, with the goal of spurring development of a far-reaching "hydrogen society."

"There's a huge opportunity for hydrogen, and not just for vehicles," Bruce Brownlee, Senior Executive Administrator at the Toyota Technical Center in Ann Arbor, MI, told *Automotive Engineering*. "We believe hydrogen will be an important part of the 21st century" in the energy sector as well.

The Toyota Mirai fuel-cell vehicle will be displayed in the booth, along with an Aisin hydrogen-based technology that can be used to power a car or a house.

Not hydrogen-powered but intriguing in its own right, the Toyota iRoad personal mobility vehicle will be another booth highlight. One of those tilting three-wheeled electric vehicles will displayed in the booth, and two will be made available for test-driving on a custom track inside the event location, Cobo Center.

An industry heavyweight with strong market powers across the globe, Toyota will have a similarly pervasive presence at the SAE Congress. Among other initiatives to make the event as exciting and useful as possible, the world's largest automaker lined up the three daily keynote speakers, helped develop the Tech Hub program (http://www.sae.org/congress/attend/program/tech_hub.htm), arranged to bring students from seven Detroit area universities to Cobo for a firsthand experience of the Congress, and encouraged its engineers to submit technical papers. With 101 submissions, it's the most technical papers Toyota engineers have ever published for an SAE Congress, according to Brownlee. Almost two-thirds of those papers are authored by Japan-based engineers.

The total number of Congress technical papers, as of mid-February, is more than 1500.

In addition, Toyota Motor Corp. Chairman Takeshi Uchiyamada will close out the SAE 2016 World Congress by speaking at the event's Annual Banquet. Brownlee noted that Uchiyamada, an SAE Fellow, first visited the United States in the late 1970s to present a paper at an SAE World Congress.

"That was a very meaningful experience for him," said Brownlee.

In the intervening years, the young man advanced through a number of positions at Toyota, including Chief Engineer of the first-generation Prius, which Brownlee described as "a 21st century vehicle that in many ways has revolutionized the way we think in terms of hybrid technologies."

The Chief Engineer of the fourth-generation Prius will present at the Detroit Section's April 13 Vehicle Event (https://www.sae-detroit.org/event-details/?id=201) devoted to the development of the all-new 2016 Prius. The Section always holds its April Vehicle Event in conjunction with the SAE Congress.

"It's kind of fun to see that the great-grandfather of the Prius will be at the Congress along with his great-grandson presenting on the fourth-generation Prius," Brownlee said. ■

WHAT'S NEW

SAE World Congress exhibitors provide a sneak peek at some of the new technologies and services they plan to showcase April 12-14 at Detroit's Cobo Center.

Driver assistance system development tool

Advanced driver assistance systems (ADAS) such as collision-avoidance, lane-departure warning, parking assistance, and backup alerts must adhere to a high level of safety requirements, and they are enabled by a large amount of embedded software to provide necessary intelligence and safety. Therefore, this software requires intensive testing and validation. A powerful tool chain from **dSPACE** supports engineering and validating of embedded software of these complex systems. This tool chain includes a virtual development environment with vehicle, sensor, traffic, and environment automotive simulation models (ASM), hardware-in-the-loop (SCALEXIO HIL) systems, VEOS PC-based simulation platform, stand-alone and in-vehicle prototyping systems, 3D online animation software, universal experiment and instrumentation software, and tools for graphical description of test sequences as well as code generation directly from Simulink/Stateflow models.

For more information, visit Booth 815 or http://www.dspaceinc.com/.

Powertrain vents

Donaldson's powertrain vents incorporate a breathable ePTFE (expanded polytetrafluoroethylene) membrane and an oil-repellent, coalescing prefilter for maximum protection in harsh environments. The vents provide protection from particles, water, oils, and automotive fluids while allowing pressure equalization in front and rear axles, transmissions, power transfer units and transfer cases, and limited slip couplings. Features of the units, which come in three sizes, include hydrophobic vents that meet water repellency ratings up to IP69K, oleophobic vents that meet oil repellency ratings up to 8 per AATCC 118-1992, rubber tube insert design for seamless integration into the component for easier assembly, and automotive-grade glass-filled Nylon 6,6 plastic for enhanced durability and resistance to high temperatures and harsh environments.

For more information, visit Booth 423 or www.donaldson.com.

On-road emissions testing

Intertek's Milton Keynes Transportation Technologies laboratory has developed a portable vehicle exhaust emissions testing system that enables manufacturers to report real-world driving emissions. The Portable Emissions Measurement System (PEMS) is vehicle mounted, thereby allowing manufacturers to report real-world driving emissions on the public roads, rather than in a laboratory, on a wide variety of cars and light commercial vehicles. As part of the testing service, the company is also developing driver aids and route management tools to ensure it delivers a high percentage of valid tests to customers. Intertek's Milton Keynes European Centre of Excellence for high-end automotive powertrain testing and engineering services has also invested in low-carbon vehicle, high-performance electric machine and hybrid testing cells at its automotive test laboratory to enable its customers to reach their goals on air quality emissions and CO_2 reduction in future vehicles.
For more information, visit Booth 908 or www.Intertek.com/Transportation.

Optical liquid silicone rubber

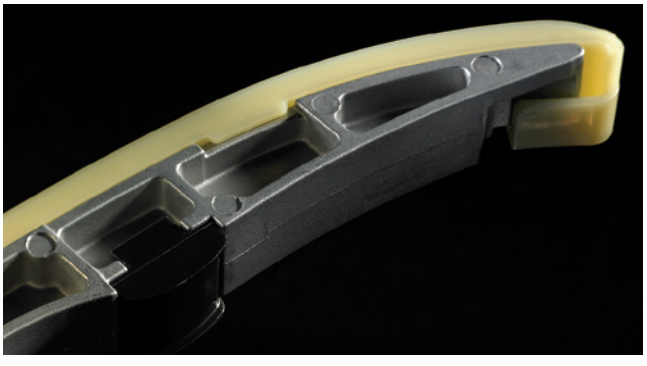
High-performance optical liquid silicone rubber (LSR) from **Proto Labs** is a transparent, flexible material that can replace glass in many optical applications. The injection-molded thermoset does not discolor or lose transparency with age or with exposure to heat or UV light. It is significantly lighter than glass and most plastics and is scratch and crack resistant. A key advantage of the material is its ability to reduce the bill of materials in a final assembly. With optical LSR, two parts, such as a lens and seal for lighting applications, can be combined into a single part, which reduces cost and inventory.
For more information, visit Booth 1335 or www.protolabs.com.

Engine simulation tool

EngineLab's EL129 control units for engine simulation and testing have a range of input and output options and can be adapted for flexible control system development. The hardware features 129 pins on two connectors with dual high-speed USB interfaces for communicating to a PC host as well as logging to any off-the-shelf mass storage device. The system enables model development, testing, and calibration in a single development environment. No compilers, linkers, assemblers, or third-party tools are required. It is built on a ROTS, allowing for flexible task control for efficient CPU load balancing. Features include 32-bit floating point and 200-MHz automotive grade semiconductor.
For more information, visit Booth 716 or http://www.enginelab.net/.

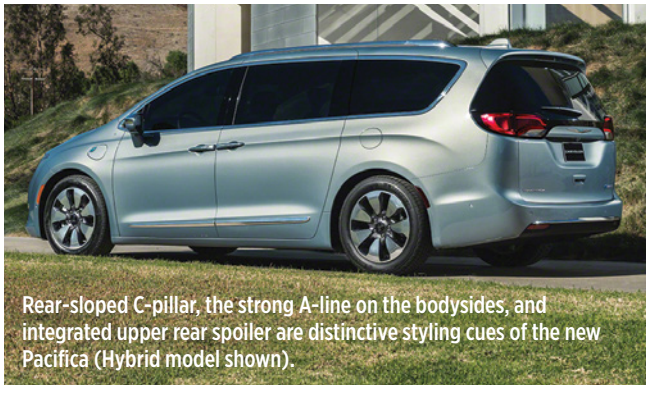
Polyamide for low-friction timing system

Stanyl PA46 from **DSM** has been chosen for low-friction slide shoes within the timing system of turbocharged gasoline engines. The timing system parts are produced by Quadrant Creative Molding & Systems, and the system items are supplied by Tsubakimoto UK. These engines represent the latest advancements in engine downsizing, and they offer an optimized combination of drivability and fuel consumption, with significantly lower CO_2 emissions, despite their higher power. Stanyl PA46 is already widely used in engine components because of its ability to withstand the highly demanding conditions found in the slide shoe, which include high temperatures, high loads, high velocities, harsh chemical environment, and heavy vibrations. Until now, the current industry standard for engine components has been Stanyl TW341, but for the new engines, this PA46 material, Stanyl TW371, provides even better friction performance. Tests have shown a 20% reduction in friction by Stanyl TW371. This provides extra benefits in terms of reduced CO_2 emissions and improved fuel economy.
For more information, visit Booth 1215 or http://www.dsm.com/products/stanyl/en_US/home.html.



2017 Pacifica is first hybrid minivan, rides on all-new FCA platform

The Hybrid version of the all-new 2017 Chrysler Pacifica features subtle styling differences compared with its non-hybrid cousin. Note charging port door on the left front fender.



Rear-sloped C-pillar, the strong A-line on the bodysides, and integrated upper rear spoiler are distinctive styling cues of the new Pacifica (Hybrid model shown).

Despite the popularity of SUVs and CUVs, nothing beats a minivan for its combination of interior flexibility, ingress/egress, passenger comfort, cargo hauling and, in some cases, fuel efficiency. While the segment isn't as large as it was in 2000, when sales peaked at 1.37 million deliveries in North America, about 500,000 minivans are still sold annually—ample profit-spinning volume that analysts expect will be sustained through at least 2020.

As millions of customers would likely attest, the minivan is "still the best transportation 'tool' for families," observed Tim Kuniskis, head of **FCA**'s passenger car brands, when he pulled the cover off **Chrysler**'s 2017 Pacifica—the company's sixth generation minivan. It was shown to *Automotive Engineering* and other media on embargo prior to the car's official debut January 11 at the 2016 **North American International Auto Show.**

Underpinned by what Chief Engineer Jessica LaFond called "an-new platform designed for this role" (FCA's global E-segment front-drive architecture), the Pacifica was developed with a focus on best-in-class ride, handling, and NVH attenuation—the latter achieved through great attention to vehicle aerodynamics. There are 37 new features LaFond and Kuniskis described as "innovations." They include the segment's first plug-in hybrid powertrain with FCA-developed electrified transmission offering up to 80 mpg equivalent (MPGe) fuel efficiency, hands-free sliding doors, standard active noise cancellation for the cabin, a 360° birds-eye-view camera, and a cleverly reconfigured and easier to use Stow 'n Go storage system that required a dedicated floorpan.

There's an optional and removable eighth-passenger seat in the second row that weighs 37 lb (16.8 kg), and a comprehensive electronic features suite that puts Pacifica into the segment's safety, HMI (with new Uconnect Theater and 8.4-in touchscreen display), and connected-car vanguard.

The overall design injects a "CUV-like character" into the two-box theme that Chrysler has refined continuously since 1984, noted Ralph Gilles, FCA's global design chief. The segment's longest wheelbase (121.6 in/3089 mm) enables a "living room on wheels" interior package with seating for eight as described by LaFond. Overall length is 203.6 in (5172 mm)

Mixed-metals mass reduction

The Pacifica's claimed coefficient of drag (Cd) is .300, which engineers claim is best in class. It is the result of 400 h of scale-model and full-size work in FCA's wind tunnel, along with a claimed 1.2 million CPU hours for CFD development. CdA is 9.95. Active grill shutters are a segment first and help reduce drag on average by 10% at highway speeds.

The body is also strong and mass efficient. LaFond's development team in Auburn Hills, MI, achieved a 30% gain in body torsional stiffness while reducing total vehicle mass by about 250 lb (113 kg), compared with the outgoing model (RT program) that debuted in 2008.

"We really optimized the new high-strength and advanced hot-stamped high-strength steels," she said, with about 22% more HSS in the 2017 vehicle than its predecessor. Use of structural adhesives to replace mechanical fasteners and welds was increased on the program. LaFond also noted the team's "extensive" FEA work to create an engine box that optimizes packaging, strength and predictable deformation, to

Pacifica cockpit has more storage solutions than previous model.

8.4-in touchscreen is centerpiece of new UConnect HMI.

meet the **IIHS**'s 25% narrow offset crash test.

With the additional feature content that was certain to increase Pacifica's curb weight over the previous-gen vehicle, mass reduction was a "big detail focus" within the development program, she explained. There's a magnesium cross-car beam, and Pacifica's exterior panels include the first aluminum sliding doors on a Chrysler minivan. The rear liftgate uses a magnesium inner and aluminum outer panel.

The hydroformed front suspension cradle is solid-mounted at six points, and features octagonal side rails in thin-wall HSS, with lightening holes strategically placed. The front MacPherson strut suspension is aluminum intensive, with forged lower control arms, cast knuckles, and an extruded aluminum cross member for the electric steering gear. Aluminum also is key to reduced mass in the engine brackets and rear upper shock mounts.

Also, the use of rebound springs inside the rear shocks enabled the rear stabilizer bar to be eliminated. The chassis team is proud of a new rear trailing-arm design, rendered in thin-gauge steel to save mass.

The independent rear suspension module mounts on an isolated, full-perimeter type steel cradle, also using lightening holes to save weight.

Attacking NVH

Pacifica's segment-longest wheelbase, combined with ample vehicle width (79.6 in/2022 mm) and wide front/rear track—68.3-in/1735-mm for non-hybrid models and 68.2-in/1734-mm for hybrids—creates a 200 ft^3 (5.66 m^3) interior volume, which LaFond claims is best in class and also has segment-leading front legroom, she said.

NVH countermeasures are designed to address root causes and noise paths, LaFond explained. Air leakage into the passenger compartment is attenuated to around 225 CFM. The 5.0-mm acoustic laminate windshield glass delivers a claimed

Yes, a 4 x 8-ft sheet of plywood will fit inside Pacifica with both seat rows stowed and the liftgate closed.

2.5 to 3.0 dB improvement over standard tempered glass. All doors feature triple sealing and the wheelhouse liners are specially designed to muffle road noise. Engineers said wind noise in the Pacifica is as low as 63 dB at 70 mph. The vehicle's Articulation Index (speech intelligibility; 0%=worst, 100%=best) is above 84% at 70 mph.

Pacifica also features a standard active noise cancellation system that uses the audio system and four strategically located microphones to introduce opposite-wave sound to the cabin as an offset to unwanted sounds. Engineers said the system also enables more fuel-efficient engine calibrations due to the reduced need for NVH-related tradeoffs, and reduces the need for acoustic-damping material that adds unwanted weight.

Segment-first hybrid drive system

Pacifica's power comes from both conventional and Atkinson-cycle (for the hybrid model) versions of FCA's newly invigorated 3.6-L Pentastar V6 (see http://articles.sae.org/14322/). A stop-start system will be added later in the 2017 model year. The conventional non-hybrid version is coupled with the **ZF**-Chrysler 9-speed planetary automatic.

In 3Q16 the Pacifica Hybrid debuts as the industry's first electrified minivan. With an estimated 248 hp (185 kW) produced by its Atkinson-cycle, 12.5:1 compression V6, the vehicle will deliver an estimated EV-only range of 30 mi (48.2 km).

Centerpiece of the new hybrid driveline is FCA's in-house designed electrically-variable transmission (EVT). The unit, long in development (and of which more will be described in a future article), uses two electric machines, both of which are capable of driving the vehicle's wheels thanks to a one-way clutch. The 16-kW·h lithium-ion battery is packaged under the second-row seats.

The vehicle has provision for **SAE** Level 1 and 2 (via combo connector) charging.

Lindsay Brooke

Prius is re-engineered on Toyota New Global Architecture

Toyota hopes an exciting color palette that includes Hypersonic Red will fire passions for the new Prius.

With 3.5 million Prius hybrids sold worldwide since its launch, **Toyota** is understandably keen to maintain the iconic hybrid-electric's momentum. To that end, the company has relied on upgrades familiar to automotive orthodoxy rather than the upstart electric-drive crowd.

In the case of the 2016 Prius, that means bodywork that is longer, lower, and wider. There's also special attention to the gasoline portion of the car's gas-electric drivetrain. Toyota claims 40% thermodynamic efficiency for the Atkinson cycle 2ZR-FXE 1.8-L I4 naturally aspirated gasoline engine under the Prius's hood, a number that rivals turbodiesels.

In an *Automotive Engineering* Q&A, Assistant Chief Engineer Kazuaki Shingo discussed the challenges of developing the 2016 Prius on the Toyota New Global Architecture (see http://articles.sae.org/14485/).

Toyota's first order of business was to make the Prius a better car to try to escape its niche as a rolling political statement. It is the first vehicle on the Toyota New Global Architecture, though it returns on exactly the same 106.3-in (2700-mm) wheelbase as the outgoing car.

Even with that similarity, the 2016 Prius is 2.4 in (61 mm) longer, 0.8 in (20 mm) lower, and 0.6 in (15 mm) wider than the outgoing car. The peak of the roof is moved forward 6.7 in (170 mm), providing for a longer taper to the rear. Automatic grille shutters close off airflow to the radiator when it isn't needed, and underbody covers smooth the flow of air around its suspension. These changes whittle the car's coefficient of drag down another notch to 0.24 from the old car's 0.25. The driver's H-point sits 2.3 in (58 mm) lower than before, imparting a more car-like feel behind the wheel.

A double-wishbone rear suspension replaces the old car's torsion beam axle, with the predictable improvement in both ride and handling quality from this change to truly independent rear suspension. The front suspension continues with ubiquitous MacPherson struts.

Engineers trimmed unsprung weight by replacing cast iron brake calipers with aluminum ones and by carving 1.5 lb (0.7 kg) from the weight of each of the car's 17-inch aluminum wheels.

Toyota uses a wide base of suppliers for its tires, as carmakers recall the pinch of supplies that can occur due to defects, as

with the **Ford** Explorer/**Firestone** recall, or with manufacturing disruptions such as the earthquake in Kobe, Japan, interrupted production of **Dunlop** tires there. So the Prius comes on Dunlop Enasave, **Yokohama** Avid, **Bridgestone** Ecopia, and **Toyo** NanoEnergy tires.

The new suspension is tied together by a unibody that has 60% better torsional stiffness than before. Increased use of high-strength steel contributes to the improved stiffness, and it combines with aluminum in the hood and rear door frames to also save weight. The lightest Prius Eco is 3010 lb (1365 kg), while the most thoroughly equipped Prius Four Touring weighs 3080 lb (1397 kg).

The Prius gains the suite of Toyota Safety Sense P crash prevention technologies including pre-collision braking, pedestrian detection, lane departure alert and assist, dynamic cruise control, and automatic high beams. The "P" in the system's name differentiates it from a lesser system on Toyota's compact models designated "C," which lacks the forward radar of the P system.

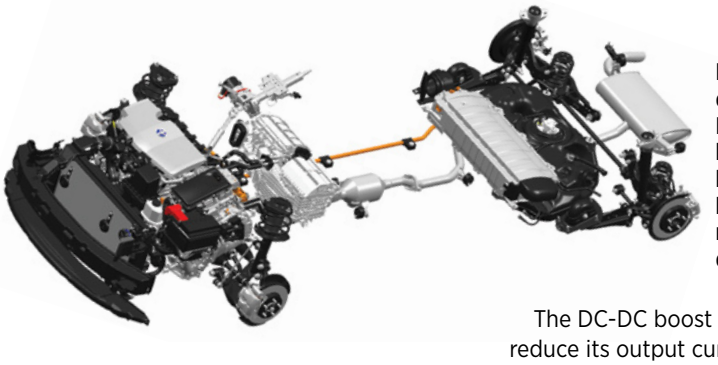
There is also a color head-up display providing vehicle data directly in the driver's line of sight, which is good because the car's instrument cluster is located in the center of the dashboard.

Toyota addresses cabin comfort with a thicker, more complete one-piece sound-deadening mat for the floor, with none of the gaps of the previous model's mat. The air conditioner features a quieter electric compressor and for heat, the car has an electric ceramic heater to warm the cabin more quickly than the main engine-coolant heater does.

The Eco model employs a heat-resisting infrared-cut windshield that substantially reduces transmission of infrared rays to the cabin for a lighter air conditioning load in summer.

The car's powertrain has a feature to assist with cabin comfort: a heat exchanger in the exhaust system that transfers exhaust heat to the coolant circuit that is routed to the car's heater core. This shortens the time needed for the engine to provide heat and quickens the availability of fuel-saving engine stop/start in cold weather.

The Prius retains its centrally located instruments for 2016, but it supplements them with a new color headup display ahead of the driver.



By shrinking components, the new Prius fits the auxiliary battery under the hood and the traction battery under the rear seat, clearing the cargo floor area.

Thermal control is a key aspect of the engine's ability to achieve 40% thermal efficiency. The car runs as much as 20% exhaust gas recirculation. Using EGR reduces pumping losses because the engine can run with its throttle plate open wider, according to Kentaro Tomo, Toyota's Group Manager for the hybrid vehicle system planning department.

"In order to do that, before we return it, we need to lower the temperature of the exhaust gas," he said. So the Prius uses the return line of the heater core circuit to flow through a heat exchanger for the EGR just before exhaust gas flows into the engine's intake side.

However, cooling recirculated exhaust isn't enough. "Combustion is not stable if you pay attention to that only," Tomo warned. "For that reason, we made improvements to the intake port to make sure that turbulence is brought to the combustion chamber." This is done through the design of the port, and not through the use of flaps that operate only when needed.

Having achieved 40% efficiency, Toyota's sights are now set on reaching 50% efficiency for gasoline engines, according to Tomo. The company is researching techniques that might let it reach that level, even without employing heterogeneous charge compression ignition, he said.

Since it is a Prius, Toyota did not ignore advances on the electric drive side. The car's electric motor is now mounted parallel to the gasoline engine, rather than to the end of its crankshaft with the flywheel. This reduces package length of the combined motors and it gives the electric motor a higher speed range through a reduction gear. Toyota claims this arrangement cuts parasitic losses by 20% compared to the old layout.

The DC-DC boost converter can now reduce its output current in low-load situations, which also aids in fuel efficiency. The car's inverter is smaller than before, allowing space under the hood for the auxiliary battery, which used to consume space at the rear of the car.

The 56-cell lithium-ion battery pack is 38% smaller than the old nickel-metal hydride pack and now fits entirely beneath the rear seat, permitting an unobstructed flat load floor when the rear seats are folded.

In the U.S., the base Prius Two will sell with a NiMH battery like the old car to provide a low entry price. This battery will continue to be popular in other markets, Toyota said.

Because of difficulty determining peak system power in a hybrid-electric drivetrain there is some debate over official rating, Toyota said. The company has chosen the **Japanese Auto Institute** standard as its benchmark, and according to that rating, the Prius's gasoline and electric engines produce a total of 121 hp (90 kW) when working together.

SAE net power for the gasoline engine is 95 hp (71 kW) and 105 lb·ft (142 N·m), while the electric motor is rated at 71 hp (53 kW) and 120 lb·ft (163 N·m).

Together, the changes produce EPA fuel economy ratings of 54 mpg city and 50 mpg highway for all Prius models other than the Eco. That one is rated at 58 mpg city and 53 mpg highway as a result of lighter weight from less equipment and harder tires with a higher specified air pressure.

This increased efficiency should continue to satisfy the car's core environmentalist customer base, but it will remain to be seen whether the improved driving dynamics and lower-slung looks expand the car's appeal to customers with less ideological motivation.

Dan Carney

2017 Porsche Boxster loses cylinders, gains power, adds frugality

Porsche's decision to downsize the new generation Boxster's engines from flat-6 to turbocharged flat-4 may shock purists, but power and torque are up, and fuel consumption and emissions down. So the 2017 Boxster is a demonstration of what efficient automotive technology can deliver. And if four cylinders still seem a bit demeaning for the brand, consider that the 919 hybrid race car uses a turbocharged V4.

Full details of the new engines were not released when this article was published, but *Automotive Engineering* soon will be sitting down with Porsche engineers and driving the new 718 Boxster; in depth story to come. Meantime, Porsche does not dispute the supposition that the new "boxer" fours are shortened versions of the current flat-6s in the latest 911s, but with only a single turbo.

The new Boxster, to be formally revealed at the 2016 Geneva Motor Show, gets fresh suspension tuning, steering that is claimed to be 10% more direct, uprated brakes, and some relatively minor cosmetic changes including a new

The new mid-engined 718 Boxster S can accelerate from standing start to 100 km/h in 4.2 s, the company claims.

dashboard. And the car's "718" nomenclature is a modern nod to 4-cylinder Porsches in the 1950s and 1960s that found success on racetracks.

But it's the engine change that is most significant. It is 20 years since the 2-seat mid-engine Boxster was launched in 2.5-L flat-6 form and it is more than 20 years since the last 4-cylinder Porsche (the front engine, rear drive 968) was produced.

The new car will initially be available in two variable-geometry-turbocharged (VG) forms: 718 Boxster with 2.0-L engine and 718 Boxster S with a 2.5-L. Its sibling coupe Cayman is expected to receive similar treatment. Later, Porsche is likely to add higher performance versions of the engines.

Not that they lack power already. The 2.0-L produces a claimed 220 kW, and 257 kW for the S (295 and 344 hp, respectively). Porsche claims it is the only manufacturer to offer VG technology for production gasoline engines, for both Boxster and 911.

Call it "seven-one-eight" or 718: the new 4-cylinder Boxster is unmistakably Porsche. Its more prominent front and side air intakes help identify the 718 from previous Boxsters.

The new models have fuel economy improvements of up to 13%, the company claims. The 718 Boxster with PDK has a NEDC combined fuel consumption of 6.9 L/100 km. The S version with PDK achieves 7.3 L/100 km combined.

The 2.0-L engine's peak torque is increased by almost 25% (100 N·m; 74 lb·ft) over the previous equivalent Boxster, with 380 N·m (280 lb·ft) available from 1950 to 4500 rpm. The 2.5-L S engine achieves 420 N·m (310 lb·ft) peak from 1900 to 4500 rpm—a gain of 60 N·m (44 lb·ft) compared to its

New Boxster, new dashboard for Porsche's latest generation of the mid-engine 2-seater.

equivalent predecessor.

Performance figures are subsequently improved. The 718 Boxster with optional PDK double-clutch automatic transmission and Sport Chrono Package, now with an Individual program plus Normal, Sport and Sport Plus settings—and a Sport Response Button that delivers an afterburner-like assist for 20 s—helps propel the car from zero to 100 km/h (0 to 62 mph) in 4.7 s, or 0.8 s quicker. The 718 Boxster S with PDK and Sport Button makes the dash in 4.2 s, a gain of 0.6 s.

Claimed top speed of the 2.0-L is 275 km/h (171 mph); the 2.5-L is claimed to achieve 285 km/h (177 mph).

Each 718 model is equipped with a 6-speed manual transmission as standard. The PDK now features the fuel-saving "virtual gears" of the 911 model series.

Stuart Birch

2016 Mini Clubman's torque-vectoring AWD system designed to give 2wd efficiency

In the 1960s, the front-wheel drive Mini Cooper S famously won the Monte Carlo Rally, propelled by a 52 kW (70 hp) engine and clawing through snow and ice on tires that looked small enough for a wheelbarrow.

The latest **Mini** offering, the 2016 Cooper S Clubman ALL4 (with all-wheel drive) makes its world debut at the 2016 New York Auto Show. It has been developed to tackle such conditions in a great deal more comfort and security than the classic rally car—and with up to 141 kW (189 hp) from its turbocharged 2.0-L 4-cylinder engine, potentially do it more quickly.

The all-new Clubman is 12.4-in (315-mm) longer and 4.6-in (117-mm) wider than the previous Clubman, making it (at 168.3-in/4274-mm long) Mini's largest product and its first in the compact segment. It shares **BMW**'s UKL2 platform with the 2-Series wagon.

The ALL4 system's design criteria included compact packaging and light weight to keep fuel consumption and emissions similar to those of the 2wd Clubman. The Cooper S ALL4 drives through a choice of 6-speed manual or 8-speed **Aisin** automatic transmission. (For comparison, the non-S Cooper powertrain uses BMW's 1.5-L turbocharged 3-cylinder rated at 134 hp (100 kW) and offers an optional 6-speed automatic.)

The AWD system, its constituent components sourced from a number of

Double rear doors for the 2016 Mini Clubman make it technically a 6-door car.

The new Mini Clubman (ALL4 version shown) is 12.4 in longer and 4.6 in wider than its predecessor and can seat five passengers. It is Mini's first product in the compact segment.

suppliers—**BorgWarner** provides its GenV AWD coupling, for example—utilizes a hang-on clutch to manage distribution of required torque to front or rear axles as necessary. But the bias under standard operating conditions is always to the front axle differential.

An integrated single-stage power take-off bevel gear diverts the power and relays it to a propeller shaft leading to the rear axle.

The hang-on clutch can relay torque to the rear wheels "within a fraction of a second" (as Mini puts it) via an electro-hydraulic pump. The ALL4 system is connected to the Driving Dynamics System (DSC) which continuously calculates the ideal power distribution between the front and rear wheels.

Wheel rotation speeds, longitudinal and lateral acceleration, road speed, accelerator position, engine torque and steering angle, plus the DSC settings and the optional Mini Driving Mode, are all correlated to provide optimum toque bias.

A standard Electronic Differential Lock Control (EDLC) is claimed to improve traction when accelerating out of bends, using selective braking. In DSC Off mode, this prevents spinning of the front wheel on the inside of the bend and transmits drive power to the outer front wheel.

The car's Performance Control (PC), described as making the vehicle agile even before the limit range is reached, has a positive effect on the self-steering response of the front-wheel drive by suppressing initial understeer. This is achieved via a combination of DTC (Dynamic Traction Control) and EDLC (Electronic Differential Lock Control) and uses the brakes to simulate the effect of a limited-slip differential function.

PC is another standard feature on the gasoline and diesel SD (for Europe) Clubman ALL4, and works regardless of the DSC mode selected.

Claimed performance figures for the 2.0-L gasoline car include a best 0-100 km/h (62 mph) time of 6.9 s and Vmax of 229 km/h (142 mph). Power-to-weight ratio is 10.3 kg/kW. Best NEDC combined fuel consumption is for the auto: 6.3 L/100 km.

The SD's engine produces a claimed 400 N·m (295 lb·ft) from 1750 to 2500 rpm. Combined fuel consumption with the automatic is a claimed 4.8 L/100 km.

And the Clubman's tires are 224/45 R17 94W XL—likely a size which no wheelbarrow will have.

Stuart Birch

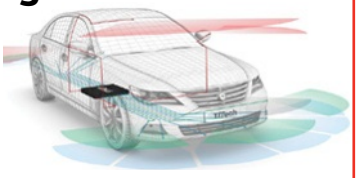
PRODUCT BRIEFS

SPOTLIGHT: SOFTWARE

Augmented reality software

As a result of **Continental**'s consolidation of **Elektrobit** (EB) as a standalone software company, Elektrobit will develop the Augmented Reality (AR) Creator software solution, in addition to continuing to develop embedded software and services for automakers and Tier 1 suppliers. AR Creator—sensor data fusion software and software framework for augmented reality head-up displays—will foster the creation of augmented reality solutions to make driving safer and improve the driver experience. It consists of a range of software features from EB, including highly precise lane positioning, and environmental modeling and prediction, plus the implementation of modules responsible for functions such as augmentation of navigation data or marking of lanes, user experience, and many more. Based on complex sensor fusion, the AR Creator augments the scene, when necessary. This will help drivers to intuitively recognize the significance of what they see in front of them. AR Creator is part of Continental's AR Head-Up Display (AR-HUD). For more information, visit http://www.elektrobit.com/.

Software integration for automated driving



An automotive platform solution from **Renesas Electronics** Corp. and **TTTech Computertechnik** AG provides an electronic control unit (ECU) development platform for advanced driver assistance systems (ADAS). The platform integrates Renesas' RH850/Plx automotive control microcontroller (MCU) and R-Car system-on-chips (SoCs) with TTTech's TTIntegration software platform to enable highly complex automotive solutions, including automated driving. The platform achieves parallel, multi-vendor development and integration of individual software components. Centerpieces of TTTech's ADAS platform are TTIntegration and Deterministic Ethernet. TTIntegration is located and runs as middleware between the CPU level and the integrated applications. It provides each application with the CPU time and memory it needs, while separating or even abstracting hardware from applications. Delivering an AUTOSAR environment for various operating systems enables system manufacturers to move applications between the embedded cores more easily. TTIntegration supports various safety levels simultaneously. A strict partitioning concept ensures at any time that a bug or defect in one application cannot harm any other or cause a collapse of the whole ECU. For more information, visit http://www.renesas.com/ and http://www.tttech.com/.

Camera-based 3D measurement

Imetrum's precision, noncontact 3D measurement system, the Precision Displacement Tracker (PDT), slashes setup times and provides richer data sets without compromising measurement resolution or sampling speed. The system uses pre-calibrated stereoscopic video cameras, combined with the firm's Video Gauge software, to deliver precise noncontact measurements on any point that can be seen within the image. The 3D PDT eliminates the need to build frames for displacement sensors, bond strain gauges, run cabling, or get too close to "hot" objects, saving time and improving the safety of test environments. Measurements can be taken at up to 0.5 µm (19.7 µin) resolution and real-time measurement speeds up to 1000 Hz. For more information, visit http://www.imetrum.com/.

3D-viewing of CAD models

KISTERS has released version 2016 of its 3DViewStation Desktop, which features modern user-interface, high-performance 3D-viewing, advanced analysis, and digital mockup (DMU). 3DViewStation ships with current and mature CAD-importers for a range of formats including Catia, NX, Creo, SolidWorks, SolidEdge, JT, 3D-PDF, and STEP, plus a set of functional tools to view, analyze, and communicate 3D-data as STEP, JT, or 3D-PDF. The development focus for 3DViewStation Desktop V2016 has been to further optimize the handling of extremely large assemblies and enhancements of the analysis functions. The graphics kernel, which is a KISTERS development, has been optimized to cut down load times by 50% in 3DVS file format and to reduce memory usage by 60-70%. The size of 3DVS files also has been reduced by 20-30%. Other new features of 3DViewStation can be reviewed at http://blog.kisters.de.

Micro-fused strain gauge pressure sensors

Sensata Technologies, Inc. has developed a line of smaller, lighter micro-fused strain gauge (MSG) pressure sensors for use in next-generation brake systems for hybrid, electric, and conventional vehicles. The eXtra-small Form Factor (XFF) sensor was available for design-in beginning January 2016. To ensure traditional braking feel in hybrid and electric vehicles, brake systems require additional pressure sensors; offering a smaller, lighter package allows customers to adopt multiple sensors without growing their module. Sensata's MSG pressure technology will now be offered at less than 5 g (0.18 oz), with a body diameter less than 7.8 mm (0.3 in) and a height less than 30 mm (1.2 in), including its spring contact system. The new XFF platform utilizes a modular port design and a modular circuit architecture offering high-fault-detectability. The MSG technology offers analog and digital integrated pressure and temperature signal conditioning, delivering an accurate, stable signal over operating temperatures of -40 to +140°C (-40 to +284°F) and a range of pressures. This MSG form factor is also suitable for integrated brake modules that eliminate the vacuum booster. For more information, visit http://sensata.com/.

Composite cooling circuit parts

Cooling circuit parts installed by automotive manufacturers consist of a direct composite comprising the special polyphthalamide (PPA) VESTAMID HTplus R1033 by the Resource Efficiency segment of **Evonik**, and a newly developed HNBR elastomer by **KACO** GmbH & Co. KG. The composite is generated with the patented plastic-rubber technology, which enables the firm bond of a component's plastic and rubber parts without pretreatment. The process does not require the application of an adhesion promoter. The plastic material, such as VESTAMID HTplus R1033, must be specifically formulated for this purpose. The newly developed HNBR elastomer by KACO shows enhanced initial adhesion. The bond with HNBR also must remain stable when the part is in contact with various media or subjected to temperature extremes, which is ensured by the high chemical resistance of PPA as well as the special properties of VESTAMID HTplus R1033 for composite bonding. The plastic part remains dimensionally stable even in the elastomer vulcanization process, which allows for trouble-free component function for a million transmission cycles depending on the transverse path. For more information, visit www.evonik.com.

COMPANIES MENTIONED

UPCOMING FROM THE EDITORS

March 7: Off-Highway Engineering Technology eNewsletter

March 15: Automotive Engineering Technology eNewsletter

March 23: Vehicle Engineering Technology eNewsletter (all markets)

March 30: Heavy Duty Engineering Technology eNewsletter

April: Aerospace & Defense Technology Print Magazine
- AUVSI Show Preview
- Electronic warfare / Weapons systems
- Alternative power sources
- Composite materials
- RF & Microwave Technology Section

April: Automotive Engineering Print Magazine
- State of Engineering 2016
- Vehicle electrification
- Virtual design and engineering
- SAE 2016 World Congress coverage
- Semiconductors product spotlight

April: Off-Highway Engineering Print Magazine
- Intelligent machine control
- Powertrain management
- Vehicle testing & quality control
- Emissions regulations: The road ahead
- Bauma product spotlight

April 6: Aerospace Engineering Technology eNewsletter

April 12: Automotive Engineering Technology eNewsletter

April 19: Off-Highway Engineering Technology eNewsletter

April 27: Automotive Engineering Technology eNewsletter

May: Aerospace & Defense Technology Print Magazine
- Special Issue: Unmanned Vehicle & Robotics Technology

AD INDEX

AUTONOMOUS VEHICLE RADAR: IMPROVING RADAR PERFORMANCE WITH SIMULATION

Wednesday, March 9, 2016 at 10:00 am U.S. EST

Automotive radars must operate in complex and dynamic environments where interactions with the vehicle and its surroundings can have a significant impact on the performance of the radar system. In particular, material properties of the vehicle fascia and the radar's location behind the fascia can impact its performance and must be accounted for by radar designers and system integrators.

This 60-minute Webinar describes the use of advanced engineering simulation in assessing the performance of an automotive radar behind various fascia designs. A detailed case study is also presented, followed by an audience Q&A.

Speakers:

Dr. Sandeep Sovani
Director, Global Automotive Industry, ANSYS

Dr. Matthew Commens
Lead Product Manager, ANSYS

Shawn Carpenter
Senior Product Specialist, ANSYS

Lisa Arrigo
SAE International

Registration:
www.sae.org/magazines/webcasts

Sponsored by: ANSYS®

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ANALYSIS OF AUTOMOTIVE ADHESIVES USING FTIR SPECTROSCOPY

Tuesday, March 22, 2016 at 2:00 pm U.S. EDT

The automobile industry is under government regulation to improve the fleet fuel economy. A significant percentage will be achieved by reducing the mass of the vehicle fleet from the use of lighter materials. These materials will require the use of adhesives for joining dissimilar materials, while maintaining strength and managing thermal expansion differences.

This 30-minute Webinar will summarize the analytical capability of adhesives by Fourier Transform InfraRed (FTIR) spectroscopy, which can be used throughout the production stream. The Webinar will show examples of these topics to help engineers and scientists in the automobile industry who are challenged with adopting lighter weight materials in automobile construction.

Speakers:

David Drapcho, Ph.D
Marketing Manager Research FTIR, Thermo Fisher Scientific

Lisa Arrigo
SAE International

Registration:
www.sae.org/magazines/webcasts

Sponsored by: Thermo SCIENTIFIC

Hosted by: SAE INTERNATIONAL®

Q&A

Tim Grewe: "We're not really hardware-limited or bandwidth-limited on our local area networks."

Controlling GM's electrified herd

As **General Motors** proliferates electrified powertrain applications among its brands, it is also rapidly commonizing those systems as much as possible. Witness the 2016 Chevrolet Volt and Malibu Hybrid; both systems were developed in parallel and share key design, engineering and certain component elements. And the 2017 Cadillac CT6 plug-in hybrid's sophisticated propulsion system marries aspects of the latest Volt and those of GM's earlier 2-Mode hybrid system. At the recent 2016 **SAE** Hybrid & EV Symposium in California, *Automotive Engineering* talked with Tim Grewe, GM's Director of General Electrification, about the role of controls in the electrified vehicle space.

It seems that going forward it's the controls, not hardware, that will separate a Volt from a Bolt from a CT6—and a Cadillac PHEV from a Mercedes or Audi.
Controls are fundamental to vehicle high performance and efficiency. And it's truly multidisciplinary, getting engineers who normally don't work together trading off the optimizations. If you take a classic control theory that's engine-centric and just about BSFC (brake specific fuel consumption), that might not be so good because the motor control is less efficient in those operating points. You've got to tie them all together.

We've got about a dozen controllers, real time, on the same network with an optimizer and security processers running all the time. Consider all the linear transformations that we do in order to deliver the most efficient propulsion solution for a given driving moment. The controllers are communicating: What's the best thing to do? How much regen did you get last time? Where's the "free" energy from the battery—oh, I don't have enough energy from the battery from the last regen, so I want to leverage into an IC engine-type efficiency point. The controls make all that happen.

An 'efficiency point' meaning optimizing the powertrain so that it's in the sweet spot of brake-specific fuel consumption?
Yes. It's one of those neat things where on the consumption chart of the engine, we're on the BSFC "island" and we want to use the electrification to stay there.

In terms of your hybrid system development teams, what sort of challenges are there now in bringing the formerly independent but now increasingly dependent domains together?
That's my group's role within Electrification. We're very strong on the integration aspects. We have experts in the various component areas—motors, batteries, etc.—but it's our job to do what's best for the customer. So I have large teams working all those details. We're not motor designers, but we know how to use motors. And we know how to talk to them [the motors] to say we've got 'chuggle' in EVT Low and we need to change something to get rid of the torque ripple—and we can't dampen it out by slipping a clutch because that's less efficient. So we find the root cause and fix it in the teeth of the motor's stator! That's what my team does—collaborate with the experts to make the best balance in the vehicle.

Now that GM is developing a new global electrical architecture, is this creating the need to rethink the electrical pathways and networks in vehicles going forward?
My perspective on it: We're not really hardware-limited or bandwidth-limited on our local area networks. So while there's a lot to do and a lot of communication, the bandwidth is there today and I don't have problems with it. A lot of the strategy you have as to how you partition your controls and different controllers, though, enables that.

As in a multi-domain controller environment?
Yes. So while the engine controller is still doing all the optimization on the engine, there is a literal engine-to-hybrid-system, torque-based control method where we can still let them coprocess and do all the heavy math and not load down the bus. We don't have this mentality of one single controller in all the bus traffic; we distribute the processing. It's very similar to the distributed-processing Internet stuff where you crunch all the math and only talk where you need to talk to each other.

So in order to make the hybrid functionality more seamless to the vehicle driver, you're not overloading the CAN buses. Or looking for a technology to replace buses?
No. I'm not in trouble on any bus! In fact, what's loading the bus is the customer-facing stuff—all the adaptive cruise control and other ADAS features. Right now we're set. We're just iterating and combining. The very natural thing you'll see in the next-generation product is just more electrical and electronics integration. The parts are being reduced in size and are now getting small enough that I can still fit the APM and TPM [control modules] on the transaxle.

So just like we got rid of the big, ugly orange high-voltage cables on the Gen-2 Volt, now we're getting rid of the little orange cables to the APM. And that process of iterating and combining will continue along with Moore's Law. As you know, the industry is converging on similar-sized batteries, similar power numbers, etc. The nice thing is, the converging is creating a focus on the technology—to make it as tiny as you can make it.

Lindsay Brooke

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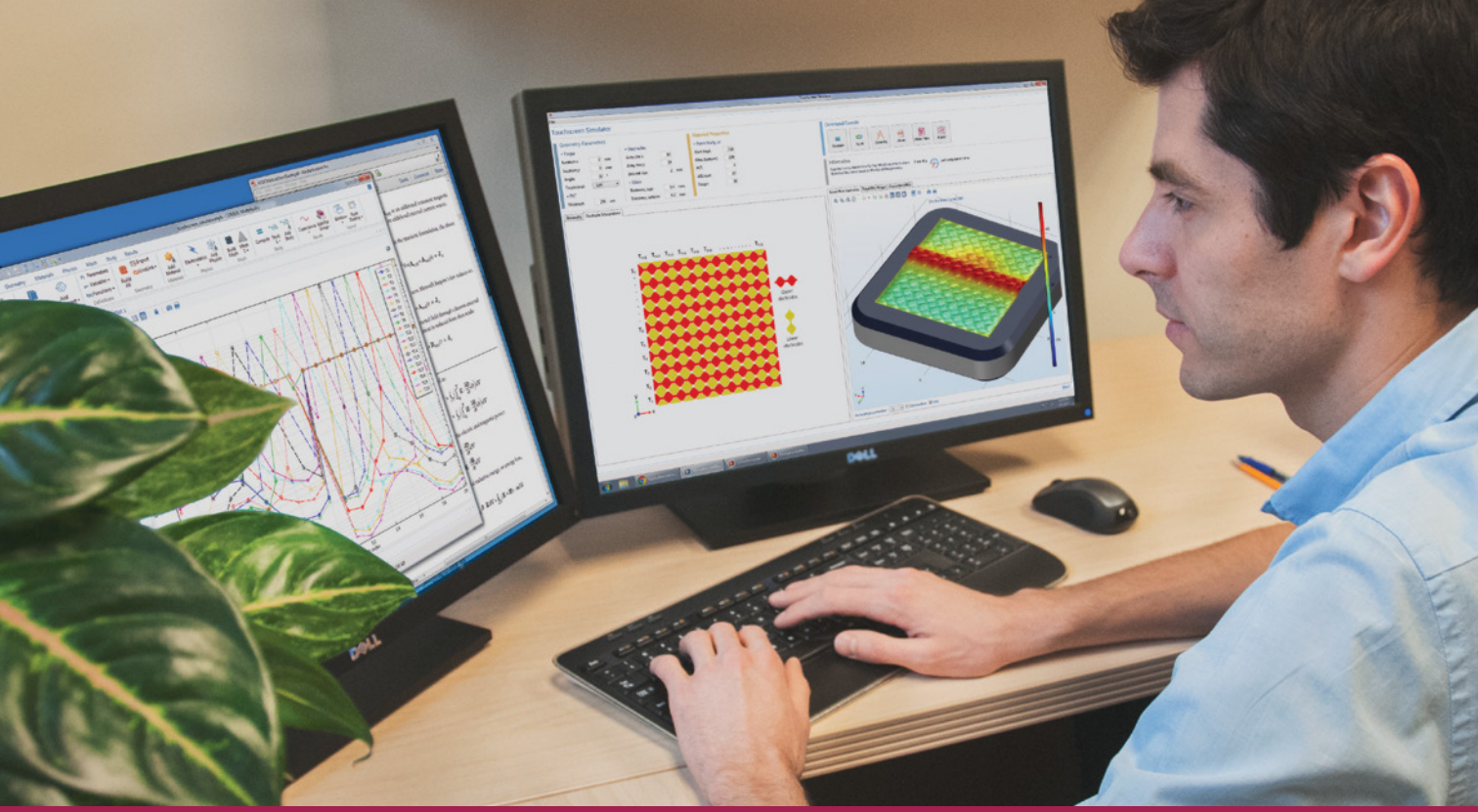

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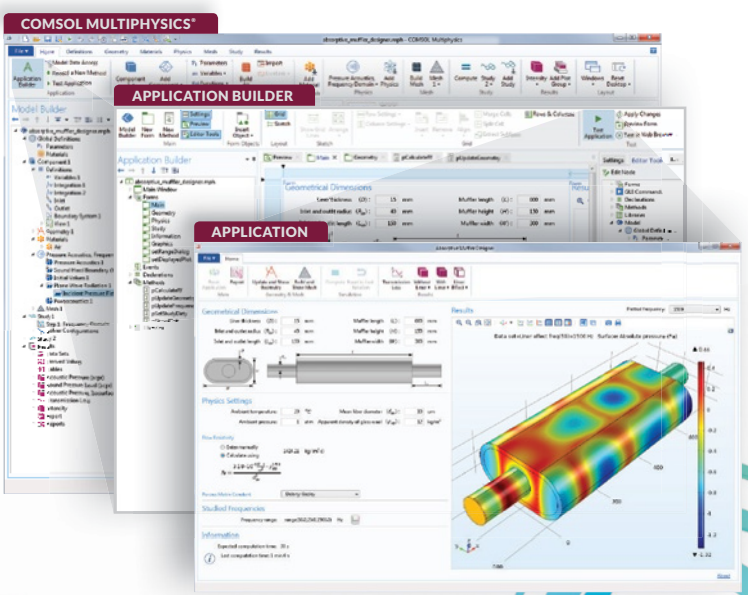

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