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Two of Ford's new GT-R endurance racers run in tight formation. The GT-R "endured" a rough start to the 2016 season but quickly found a groove, winning its first race, a two-hour sprint in California, in early May—an immense confidence-builder as the GT-R heads to its first-ever appearance in world-famous crucible of the Le Mans 24-hour endurance race this month.

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## REGULARS




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# EDITORIAL

## Elon, Henry, and the mastery of manufacturing

"Do you want to make a bet on Musk's latest pronouncement?" asked my friend the Tier 1 supplier engineer, whose company is part of **Tesla**'s supply chain.

"I'm betting against it," he followed, "because they haven't yet proved they're capable of big volumes. When they increase product complexity and volume at the Fremont plant it stumbles in end-of-line quality. Product is delayed. They're still teething while talking like they're big boys."

Not being a betting kind of guy, I acknowledged that this was sound logic.

Then I added: "My concern is not with Tesla's ambition for such a huge production leap—from 50,000 Model S and X units built in 2015 to 500,000 units including Model 3 in 2018. They plan to double that again, to 1 million units, by 2020.

**Model 3 and Model T makers: Musk and Ford**

"My biggest concern is this: Elon Musk has yet to create a sufficiently robust manufacturing organization to pull it off."

Readers of this magazine who follow industry news know the scenario. Tesla's recent unveiling of its lower priced Model 3 brought an avalanche of customer orders. It was reminiscent of the public's reaction to the 1964½ **Ford** Mustang, whose sales surpassed its maker's projections for the year just three months after launch.

That Ford was able to meet unforeseen levels of demand for its original pony car showed why it was then, and remains today, a master of high-volume manufacturing. Such proficiency in building a complex, high quality project, while driving cost out, doesn't just happen overnight. Pulling the tarp off the shiny new Model 3 in front of adoring fans is easy; cranking them out in volume is the tough part.

Jumping from 50,000 units to 500,000 units is a 900% increase. If Musk pulls that off, it would be a rare and historic feat. I pulled a book I wrote in 2008, *Ford Model T: The Car that Put the World on Wheels*, off the shelf to look at Henry Ford's accomplishment. From 1910 to 1914, annual output at the new Highland Park plant skyrocketed from 19,050 cars to 202,667—a 968% increase in four years. And that was just the start of a colossus that was churning out over two million Model Ts annually by 1922.

If Musk can execute his Tesla plan by 2018, comparisons to Henry Ford will inevitably be made. Both men built billion-dollar empires and were global disruptors. Both were dictatorial leaders. Ford became an instant folk hero when he announced the $5 work day. Musk's fans treat him like a rock star.

But his manufacturing vision relies on finding veteran production engineers to ramp up volume ten-fold in two years. Unfortunately for Tesla, Musk hasn't been able to keep vice presidents in charge of manufacturing around long enough to create that robust structure. Indeed, according to my supplier friend and experts familiar with the Fremont operation, Tesla has been a "revolving door" for manufacturing experts.

But a dream-maker has arrived: Peter Hochholdinger, the former *produktion meister* at **Audi**, is Tesla's new Vice President of Vehicle Production. He is charged with rapidly implementing a strategy to make the Fremont plant into a Californian Ingolstadt. Bets are already being placed on how long Hochholdinger will last there.

Behind Henry Ford was a loyal team of determined, hands-on plant men—"Cast Iron Charlie" Sorensen, Peter Martin, Bill Knudsen and others. They were the real brains behind their company's early success. Elon would do well to heed Henry's example.

**Lindsay Brooke**, Editor-in-Chief


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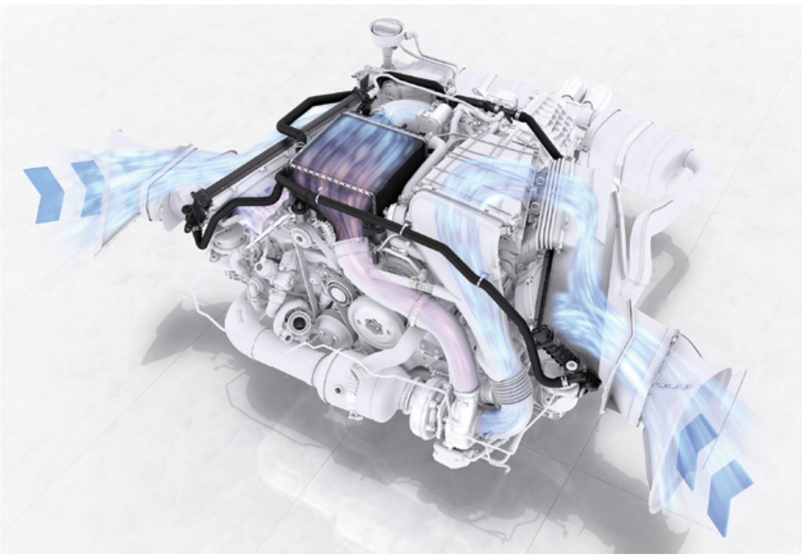
**POWERTRAIN**

# How Porsche met cooling challenges on the new 4-cylinder Boxster



Charge air cooling system of the Porsche 718 Boxster S. Engineers noted that packaging was a challenge.

New engines always bring fresh design and engineering challenges, but **Porsche**'s switch to a turbocharged flat 4-cylinder for the latest generation 718 Boxster (http://articles.sae.org/14582/) created one that resulted in 34 possible solutions.

The challenge: How to install the car's intercooler and associated pipework for two lateral cooling systems in an engine bay designed for a naturally aspirated flat-six?

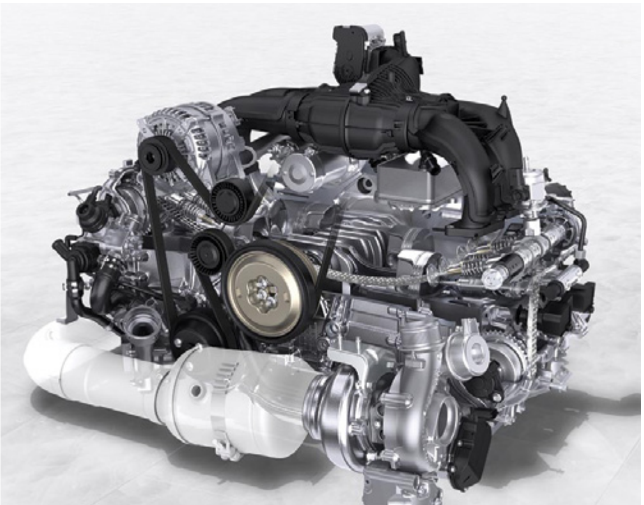
"We needed to ensure all components were in the right place, with no compromise of efficiency," said senior engineer Michael Wessels, who has the unusual job title of Manager, Vehicle Periphery Design, Boxer Engines.

The potential packaging solutions list was narrowed again and again until there were two, he explained. These were rigorously pursued: "Eventually a final decision was reached that met all criteria."

The engine, designed in parallel with the new 3.0-L bi-turbo flat-six, coded B6, for the Porsche 911 (see http://articles.sae.org/14336/), took four years to complete from conception to production. Wessels and his team of 20 were occupied with the intercooler, its air control and its thermal requirements throughout that period.

He explained that indirect cooling using an extended circulation loop was used to cohere

Rolling chassis of the new Porsche 718 Boxster. Particular attention has been given to the exhaust system and the sound it produces.



The 2.5-L Porsche 718 Boxster engine produces a claimed 257 kW.

Variable-geometery turbocharger used on the 2.5-L Porsche 718 Boxster.

with required design and aerodynamics criteria.

The lateral air intakes behind the trailing edge of the car's doors are used for indirect cooling. Reducing the temperature of charge air is via an auxiliary loop of the cooling system. A heat exchanger is positioned over the engine in which compressed air from the turbocharger transfers some of its heat to the coolant, the liquid then flowing through one radiator per air intake.

There are two lateral cooling systems and Wessels said the intercooler is sufficient for both road and track duty.

## Turbocharger "preconditioning"

The Boxster's engines—Porsche's first production 4-cylinder units since the 911E 40 years ago, although the hybrid 919 race car has only four—are codenamed B4. They share about 40% of their bill of material with the 911's B6 unit. The new Boxster engines include a 2.0-L that is rated at 220 kW (295 hp) and a 2.5-L for the 'S' version of the car rated at 257 kW (345 hp). These represent about a 26-kW (35-hp) gain over the previous Boxster flat-sixes.

Also impressive is the B4s' torque production. The 2.5-L achieves 420 N·m (310 lb·ft) from 1900 to 4500 rpm, an improvement of 60 N·m (44 lb·ft), while the 2.0 L gains an extraordinary 100 N·m (74 lb·ft) to reach a peak 380 N·m (280 lb·ft). Each engine has a short stroke of 76.4 mm (3.0 in) and is redlined at 7500 rpm.

The 2.0-L with optional PDK (dual-clutch) 7-speed transmission and Sport Chrono Package reaches 100 km/h (62 mph) in a claimed 4.7 s—0.8 s quicker than the outgoing comparable model. The S achieves it in 4.2 s, 0.67 s ahead of the old S. The 2.0-L Boxster's Vmax is 275 km/h (171 mph) and the 2.5-L S can do 285 km/h (177 mph), claims Porsche. Fuel economy with PDK improves by a best 13%. A 6-speed manual gearbox is standard.

To handle the additional torque, the new engines' driveshafts are thicker in cross section.

Porsche decided a single turbocharger for each engine was satisfactory. The 2.0-L has a classic wastegate design but the 2.5-L gets VTG (variable turbine geometry) technology a la the 911 Turbo. Porsche claims to be the only auto manufacturer using VTG in production gasoline-engined cars. It gets a second waste gate for optimal efficiency by targeted control of the exhaust gas stream, according to Porsche engineers.

The VTG turbocharger also has a "pre-conditioning" mode at part load when the driver selects Sport or Sport Plus profiles. The bypass valve is closed, ignition timing retarded, and the throttle opened slightly. The effect is to boost air throughout and also boost charge pressure, so when the accelerator pedal is flattened again, the higher charge pressure immediately delivers higher torque.

Additionally, a Dynamic Boost function operates when the accelerator is briefly lifted, the throttle remaining open but with fuel injection cancelled. In this situation, charge pressure doesn't drop completely and the engine will react immediately to another shove on the pedal by responding like a naturally-aspirated engine.

Getting the turbo to sound "right" to the driver's ears in all conditions was an added challenge, the engineers noted. And as with the 911, the Boxsters get a Sport response button for 20 s of what Porsche terms "spontaneous responsiveness."

Like the new 3.0-L 911 engines, the Boxster's use centrally-positioned fuel injectors. System pressure has been increased to 250 bar (3626 psi). Variable valve lift control is employed on the exhaust camshaft, while the inlet side uses Porsche's established VarioCam Plus system.

Porsche engine designers focused on reduction of friction losses as well as increased output. The B4's cylinder liners feature an iron-plasma-coated surface, and a fully variable oil pump and switchable water pump are used.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## Aural integrity maintained

The new 718 may look externally similar to the outgoing model but in fact it is very extensively, if subtly, changed. All panels and exterior components except its folding fabric roof (operating time to open or shut: 9 s at vehicle speeds up to 50 km/h) and its windshield are different, giving the car a tauter look and an enhanced road presence. The car's nose is lower and features exceptionally large air front intakes. Fenders and side sills are re-styled and wheels are 19-in standard, 20-in optional.

The rear wing is wider, its aerodynamic effect optimized according to roof up or down; the wing extends 45 mm with the roof up and 55 mm when the roof is folded (1.77 and 2.16 in). The car's optimum aerodynamic figure is 0.31 Cd.

The Boxster chassis has been retuned and there is a new lateral member to strengthen the rear subframe and enhance rigidity. Shock absorbers get larger piston and cylinder tube diameters and additional rebound buffer springs are used. The 911 Turbo's electric power steering has been adapted and is claimed to be 10% more direct than the outgoing car's.

Porsche Active Suspension Management (PASM) with a 10 mm (0.39 in) lower ride height is available. The S offers an optional 20 mm (0.79 in) lower sport chassis.

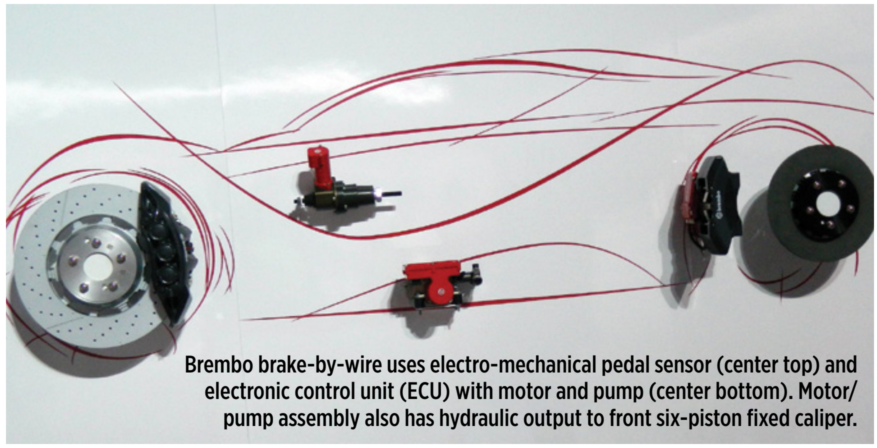
How does the new 4-banger boxer go? Very well indeed. The author's brief experience with both versions at the Fontage **Michelin** Test Center near Marseilles, France, showed the 2.5-L S reaching more than an indicated 250 km/h (155 mph) on the long straight before a banked left hand corner.

Aficionados of the aural signature of all Porsches who are fearful something may have been lost in the translation to 4-cylinder turbo power, need fear no more. Both 2.0-L and 2.5-L 718 Boxsters have convincing "sound" engineering. The 2.0-L car has a single oval tailpipe, the S two round tailpipes. Both have an optional, driver-selected sport exhaust system that produces more than a hint of race-car decibel levels.

**Stuart Birch**

CHASSIS

# Brembo brake-by-wire will be production-ready before 2020



**Brembo brake-by-wire uses electro-mechanical pedal sensor (center top) and electronic control unit (ECU) with motor and pump (center bottom). Motor/pump assembly also has hydraulic output to front six-piston fixed caliper.**

The potential market for an electric braking system is apparent to automotive engineers, but none is now in vehicle production. Such a system adds a level of precision to braking itself, but even more important, brake-by-wire fits into the engineering picture to meet the low-emissions/higher fuel economy mandates in government regulation. And it obviously could be easier to integrate into semi-autonomous and autonomous operation.

Premium braking system supplier **Brembo**, in an auto-show display, featured a system it already has shown to many automakers. Electric foundation braking has been in development at Brembo for some 15 years and as Chief Technical Officer Georgio Ascanelli told *Automotive Engineering*, it has potential for considerable further development.

Other electric braking systems developed to date have posed durability/reliability questions, Ascanelli noted. For contrast, he pointed to the Brembo design's use of one central ECU and four corner modules.

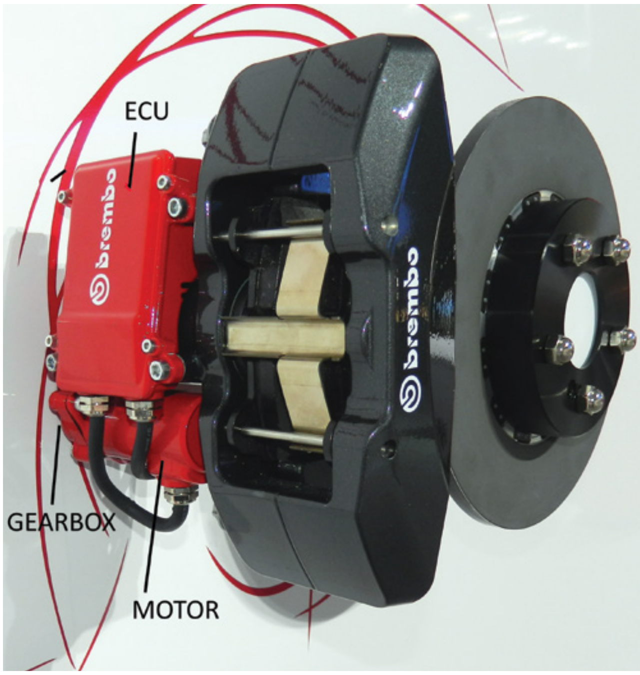
"It could operate with a failure of the other four," he said, so there is coverage for even simultaneous multiple failures. Some separation of the battery supply system also would be needed to fit into this picture. With all the failure-mode analysis normal for safety-related systems, there should be an overall confidence level even for autonomous driving.

The Brembo test system has accumulated more than 500,000 km (300,000 mi) of safe operation on a sports car, Ascanelli said, and the company is completing a demonstrator to provide further evidence to vehicle OEMs. Technically, he expects the system to be ready for use well before 2020, while admitting that some OEMs consider such innovations to be risky.

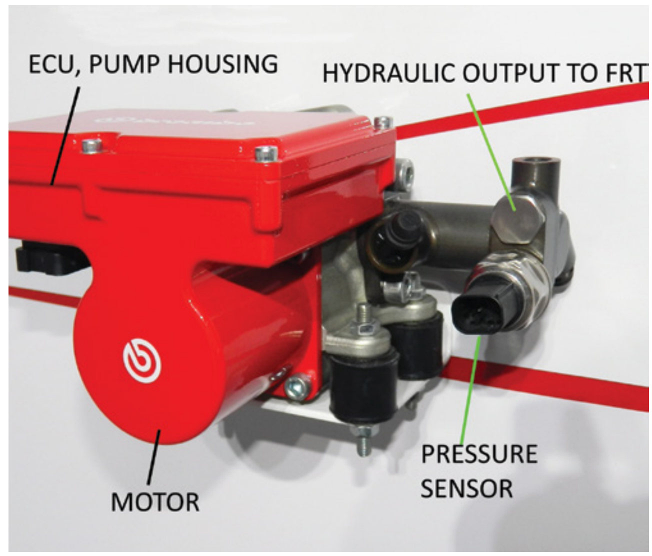
## Brake pedal just a sensor

The system begins at the "brake pedal," in this case a spring-loaded electro-mechanical sensor (with potential for redesign/downsizing) that produces a proportional signal to the ECU. This module both confirms battery system state of charge and operates a pump/motor assembly to produce a hydraulic output to the front caliper, a six-piston unit. Doesn't this make it an electro-hydraulic system? For larger cars, yes, because the design of the present rotor and caliper do not provide the wheel space needed for a purely electrical system.

Using the basic architecture, an all-electric system could be produced for small cars, such as the **Renault** Twingo, Ascanelli explained. And with product redesign and continuous improvement, the potential of




The Brembo rear brake is all-electric, with motor operating through gearbox to actuate floating caliper. Unit also serves as parking brake.




ECU assembly checks battery system state of charge and operates motor and pump to produce hydraulic output, through fitting with pressure sensor.


Front caliper is six-piston hydraulic to provide adequate braking for larger cars. It incorporates wear sensors in the brake linings.

all-electric foundation brakes for larger models can be anticipated.

At its present state, the system response time is just 90 ms, vs. 300 ms on a conventional all-hydraulic braking system with booster and anti-lock braking actuator. The fast response time means the system can provide auto-braking improvements for both basic collision-mitigation systems and the more demanding requirements of autonomous driving, he noted.

Because the rear system is "dry" (i.e., fully electro-mechanical), using a motor and gearbox, it also lends itself to serving as the parking brake.

## Pistons positively retracted

Although the system does use hydraulics for the front brakes, the overall electrical operation permits quickly and positively retracting pistons front and rear because the circuits are being controlled with motors and an ECU. The retracted piston clearance, 0.2 mm (.001-in) or more totally eliminates piston drag on the rotor friction surfaces, Ascanelli said, which he claims accounts for about 10% of fuel consumption in city operation with a gasoline engine.

The precise control of an electric braking system also permits calibration to improve the efficiency of regenerative braking on electric vehicles and hybrids, so it boosts fuel economy for these cars. Those two factors—no drag and improved regen braking—therefore reduce carbon-dioxide emissions, he added.

An electric braking system does add components, but in addition to a simpler parking brake it eliminates the brake booster and anti-lock brake actuator. So Ascanelli said he believes the overall system can be lighter than a conventional one. The initial selling price to OEMs would have to be competitive with the conventional systems in use, he admitted, even if it costs suppliers more.

However, he believes suppliers can "get to a comparable price" by increasing volume and using feedback from the market to correct the natural over-engineering that is typical of a new design, particularly one so safety-related.

**Paul Weissler**

**ELECTRONICS**

# Powering up the new stop-start systems

**Ghosted view of the base 2.5-L Malibu stop-start system showing 1. the 12V AGM primary battery; 2. the dual battery isolation module; and 3. the auxiliary 12V AGM battery mounted in the rear for mass distribution.**

As stop-start systems gain acceptance in North America, a range of technologies including lithium ion batteries, ultracapacitors, and 48-V "mild hybrid" systems are under consideration to handle the aggressive start cycles, typically more than 20 per day, that are required of these systems. Stop-start is aimed at reducing vehicle fuel consumption and emissions by reducing engine idling.

**Johnson Controls is ramping up production of absorbent glass mat (AGM) batteries to meet expected North American market demands for stop-start systems.**

Even the venerable lead acid battery is evolving. Enhanced flooded batteries and absorbent glass mat (AGM) technologies with deep-cycling capability are slowly displacing batteries used for several decades. While the rapid expansion of electronics overall is a factor, a key reason is the rise of stop-start applications, which require quick recharging and long lifetimes.

"Larger 12-volt AGM batteries, which deliver up to four times the typical life cycle of a conventional battery, are important to the current implementation of stop-start," said Kathi Walker, **GM** Global Engineering Lead for Stop-Start Systems. "Lithium-ion batteries could be used in the near future."

While Li-ion batteries may someday take over, they're currently too expensive to displace the primary storage source for starting, lighting and ignition. However, Li-ion may expand beyond its role in electrified powertrains.

"Lead-acid and advanced lead-acid batteries continue to be the best technology for internal combustion vehicles in terms of performance and cost, and this will continue well into the next decade," said Craig Rigby, Advanced Market & Technology Strategist at **Johnson Controls Power Solutions**, the largest global supplier of lead-acid batteries. "That said, fuel efficiency can be found by supplementing the lead-acid battery with other technologies such as Li-ion to deliver brake regeneration and support more electrified functions in the vehicle."

At present, stop-start is the driving force for these changes. Research published in 2015 by **Argonne National Laboratory** examined the impact of stop-start systems on vehicle starter system component life, including the battery. The study revealed that the expected lifespan of a conventional flooded lead-acid starter battery is impacted minimally from the number of starting events. Rather, battery life is mostly impacted by limited charge times between frequent engine start events and from excessive discharge during engine-off events from accessory loads. The length of and the cumulative accessory power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All-new Kia Niro hybrid uses its 48V lithium-ion battery pack for hotel loads, eliminating 12V battery.

draw during each engine shutdown event has a direct and strong effect on battery longevity because of the depth of discharge. If the battery is returned to a full charge between engine starts, the effect on battery life is negligible or nonexistent.

Conversely, the ANL research showed that battery failure will occur more quickly if a full charge is never reached regardless of the number of engine start cycles. Also, idling was determined to not be an effective method of recharging the battery because of low alternator power output; driving is best. (See http://www.anl.gov/energy-systems/publication/stop-and-restart-effects-modern-vehicle-starting-system-components.)

Simply providing the power to regularly restart engines is just one challenge for electrical system designers. Keeping radios and interior lights at constant levels—a "buffering" role played by the 12V battery—is a critical factor for consumer acceptance of stop-start vehicles.

"During an auto start, there is a voltage dip in the vehicle's electrical system," Walker said. "In order to maintain functionality of cabin systems such as interior lights, there are technologies that can be added to a vehicle to protect the components against a voltage dip and maintain customer satisfaction during an auto start. These technologies include dual batteries, DC/DC converters and ultracapacitors."

A handful of vehicles already use dual battery systems to support large numbers of power-hungry features and functions. It may become more common as more safety critical technologies are combined on vehicles that use complex fuel-saving techniques.

The 2016 **Chevrolet** Malibu 2.5-L's stop-start system, for example, uses two batteries: a 12V battery under the hood and a second one mounted in the rear. The system (equipped with a tandem-solenoid starter for faster starts) is calibrated so that when the ICE shuts off, the second battery is signaled to handle the car's hotel loads—i.e., power the lights, climate control, audio, windows and door locks. Also, with the engine off the car's climate control remains on, albeit operating on reduced power.

"Dual battery systems will become more common as they provide value in several ways," Rigby said. "Having two batteries provides better voltage stability during start-stop events as well as redundancy to support the high degree of reliability necessary with advanced safety systems. In addition, a dual battery, dual-chemistry system allows the optimization of performance and cost to deliver the best value for automakers and consumers."

Often, the second battery is part of a 48V system. Engineering higher-voltage systems can make it simpler to power functions such as parking cameras and integrated sensors. Though going to 48V is beneficial, experts said the industry trend has been to retain the 12V systems. But at the 2016 Chicago auto show, **Kia** unveiled its 2017 Niro hybrid CUV, which uses its lithium battery pack to power the headlights, windshield wipers, and other traditional tasks of the 12V lead-acid battery, which has been eliminated (see http://articles.sae.org/14614/).

"Higher voltages help keeping the peak amperage down," explained Stefano Zanella, Business Development Manager at **Texas Instruments**. "Batteries are sensitive to the ratio of their capacity expressed in amp hours and the load current, increasing their lifetime and reducing cable size, making them cheaper and lighter."

A 48V rail will require a DC/DC converter or a second 12V battery, he explained, because there are just too many 12V components in a car that are very cheap and cannot be effectively replaced by 48V components.

Some developers are turning to ultracapacitors to provide quick boosts for stop-start systems. They can provide power to turn the engine over without straining the battery.

"Since ultracapacitors do not rely on a chemical reaction to supply their energy, ultracapacitors can discharge their stored energy very quickly," GM's Walker said. "The 2016 Cadillac ATS and CTS take advantage of ultracapacitors to provide a quick energy boost during the auto start. This burst of energy allows the engine to start faster and helps in providing a more seamless restart for the driver."

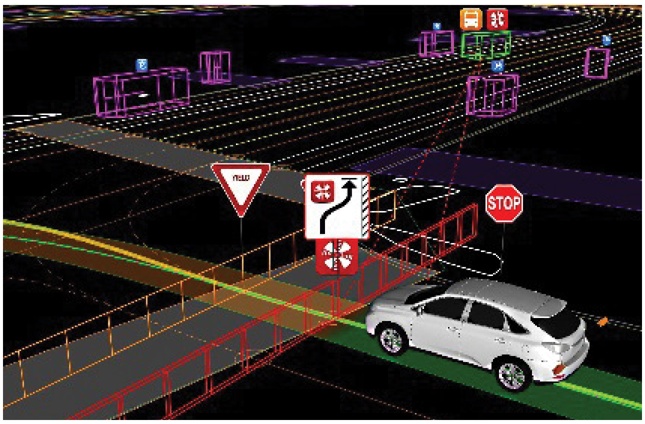
This design technique can extend the lifetimes of lead acid batteries. The Cadillac system, co-developed with **Continental**, uses **Maxwell Technologies** ultracaps to augment battery power. It is not available on the ATS-V and CTS-V performance versions.

"Adding an ultracapacitor lets the battery deliver significantly lower starting currents, which leads to less degradation of the battery chemistry," said Jens Keiser, Maxwell's senior product marketing manager. "Also, the battery sees fewer high-current peak demands."

**Terry Costlow**

ELECTRONICS

## Google talks self-driving vehicle development




**In this scenario, a Google vehicle detects an ambulance siren, uses its sensors to "see" the area and yields at intersection until an emergency vehicle passes through safely.**

As automakers add advanced driver-assist systems to conventional passenger vehicles, they are developing one path to the fully autonomous vehicle—but not the only one. So, the inevitable question: When will fully self-driving cars arrive and what will they be like?

**Google**, with years of experience in this area, has predicted as early as 2020. Work underway was described by the project's CEO, John Krafcik, who spoke at the recent **J.D. Power/ NADA**/NY Auto Show forum.

Many people envision getting into their fully-autonomous cars, sitting back and perhaps taking a nap, reading the latest news on a tablet or even eating breakfast during a drive to work. But there's an application that is likely to come sooner, and it promises to create a whole new market: a self-driving car for the handicapped, visually impaired, and elderly who no longer can drive safely. That was the vision that excited Peter Welch, President of NADA (National Automobile Dealers Association), who also spoke at the forum.

### Short range mobility

Krafcik described readiness of self-driving cars as a "process, not a point in time." So at first, as Welch envisions, the cars might provide mobility for people who can be satisfied with a shorter range. As the process improves, the range and top speed should increase and the potential market should grow correspondingly.

However, Krafcik said Google's 25 mph (40 km/h) speed-limited vehicle is easier for the development process because kinetic energy at 35 mph (56 kph) is twice that at 25 mph.

For many people who are no longer able to drive, the mobility afforded by a self-driving car would justify its

**Halloween brings a special situation to local streets—children in costume and in some cases carrying large objects.**

ownership. Currently, Google precisely maps routes for its test cars, so a similar practice could provide owners a list of trips to take, with new ones added as needed and possible.

The Google-developed cars are EVs without steering wheels or pedals. Because they're limited to 25 mph, they fit the description of smart "neighborhood cars." They could serve relatively large areas with adult communities, many of which are located close to shopping and medical facilities. Owners in such areas also could be satisfied with slow-but-safe personal transportation suited primarily for generally good-to-fair weather.

Google also has a fleet of **Lexus** RX450h's, modified for the self-driving system, and with steering wheel and pedals removed.

## Predictive software

The Google software is written to be predictive, that is to know what everything movable around the car will do. According to Krafcik, it generally will predict a cyclist will ride by and a pedestrian will cross the street. So the car will slow to a safe speed and move away from the cyclist, then yield to the pedestrian. But road situations can be complex. On Halloween, for example, costumed children in the street were a new experience, he explained, and Google rightly decided children can be more unpredictable than adults, particularly when in costume.

The ability to deal with emergency vehicles on the road was addressed early by Google. It has a "library" of various sirens (a fire truck siren has a long wail, an ambulance a series of short shrills) and as soon as the car "hears" the siren it will stop to let it through an intersection. If the vehicle is coming from behind, it will slow down and pull over.

Google's official position is that "we will be ready for some people and road environments first, and as our technology improves, it will be available to more people."

Krafcik quipped that Google is "all about data and measurements," noting that company engineers have developed hundreds of tests, in addition to logging over 1.5 M miles in real-world road testing since 2009. The company each day performs 3 M miles of simulation.

The Google project began by using a flat section of CA Route 101, with volunteering employees as passenger/drivers.

## Self-contained software

A noteworthy aspect of the Google project, Krafcik told the forum, is that presently all the software is self-contained. "Our autonomous cars use on-board processing power, nothing from the cloud," he said. "We are not relying on communication via V2V (vehicle-to-vehicle) or V2X (vehicle-to-infrastructure) because either can go down."

Such cars seem to involve more complexity than a full-range autonomous car with a capable driver available for special situations, such as sudden changes in weather, highway blockages and high road speeds. However, the opposite may be more likely to be true, because of the limits on its use.

The two-passenger Google self-driving cars have been rolling along streets in Mountain View, CA, near Google HQ, in Austin, TX, and, to increase experience with rain, in Kirkland, WA. In addition, Krafcik said, Google recently began testing in snow, but he provided no details.

The cars' dome-shaped sensors have what was described as the equivalent of a windscreen wiper, but in general the weather has more effect on cameras than lasers, as the latter can "see through" the raindrops. At this stage, if the rain is severe, visibility is poor and/or road conditions are slippery, the cars slow down and may even pull to the side of the road until conditions improve.

## Prediction was wrong

No cars are totally accident free, even if that's the dream of self-driving car proponents, and certainly not with driver-operated vehicles also on the road. In a widely-reported accident last February in Mountain View, the Google car pulled into the right lane to prepare for a right turn on red. It detected sandbags near a storm drain blocking its path. So it stopped, let several cars pass by, then angled out to pull around. In doing so, it "predicted" a slow approaching bus would yield, but it didn't and a minor collision resulted.

Google is not working solo on its project. A long list of suppliers are assisting, including **Bosch**, **Continental**, **FRIMO**, **LG Electronics**, **Prefix**, **RCO**, and **Roush Industries**.

Legal issues must be sorted out, Krafcik maintained. California requires a licensed driver behind the wheel. NHTSA's interpretation has been that with what the agency considers to be the highest level of autonomy (Level 4, or "L4"), robotic controls can count as a driver, with financial responsibility assumed by the owner—or if an accident is caused by a defect, by the manufacturer.

There are NGOs (non-governmental organizations) such as California-based **Consumer Watchdog**, that have objected to this. So the autonomous car will need a very high level of "proof." However, the potentially large market for a continuously improving lower-speed self-driving car, for a broadly-defined "neighborhood" area, is recognized, and so seems to be likely the first to come.

**Paul Weissler**

TESTING

# Ford upgrades dyno sleds to handle 2017 Super Duty diesel's might

What happens when the performance of your newly-developed vehicle exceeds the capabilities of the test equipment used to measure it? **Ford** Truck engineers faced that dilemma while preparing for the **SAE** J2807 towing tests of the all-new 2017 F-Series Super Duty.

Their conclusion: "We need a new dyno."

The SAE J-standard, "Performance Requirements for Determining Tow-Vehicle Gross Combination Weight Rating and Trailer Weight Rating" (http://standards.sae.org/j2807_201602/) replicates how a laden vehicle climbs the infamous Davis Dam grade—a daunting 11.4-mi (18.3-km) section of Arizona State Road 68 near the Colorado River. That long, tortuous pull starts at sea level and climbs to above 3000 ft, and its maximum 7% grade—a seven-foot incline per every 100 ft of linear distance—is renowned among automotive test teams for overtaxing cooling systems, frying brakes, and separating the champs from the chumps in terms of towing and hauling capability.

During development of the 2017 F-250/350, Ford engineers recognized that the increased torque of the 6.7-L diesel V8, expected to exceed 900 lb·ft (1220 N·m) and top that of the 2016 **Ram**'s **Cummins** diesel (Ford has yet to release its SAE-certified power and torque ratings), along with the new truck's significantly stiffened chassis, would outpace the capability of their existing dyno sleds.

This is no real surprise, given the steady escalation of American diesel pickup muscle. Consider that Ford's first 6.9-L diesel V8 (**Navistar**-built) entered the fray in 1982 with 170 hp (127 kW) and 315 lb·ft (430 N·m). The 2016 Super Duty's 6.7-L V8 delivers 440 hp (328 kW) and 860 lb·ft (1166 N·m)—output that not long ago would've qualified for Class-8 truck duty.

"In more than 25 years of doing this [tow testing] work, we used the same dyno, which did the job," explained Jim Sumner, Ford product development engineer. "But the new truck is so powerful we needed new equipment to test out its capability." The upgraded towing dynamometer is in service at Ford's Arizona Proving Grounds, allowing engineers to simulate the actual Davis Dam road testing (as well as testing on other U.S. mountain highways).

Engineers upload digitized map topography to the dyno sled, which adjusts to the correct grade. The sled employs an electric brake limiter to provide drawbar "pull" against the vehicle, simulating a climb even while on level ground.

2017 Super Duty prototype with new Taylor RSL-25K dyno sled replicates the Davis Dam climb at Ford's Arizona P.G.

Slick and compact RSL-25K Taylor dyno sled weighs 6173 lb, has maximum drawbar capability of 5620 lb.

Designed and supplied by Milwaukee-based **Taylor Dynamometer** (http://www.taylordyno.com/), the RSL-25K dyno sled acquired by Ford is capable of a maximum drawbar pull of 5620 lb (2549 kg)—a 181% increase compared with the 2000 lb (907 kg) from Ford's previous dyno. This enabled simulation of steeper hills, Sumner noted. He said a common simulated grade used for testing is approximately 7%, to replicate the Davis Dam run, but the new towing dynamometer used at Ford's Arizona Proving Grounds can simulate up to a 30% grade.

The SAE J2807 standard includes acceleration, climbing, launching, and vehicle weight parameters. Vehicles with a gross vehicle weight rating (GVWR) less than 8500 lb (3855 kg) must carry a 150-lb (68-kg) driver and a 150-lb passenger. Vehicles heavier than 8500 lb add an extra 100 lb of equipment.

For a given trailer weight, J2807 compliance means the tow vehicle must accelerate to 30 mph in under 12 s, and accelerate to 60 mph in under 30 s. Roll-on acceleration 40 to 60 mph on a level surface must be accomplished in under 18 s. Vehicles with dual rear wheels are permitted extra time to complete this test. For the climb test that replicates Davis Dam, tow vehicles must sustain a minimum 40 mph with their A/C on its highest setting. "Duallies" again have a lesser (35 mph) minimum-speed bogie.

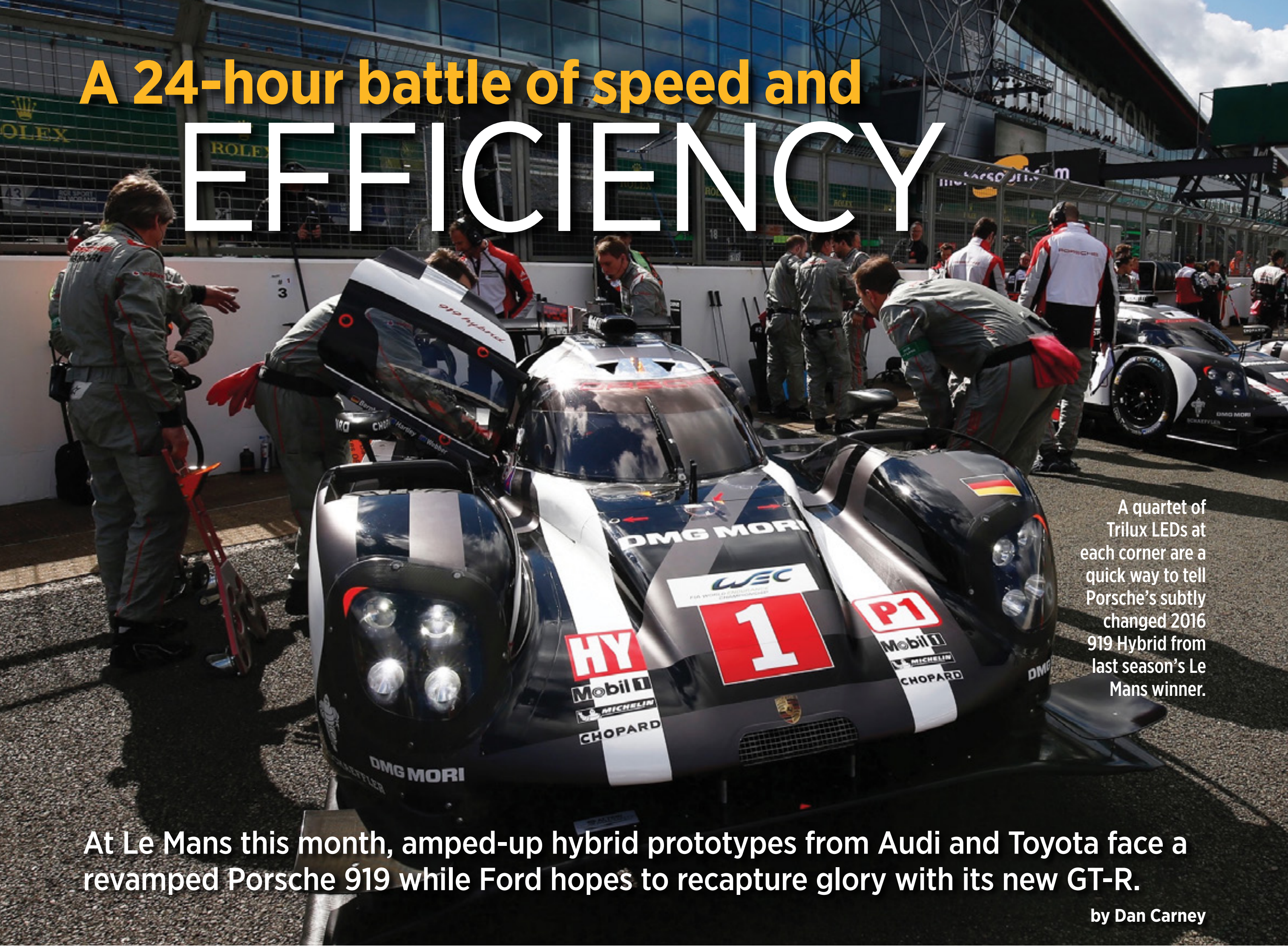
The J2807 launch test replicates a 12% grade, and requires the tow vehicle to move 16 ft (4.9 m) uphill, from a standstill, five times within five minutes in both forward and reverse.

Expect **GM**, **FCA**, and possibly **Nissan** to follow suit and upgrade to more-capable testing equipment—good news for Taylor and other dyno makers—as the industry battle for heavy-duty pickup hauling and towing bragging rights shows no sign of abatement.

**Lindsay Brooke**


Ford test engineer observes vehicle towing performance while undertaking SAE J2807 testing at the Arizona P.G.

# A 24-hour battle of speed and EFFICIENCY




A quartet of Trilux LEDs at each corner are a quick way to tell Porsche's subtly changed 2016 919 Hybrid from last season's Le Mans winner.

**At Le Mans this month, amped-up hybrid prototypes from Audi and Toyota face a revamped Porsche 919 while Ford hopes to recapture glory with its new GT-R.**

**by Dan Carney**

World endurance racing at Le Mans is no longer only about who finishes first after a grueling 24 hours, but also about winning with the greatest energy efficiency. For 2016, the **Federation Internationale de L'Automobile** (FIA) has tightened the fuel allowance for the top-echelon Le Mans Prototype 1 (LMP1) category in an attempt to further link racing and efficiency—and as an attempt to arrest the stunning increases in speed seen during 2015.

This year, the fuel allowed per lap has been reduced by 10%, for an approximate reduction in energy per lap of about 10 megajoules (2.77 kW·h). Peak instantaneous fuel flow also is reduced by 10%.

At the same time they are facing this new energy restriction, the **Audi** and **Toyota** works teams are addressing performance deficits that put their hybrids behind the **Porsche** team that dominated both the World Endurance Championship and the 24 Hours of Le Mans in 2015.

Porsche ran the most electrically intensive of the available formulae in the FIA's mandatory hybrid-electric specifications, a system that provides 8 MJ (2.22 kW·h) of electric assist per lap to the combustion engine.

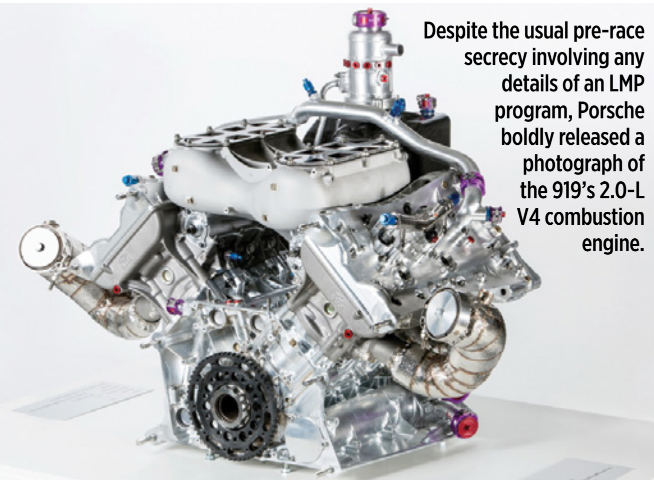
Previously, Toyota and Audi opted for more combustion-oriented specifications, with Toyota at a 6 MJ (1.66 kW·h) level with a large-displacement naturally aspirated V8 gasoline engine and Audi with a 4 MJ (1.11 kW·h) electric drive mated to its turbodiesel V6 combustion engine.

Porsche's speed in 2015, along with the reduced fuel flow for 2016, convinced Audi and Toyota each to move up one step in the electrification hierarchy. Toyota joined Porsche at 8 MJ of assist, while Audi prefers the additional fossil fuel available to its turbodiesel at the 6 MJ level.

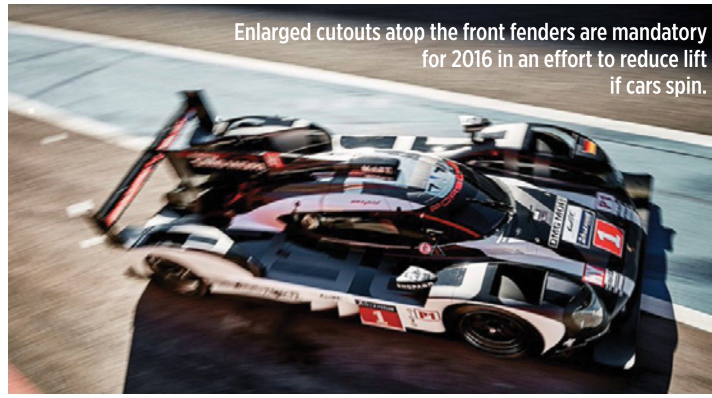
According to 2016 rules, gasoline engines with 8 MJ electric assist are allowed 134.9 MJ (37.47 kW·h) per lap of fuel and a maximum fuel flow of 87 kg (192 lb) per hour. Diesels with 6 MJ electric assist have 131.2 MJ (36.44 kW·h) of fuel allowed per lap and 77 kg/h (169.7 lb/h). If Audi had opted for 8 MJ of assist to match its gasoline-powered rivals, its energy per lap would have been limited to 126.3 MJ (35.08 kW·h) and peak fuel flow would have been 74.1 kg/h (163 lb/h).

A review of the LMP1 contenders for 2016 shows all three works team cars measure 4650 mm long, 1900 mm wide and 1050 mm high (183 x 75 x 41 in), with a minimum weight of 875 kg (1929 lb). The three teams rely on **Michelin** for their tires. A required change to the cars' design is a 45% enlargement of the openings in the tops of the front fenders. This is intended to reduce lift in the event a car turns sideways at speed.

And LMP1 teams have agreed with the FIA to limit entries to two cars per team, in an effort to contain costs. This means that it is not possible, however difficult and unlikely, for a single team to sweep the top three podium spots. It also might increase the likelihood of each team earning a spot in the final photograph.



Despite the usual pre-race secrecy involving any details of an LMP program, Porsche boldly released a photograph of the 919's 2.0-L V4 combustion engine.



Enlarged cutouts atop the front fenders are mandatory for 2016 in an effort to reduce lift if cars spin.

## Porsche 919 Hybrid

As the incumbent champion, Porsche has unsurprisingly returned with less-dramatic changes than its challengers. The 2016 919 Hybrid retains its 2.0-L 90° V4 gasoline engine boosted by twin **Honeywell** turbochargers that drives the rear wheels through a 7-speed sequential gearbox. The case's construction is a blend of carbon fiber with titanium inserts and aluminum castings. The combustion engine uses **Bosch** engine management and is fed from a 62.5-L fuel cell.

Electric power from the 8 MJ-class hybrid drive system is stored in an 800-V **A123 Systems** lithium-ion battery pack; that power is directed to the front wheels. By doubling the usual system voltage from 400 V to 800, the 919 enjoys quicker recharges and is able to use thinner gauge (and thus lighter) wiring. The 919 rolls on **BBS** forged magnesium wheels.

However, while the fundamentals of the car are carried over, each of these parts has been massaged and refined, according to Porsche team principal Andreas Seidl. That's because as fast and dominant as last year's car was relative to its competitors, the team was nevertheless immediately aware of specific shortcomings that needed to be addressed, he said.

Last year's car was built after only a year of LMP1 competition for Porsche, so naturally there was the opportunity for many more lessons to be learned. That experience applied to this year's car, Seidl explained.

"There's not a single main evolution," he said. "We are quite happy with the basic concept of the car. Which means the new car is again more an evolution. They worked on really every single part of the car. Now it is all about getting the maximum performance out of this package as well as making sure the car is reliable."

The aerodynamic refinements made to the 919 aren't immediately visible, but they have achieved the goal of reducing drag to help offset the loss of available fuel, according to Seidl. Trilux quad LED headlights are both brighter and more efficient than last year's lights, saving energy and helping the team's drivers see better during the long hours of darkness at Le Mans.

Meanwhile, the team toiled to wring additional fractions of percentages of efficiency from each of the car's parts, seeking to mitigate the speed loss from the reduced fuel allowance.

## Audi R18 e-tron

In contrast, Audi was frustrated by last year's results and built a new car. The clean-sheet design carried over little more than the R18 e-tron name and the 4.0-L diesel combustion engine claimed to produce 514 hp (383 kW). The basic design of the 120° V6, boosted via a single **Garrett** variable turbine-geometry turbocharger, is now in its sixth racing season after starting life at 3.7 L. The latest iteration drives the R18's rear wheels through an Audi-designed 6-speed sequential gearbox that uses **Xtrac** gears. The hybrid's fuel capacity is 49.9 L.

Audi ditched its previous **Flybrid Automotive** energy storage system in favor of a lithium-ion battery pack because of the need to recover more energy for its 6-MJ boost system powering the car's front wheels. The single front electric motor drives the front wheels through a limited-slip differential.

The R18's chassis features an entirely new aerodynamic concept and completely revised front-suspension design, as the company is pressing for every possible advantage. The biggest innovation may be a change to a central high-pressure hydraulic system for running all the car's ancillary systems in place of various electric servo motors, which are much heavier.

The new hydraulic system provides boost for the power steering, brakes and clutch. It also operates some engine subsystems. Such a centralized approach may appear to present a single point of critical failure that could knock out multiple systems, but Audi engineers are satisfied with its projected reliability; the central hydraulics did not prove to be an issue during the 2016 Silverstone 6-hour race.

Audi's diesel engine is heavier than its competitors' gasoline engines, while the cars' minimum weights are the same. This handicaps Audi regarding the weight of other components, noted Technical Director Jörg Zander. Considering his car's heavier combustion engine, the idea of using a battery pack as heavy as competitors' wasn't a practical option, which steered the team to the 6 MJ category.


Audi's dramatically narrowed and raised nose increases the airflow to the front wings between the wheel arches for increased downforce with less drag.

The smaller battery pack also provides a potential packaging advantage compared to rivals' cars. But the new lithium-ion pack is considerably larger than the previous flywheel storage system, which presented a challenge to designers.

Another concern was uneven tire wear, which handicapped Audi last season because teams expect to go a pit stop or two with just fuel rather than mounting new tires at every stop. Over the course of a 24-hour endurance race, the accumulated time of additional tire changes adds up, so teams typically double- and triple-stint the tires to reduce that time spent stationary in the pits. Audi uses **OZ** magnesium wheels on its car.

This year's R18 has a much narrower central section of its monocoque and a raised nose to flow more air between the wheel arches and the nose. According to Zander, this lets the front wing provide more downforce with a smaller angle of attack, for reduced drag.

The team scrapped the linked hydraulic damper system used last year to provide anti-dive characteristics for keeping the R18 aerodynamically stable. This year's car uses more conventional dampers and also replaces the front unequal-length control arms with individual links to optimize geometry for improved use of the tires.

"We had an issue with tire temperatures last year where we had to accept big differences between the front and the rear," Zander said. "This looks much better."

## Toyota TS050

Toyota was the furthest adrift last year in terms of performance, so the company moved its TS050 racer much closer to Porsche's winning 2015 formula. In place of the TS040's 3.7-L naturally aspirated gasoline V8, the TS050 features a 500-hp (373-kW) 2.4-L twin-turbo gasoline V6.

The team was shocked by Porsche and Audi's progress last year, admitted Toyota technical director Pascal Vasselon.

"With stable regulations, when you gain 1-1.5 seconds [in lap time compared to the prior year] you are happy," he said. "Last year we gained 2.5 seconds. We were quite happy and expecting to be competitive. We found the others have gained 5 seconds.

"Things which are completely unbelievable but are facts," Vasselon asserted. "At Spa [2015] we realized we were not chasing tenths of seconds, but four seconds."

It was this stunning realization that drove Toyota to pull ahead adoption of the new engine to this year rather than 2017. The problem with last season's naturally aspirated V8: while its output was comparable to a turbocharged unit, its powerband was narrower. This left drivers at a disadvantage on the track.

"So the decision was made in May last year to change to turbocharging and not wait for 2017," revealed Vasselon. "The sweet spot [for naturally aspirated engines] is quite narrow. A turbo will give you a very wide range of rpm with fuel efficiency and at different temperature and pressure."

The TS050's gearbox is a redesigned transverse 7-speed sequential unit with a **ZF** multi-plate clutch. A new gearbox was needed because of the additional torque produced by the boosted engine.

"The gearbox had to be totally different," Vasselon said. The trouble was that last May, when the team made the decision to switch to a turbocharged engine, they had already passed the deadline for designing a new gearbox for 2016. So the Toyota engineers designed and built a new gearbox using model-based development to represent the expected loads from an


Audi aerodynamicists sought to more carefully manage the airflow over the rear of the car to whittle away at drag.

engine that did not yet exist. The good news is that this approach worked.

"It is clear that we are able to get a good anticipation of the performance of an engine before building it, as well as the dynamic behavior of the mechanical elements," said Vasselon.

But the car has yet to race 24 hours. "At the moment so far we have not seen reliability issues in the powertrain," he said, almost as if hoping it will remain so. If it does, it may be because the team was conservative in its design, producing a gearbox that surely is heavier than is absolutely required. "We could do some weight-saving" on the transmission, Vasselon conceded.

The TS050 uses **Akebono** monobloc brake calipers and **RAYS** magnesium wheels. It carries 62.5 L of gasoline.

For its driveline, Toyota dumped the supercapacitor used for last year's 6 MJ electric drive system, replacing it with a lithium-ion battery

A 24-hour battle of speed and
# EFFICIENCY

## Multimatic-built Ford GT-Rs aim to retake Le Mans, 50 years after Ford's great triumph

Despite the striking looks of **Ford**'s production 2017 GT supercar, every detail was developed in consultation with the engineers charged with preparing it for racing.

"We were able to design both [the street and racing versions] alongside each other," recalled Mark Rushbrook, Ford's Motorsports Engineering Manager. "We had a somewhat clean sheet and were able to create the great road car and great race car we wanted."

A substantial portion of Ford's raison d'etre for the revived GT was to reprise the original GT40's historic 1-2-3 finish at the 1966 24 Hours of Le Mans. It was vital that the new car be built to race so it will have the best possible chance of reclaiming Le Mans glory on the golden anniversary of its famous victory.

Typically, teams run at Le Mans with a pair of cars. Big teams sometimes run a trio, in pursuit of the podium sweep. Ford aims to maximize its chances this year by entering a pair of two-car teams. The Target Chip Ganassi team will run the International Motor Sports Association's **WeatherTech** Sports Car Championship in the U.S., while Ford races two other cars in the World Endurance Championship series. The two teams will converge with all four cars for the Le Mans effort.

The Ford GT-R was developed alongside the production version from the car's inception.

Superficially, the GT-R has the goods. Slippery appearance suggests low drag for the long Mulsanne Straight at Le Mans. A mid-engine layout suggests the car's balance should be good. A **Roush & Yates Racing Engines**-prepared twin-turbocharged 3.6-L V6 borrowed from one already proven in the IMSA Daytona Prototype category indicates the GT-R's power is strong and reliable.

But endurance racing requires a special machine and some changes were needed just to meet the GT class rules, Rushbrook pointed out. Performance equalization among cars with engines of different displacements, number of cylinders and induction types means the race car will produce less power than the street car.

While the racing GT-R shares its cylinder block with the street car, its extreme duty cycle and the reduction in power means it wears larger turbochargers, said Rushbrook. The production gearbox is not suitable for the rigors of endurance racing and has been replaced by a **Ricardo** 6-speed sequential racing transaxle. And the production GT's active rear wing that even pops up to serve as an air brake when stopping has been removed from the GT-R because movable aerodynamic surfaces are prohibited in racing.

The GT-R race cars, like the street cars, are

**Computer modeling made it possible to speed development of the new transaxle needed to handle the increased torque of the TS050's new turbocharged engine.**

pack using a **Denso** inverter. It drives an **Aisin** front electric motor and a Denso rear electric motor that assists the combustion engine driving the rear wheels. The electric motors combine for another 500 hp, but 2016 regulations limit electric drive at the Le Mans race to a maximum of 408 hp (304 kW).

Toyota switched from supercapacitors to batteries because batteries' characteristics better-suited the 8 MJ design, Vasselon said. Also, battery technology development is outpacing that of capacitors. "The batteries initially are lacking power density," he said. "A battery is good for energy density, good by weight.

"The capacitor is the opposite, it has good power density," he continued. "These devices require very high power. You have to capture the energy generated in 2 seconds. Two years ago, batteries were not good enough. Now we achieve higher power capacity with the battery than with the capacitor."

built by **Multimatic** Inc. Naturally, the Canadian company provides its Dynamic Suspensions Spool Valve technology racing dampers for the race cars. This technology was developed for Formula One and has now found its way to production cars like the **Chevrolet** Camaro Z28.

With the race- and production-car teams involved from the start with the car's design, the racing version's development has gone smoothly, Rushbrook said.

"That has been a real strength of our program and a testament to the tools we have available," he said, noting the hundreds of chassis simulations, CFD, and powertrain modeling run before a single vehicle was built. Because Ford and Multimatic have carefully correlated their models, the physical cars performed much as expected, according to Rushbrook, with only fine adjustments required.

But the racetrack always brings unexpected challenges. At the 2016 24 Hours of Daytona in January, the Ford GT-Rs were taken out of contention by a stream of surprise reliability problems. Some of these issues arose as the result of suppliers changing parts' specifications without Ford's knowledge, Rushbrook said. Other issues were said to be expected teething pains.

This year's Daytona race saw a number of full-course yellow-flag periods, when the cars circulate at reduced speed. This exposed an unforeseen problem with driveline lash at part throttle.

But by the time of the Sebring 12-Hour race in late March, the cars' problems apparently were sorted, letting them race to the finish without incident. This bodes well for Le Mans, but asking a new team to win the GT class in its first try is a tall order. Recall that in the 1960s, Ford didn't win Le Mans with the GT40 until the company's third try. But maybe modern modeling tools have let them iterate through those failures virtually.

**D.C.**

## Who will win?

The only reason OEMs compete in a full season of LMP1 racing is for the chance to win the big one: the 24 Hours of Le Mans. The season's other endurance races are barely more than test sessions when compared to the importance of the iconic French competition. But Le Mans has some of its own rules, such as the cap on electric assistance for 2016 and the cars run a unique aerodynamic configuration not seen at the Silverstone season opener in April.

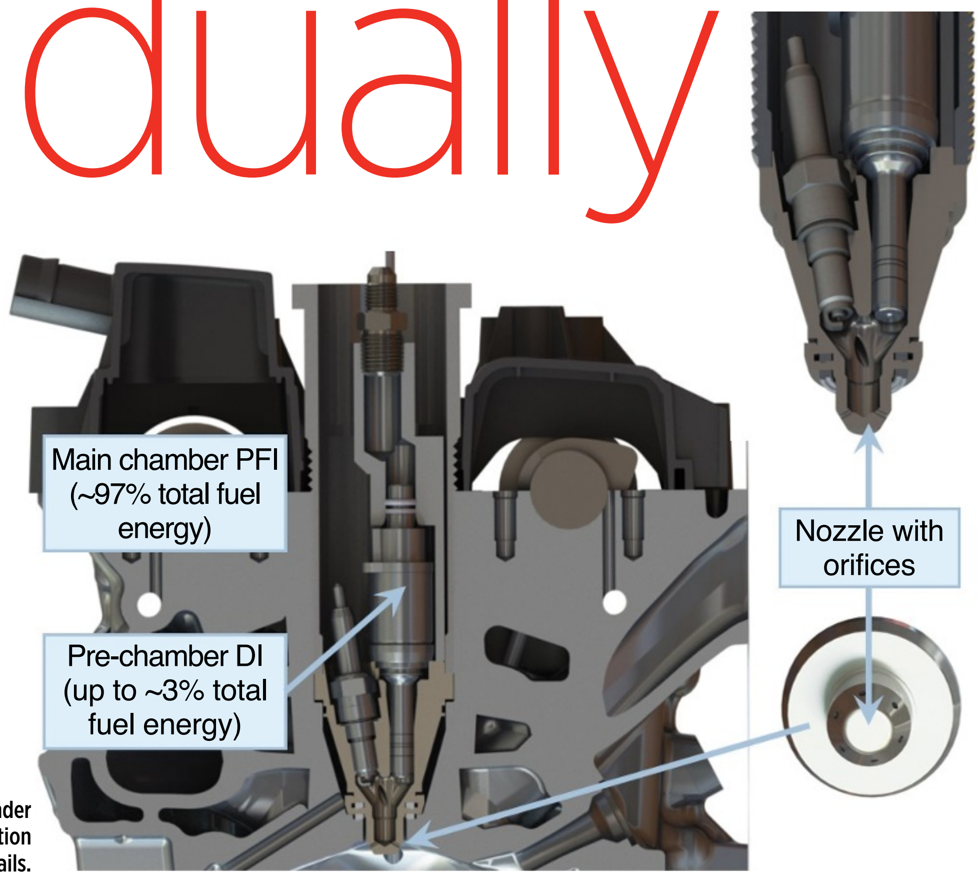
Nevertheless, as with times from test days, the results hint at the relative performance the might be expected at Le Mans. Audi Sport's Team Joest won the Silverstone race, closely followed by Porsche. But team Joest was subsequently stripped of the win for a minor technical infraction involving the post-race thickness of a chassis skid plate, a decision team leaders decided not to appeal.

Regardless, it suggests that Audi's focused effort to regain its competitive position compared to Porsche has worked. When this issue of *Automotive Engineering* went to press in late May, both teams showed they had an excellent chance to win at Le Mans. Toyota did not look as good at Silverstone, with much slower lap times. But that car's compressed development schedule likely means there could be more to be extracted before the June 18-19 race. It surely will be exciting to see each team's technical strategies play out on the track. ■

# Pushing the ICE forward, gradually

**Emergent technologies from BorgWarner, Eaton and Mahle aim for greater efficiency in gasoline and diesel engines.**

**by Lindsay Brooke**




**Cutaway view of a Mahle Jet Ignition cylinder head showing small and main combustion spaces and injector/plug details.**

Free lunches don't exist in the quest to improve vehicle efficiency and reduce emissions. No one knows this better than powertrain engineers whose work is a constant series of tradeoffs that must be tackled if the auto industry is serious about reducing $CO_2$.

Do you want enhanced drive-cycle fuel economy? It could cost you real-world performance. You say your latest dyno tests indicate efficiency improvements through charge dilution? Well, what about the impact to specific power and torque and full-load pumping losses? These are the arcane kinds of tradeoffs the industry grapples with as it seeks effective, low-cost production engine solutions, noted Dr. Terry Alger, who directs spark-ignition R&D at the **Southwest Research Institute** (SwRI).

Speaking at the 2016 **SAE** High-Efficiency Engines Symposium, Dr. Alger observed that as global emissions and fuel-consumption regulations have tightened, various engine technologies have evolved (i.e., downsizing/right-sizing) while others have gained popularity (boosting, valvetrain variability, late intake- and exhaust-valve closing strategies and waste heat recovery). All are moving forward within the confines of combustion 'knock' and stability.

"Improvements need to be on the systems level," Dr. Alger told the SAE audience.

At no time in its 130-year history has the industry worked with greater urgency to investigate and develop such solutions.

*Automotive Engineering* editors track powertrain developments as part of their regular engagements with engineers and technical specialists. The following technologies are among the newest worth noting in the promising advanced-ICE space.

## Mahle: Proving new Jet Ignition in F1

When Kimi Raikkonen's blood-red **Ferrari** SF15-T crossed the finish line in fourth place at the 2015 Canadian Grand Prix, it carried an engine technology known only to Scuderia Ferrari leadership—and a small circle of engineers at **Mahle**.

The secret is Mahle Jet Ignition, previously known within the advanced-ICE development community and SAE magazines readers as TJI, or Turbulent Jet Ignition. Capable of lean-burn operation in excess of Lambda 2, the patented pre-chamber technology is improving the combustion efficiency (and thus reducing the fuel burn) of Ferrari, **Mercedes** and reportedly other F1 teams' power-dense engines, which now must complete races with a limited quantity of fuel.

The intense F1 competition is crucial to Mahle, which hopes to productionize the technology in high volume.


**Underneath the rear cowling of Kimi Raikkonen's 2015 Ferrari F1 racecar at the Canadian GP was a secret weapon: Mahle's Jet Ignition, for greater fuel efficiency without a power sacrifice. (Photo by Veilleux79/Wiki Commons)**

In development since 2009, Jet Ignition has enabled a testbed 2.4-L production engine to achieve drive-cycle fuel economy gains of up to 25%, and has shown brake-specific fuel consumption (BSFC) of less than 200 g/kW·h with greater than 41% peak brake thermal efficiency.

"And we've seen significant reductions in engine-out NOx—levels under 100 ppm in lean conditions," noted Mike Bunce, a Mahle research specialist and expert on the technology based in Michigan.

Mahle's unique design effectively decouples the main combustion chamber and pre-chamber air/fuel charges, with the smaller pre-chamber receiving (in production-engine testing) 3% of the injected fuel, the rest going to the main chamber. Both chambers are connected by a nozzle containing multiple orifices. Injection occurs at around 60° before TDC and spark reaches the pre-chamber at around 22° BTDC. Depending on engine application, up to eight high-pressure plasma jets shoot through the inter-chamber orifices and ignite the mixture in the main combustion chamber at between 12 and 5° BTDC.

The turbulent ignition event improves combustion—the inter-chamber orifices help create swirl and the decoupled chambers enable relatively segregated rich (small chamber) and lean (main chamber) mixtures, extending the knock limit and allowing higher compression ratio. This yields more power with significantly lower emissions, said Bunce.

Early last year, Mahle and Ferrari engineered Jet Ignition into the SF15-T race engines per F1 technical regulations. The system proved flawless in its first outing at the 2015 Canadian GP— reportedly months after Mercedes-Benz first used the Mahle system in some 2014 F1 events.

Mahle's development of the technology for series-production engines continues. Certainly adoption of the concept requires dedicated cylinder-head designs, with boosting and aftertreatment systems tailored to it. But diesel-like thermal efficiencies are potentially in sight for gasoline engines using the Jet Ignition system—and Formula One has another "lever" to pull when the fueling regulations become tighter in the future.

## Eaton: Cylinder deactivation for Diesels

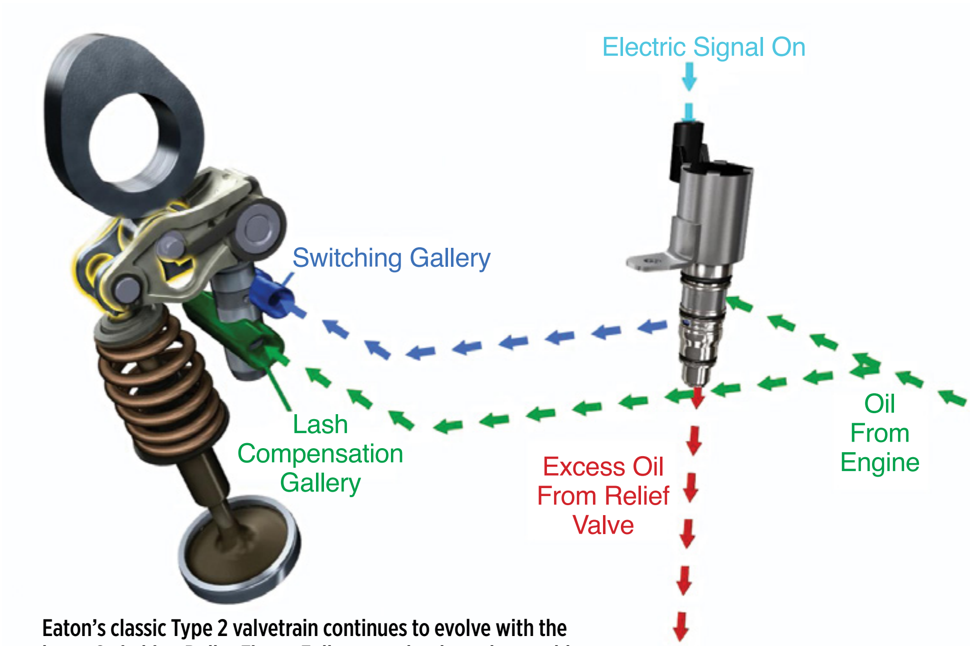
The benefit of cylinder deactivation (CDA) technology for passenger vehicle gasoline engines is greater fuel efficiency through reduced engine pumping losses. Vehicle fuel economy can be improved by an average of 2-6% using CDA, while operating in light-load (typically steady-state) conditions. Effectively a "virtual downsizing" play, CDA allows larger-displacement engines with more cylinders to maintain their power and torque while delivering the fuel consumption of powerplants packing fewer cylinders.

**Eaton** Corp.'s valvetrain system expertise has put it in the forefront of CDA developments, with research engineers now setting their sights on a new opportunity: diesel engines. Their aim is to actively regenerate the diesel particulate filter (DPF) at higher rates, during steady-state cruise (65 mph, 1200 rpm, 7.6 bar brake mean effective pressure) without the efficiency-reducing solutions of a burner, fuel dosing, or a diesel oxidation catalyst.

"While there are many definitions for CDA in the industry, ours is: Shut off the air going in, shut off the valves letting air out, and shut off the fuel. If you let the exhaust valves open you'll lose your 'air spring' [the exhaust gas charge remaining in the cylinder]," explained Jim McCarthy, Ph.D, Eaton's Engineering Manager for advanced valvetrains. The air spring he refers to results in a reduction of piston-motion induced compression during the four-stroke cycle that's worth perhaps 1% in fuel economy.

McCarthy's Eaton team, in collaboration with **Cummins Engine** and Purdue University's Herrick Laboratory, is busy these days, investigating

# Pushing the ICE forward, gradually




**Eaton's classic Type 2 valvetrain continues to evolve with the latest Switching Roller Finger Follower technology that enables cylinder-deactivation systems.**

**BorgWarner CTO Chris Thomas: to meet 2020 fuel-efficiency mandates, even the best current engines will need 'diesel like' brake-thermal efficiency—about 42% BTE, or about 30% BTE on a cycle average.**

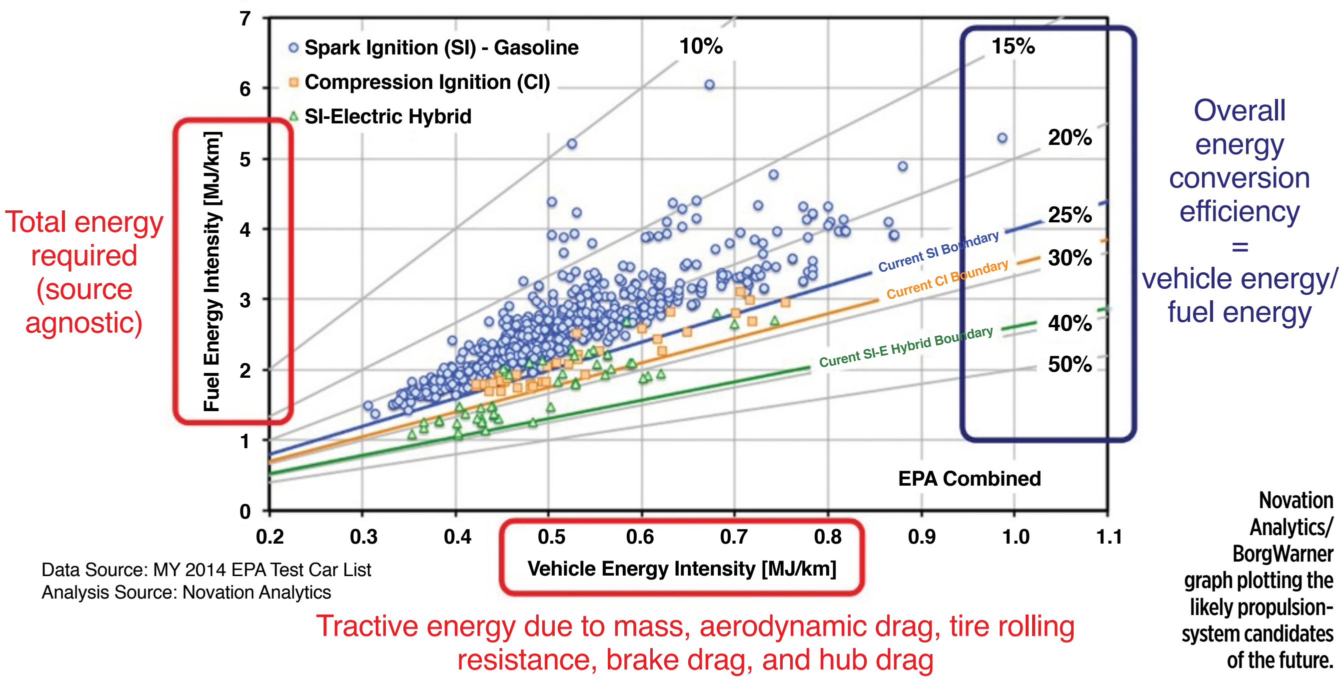
the effects of early and late intake- and exhaust-valve timing on diesel aftertreatment system thermal performance. A flurry of SAE and other technical papers reveal the promising findings of their work. Catalysts are typically effective between 250 and 450°C—and "waking them up" to clean the exhaust is a major challenge at lower engine loads, during cold start and at idle (where diesel exhaust temperatures hover between 110° and 130°C) and in colder ambient conditions. Using variable valve actuation (VVA), intake throttling can increase exhaust-gas temperatures at the turbocharger outlet and deliver reductions in fuel consumption, NOx and engine-out particulates.

Eaton's switching-roller finger followers (SRFF) and the company's classic Type 2 valvetrain, proven in millions of light-duty gasoline engines, serve as baseline hardware and are capable of response times in the 12 to 18 ms range. The SRFF design is scalable for light-, medium-, and heavy-duty diesel applications. (see SAE Technical paper 2015-01-2816.)

The diesel CDA work is being conducted on a Cummins 6-cylinder testbed at Purdue; the engine also is equipped with a variable-geometry turbo and cooled EGR. "The testbed is fitted with 'camless' VVA giving fully independent authority of all valve events, cycle-to-cycle" McCarthy told *Automotive Engineering*. "We're using the camless to figure out what VVA functions work well, what the benefits are and why it will work for production. We're looking at scalable light- and heavy-duty diesel applications, in concert with aftertreatment."

While the team has hit its share of setbacks, there are many reasons for optimism. Cylinder deactivation does increase the rate at which the particulate filter heats up, and deactivation (through valve motion and fuel injection shut-off) of two of the six cylinders enables engine-outlet temperatures up to 520°C due to the reduced air/fuel ratio. Deactivating three of six cylinders—"and we have capability to deactivate more than three," McCarthy said—at loaded idle enables a rise of 190° to 310°C at the turbine outlet with only a 2% fuel economy penalty compared with the most efficient six-cylinder operation. But a 39% reduction in fuel consumption was shown versus six-cylinder operation achieving the same 310°C turbine outlet temperature.

"By reducing airflow through the engine with our valvetrain technology, we get higher exhaust temperatures, faster aftertreatment warm-up and reduced pumping work compared with non-deactivated operation," McCarthy said. His extended team continues its work with additional focus on transient operation and control-algorithm development: transitioning groups of cylinders in and out of activation needs to be as seamless in a Class-8 diesel as it is in a passenger-vehicle V6, Eaton insists.




Novation Analytics/ BorgWarner graph plotting the likely propulsion-system candidates of the future.

## BorgWarner: Divided Exhaust Boosting

Chris Thomas paused for effect as he clicked to the next PowerPoint slide, an X/Y-axis graph loaded with data and an ominous-looking trend line. He was giving *Automotive Engineering* a preview of his upcoming talk at the 2016 SAE High Efficiency Engines Symposium.

"There's no way around it," said Thomas, **BorgWarner**'s Vice President and CTO. "Only electrified vehicles can meet the U.S. 2025 $CO_2$ targets. Okay, maybe a few extreme lightweighted vehicles with non-electrified powertrains will squeak through. But even the best engines today will need 'diesel like' brake-thermal efficiency—about 42% BTE, or about 30% BTE on a cycle average—coupled with precisely calibrated state-of-the-art transmissions and drivelines, energy recuperation, 'sailing,' engine load shifting, and more.

"If the U.S. fleet achieved an average efficiency equal to the current top 1% of SI powertrains, they wouldn't get past MY2020 regulations," Thomas noted. "And diesel-like efficiency would provide compliance only through MY2023. We're at about 21.5% propulsion system efficiency today, which is about a 14% increase from 2005. That's a huge gain—but we need to be at about 29% by 2025. That's why BorgWarner spent $1.2B acquiring Remy International—for the electrification of the propulsion system."

Thomas discussed various promising technologies aimed at getting there, including one that's elegant and comparatively low-cost: divided exhaust boosting (DEB) is a concept born of a conversation among Thomas and a few other BorgWarner engineers while waiting for an outbound flight at Frankfurt airport. It uses bifurcated exhaust ports in the cylinder head, a second integrated exhaust manifold and a few simple valves to split the engine-out exhaust gas stream into two routes: to the turbocharger and to the catalyst.

The DEB concept enables faster catalyst light-off, use of a smaller turbine and an 18° shift in the knock limit at 4000 rpm and wide-open throttle, among other benefits.

"We'd had this concept for years, valve-event modulated boost (VEMB), but it was far too complicated. It needed to be simplified dramatically. In short, we arrived at DEB using a valve that resembles the EGR valves we make. When it opens, all of the hot, blow-down gas is sent directly to the turbo," Thomas explained. "And all the exhaust gas that the piston has to push out, the residual, is directed by another valve to bypasses the turbo and go directly to the catalyst."

While the DEB concept helps Miller-cycle operation as well as enabling dedicated EGR, lean-burn and gasoline compression-ignition strategies, it's basically combustion-system agnostic. The significant change to current engine architectures would be the additional cast-in exhaust manifold and coolant jacket.

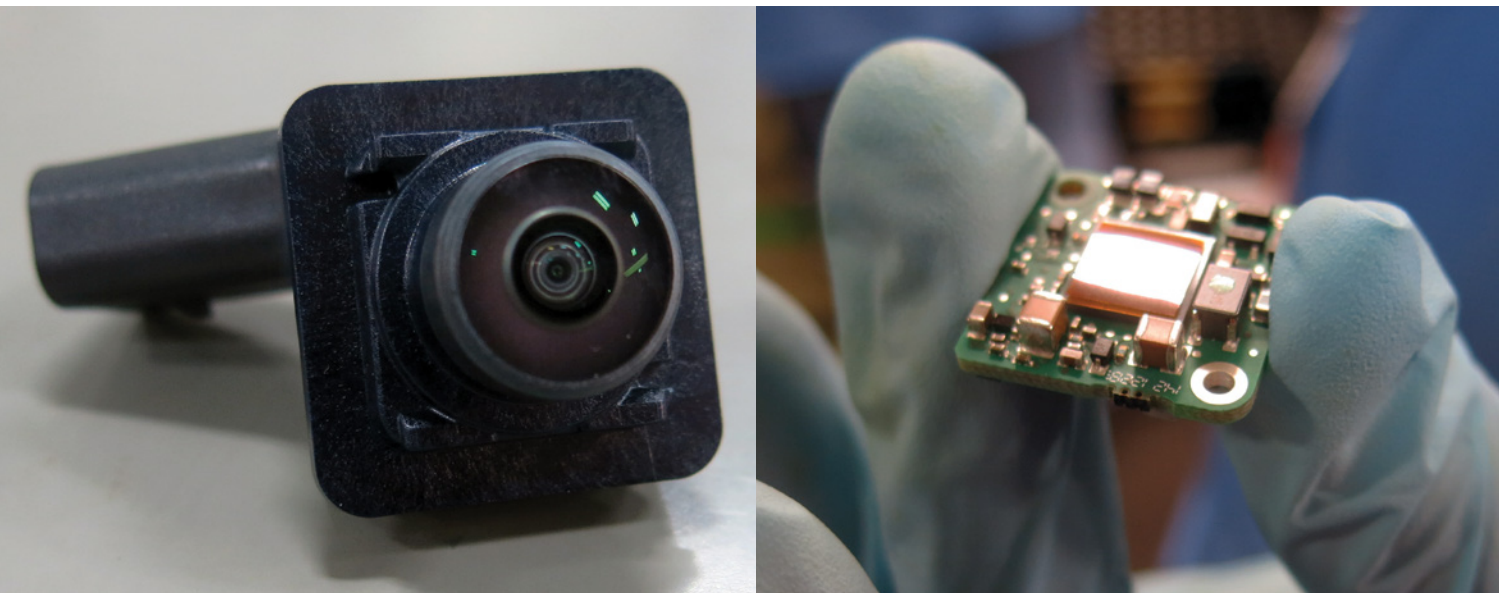
"The benefits of this are interesting," Thomas said of the DEB. "We're throttling it, but only on cold start. With all of the exhaust gas routed directly to the catalyst it lights off much faster—in fact, faster than a naturally-aspirated engine. We had to resize and rematch the turbo and we actually get a pumping benefit and about 25% more low-end torque with up to 4% higher fuel economy."

Thomas reckons that between 2025 and 2030, the majority of gasoline ICEs in the market will be running either Miller or Atkinson cycles, as they'll be part of electrified vehicle systems. The majority will be boosted (Miller-cycle), he said: "When you do really early intake valve closing you need boosting to get sufficient air into the engine." ■

# SMILE, YOU'RE ON **MAGNA CAMERA!**

**Magna Electronics is rapidly expanding production of its made-in-U.S.A. onboard cameras to keep pace with booming OEM demand for safety and vehicle-autonomy vision systems technology.**

**by Lindsay Brooke**



**The "business end" of a Magna Electronics rear-view camera (left) with the miniature image sensor board that backs it up. (All photos by Lindsay Brooke)**

Near the small Michigan town of Holly (pop. 6300) an hour north of Detroit, the **Magna Electronics** complex has quietly become a goliath within the automotive sensor industry.

Output of tiny and complex CMOS rearview cameras in Holly, currently the sole U.S. source for these increasingly vital optical components, has nearly doubled since 2014, when the facility—two plants totaling 130,000-$ft^2$—shipped its milestone 10-millionth rear-view camera to one of 47 customer locations. Since then, the Magna Holly operation has grown like the Incredible Hulk.

The site has added a third plant and now totals 190,000 $ft^2$ of camera-making floor space, noted General Manager Jeff Gary. He said daily output of rearview cameras has been expanded to about 33,000 units, up from 20,000 two years ago. They are produced on 10 dedicated assembly lines, an increase of three lines since 2014 and fed by an impressive cell-manufacturing system whose quality-assurance processes would not seem out of place in the Swiss watchmaking industry.

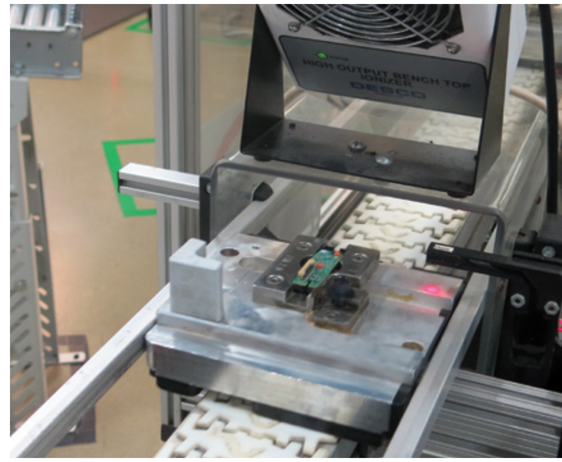
Three separate lines dedicated to more sophisticated front-view cameras with greater processing speed—a fourth line is in the works—have added nearly 1.5 M units per year since 2014. The Holly complex now ships to 181 customer points, mostly in North America. To handle the additional volume, Magna has boosted employment to 560, up from 400 workers (including engineers and technical staff) in 2014. They work a three-shift/five-day week and consider the facility to be a highly desirable place to work, at least according to a review of local social-media posts.

Employees expect daily output to reach 40,000 units as they ramp up this summer to meet the 2017 rearview-camera regulatory milestone. The Holly complex also holds the distinction of the "mother" plant for all Magna Electronics' global camera manufacturing, proving-out new processes and tooling prior to their use in sister pants in Zhangjiagang, China and Waldshut-Tiengen, Germany, Gary noted.

## Driven by (and driving) ADAS

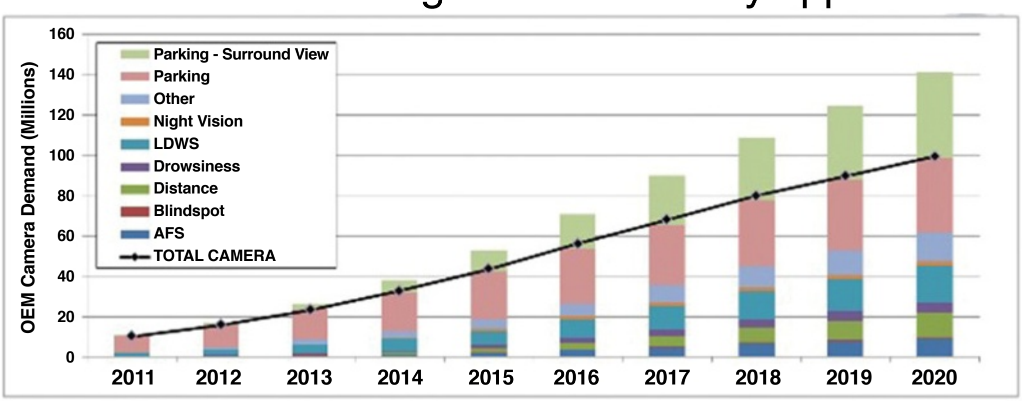
"We've been planning for this [growth] with plenty of room to expand since the government mandate was issued. But there's much more driving it," said Gary during an *Automotive Engineering* plant tour. He was referring to the **U.S. DoT** ruling that requires rearview cameras to be standard equipment by 2018 in all vehicles weighing less than 10,000 lb (4535 kg), with a 10% phase-in by May 1, 2017. That rises to 40% in 2018 then becomes 100% penetration a year later.

Camera manufacturing at Magna Electronics' Holly, MI, plant nearly approaches a clean-room environment.



Camera boards pass under ionizing blower during production. Controlling static charges is important in electronics manufacturing due to the impact they can have on device yields. Defects caused by electrostatically-attracted foreign matter can contribute to manufacturing yield losses.

Automotive camera growth forecast by application




Strategic Analytics forecasts 100 M cameras to be fitted to light vehicles in 2020. Parking cameras dominate demand. The total camera market is less than the sum of applications due to multiple applications handled by a single camera.

More than 200 fatalities and 15,000 injuries per year are caused by backup accidents and crashes in the U.S., according to **NHTSA**.

Beyond the DoT's full-production mandate, however, Gary and other Magna Electronics officials at Holly noted that rear cameras have a major role in advanced driver assistance systems (ADAS) that underpin the connected- and autonomous-vehicle future. ADAS fuses optical and radar/LiDAR sensing plus ultrasonics and V2X connectivity. The systems' increasingly capable cameras and their ECUs are integral to self-parking systems, lane-departure warning and 360° surround view—the latter offering a minimum 4-cameras-per vehicle platform.

The CMOS (complementary metal-oxide semiconductor) sensor technology was perfected in consumer digital cameras and offers small package size, low power consumption, increasingly higher resolution and steadily decreasing cost for automotive applications, Gary explained. While Magna officials at Holly refrained from providing per-unit costs, industry experts say rearview camera costs have dropped from about $130 per unit in the early 1990s, when Magna landed its first application for the **General Motors** Hummer H2, to less than $40 in 2016.

Parking assistance currently is the biggest slice of the North American automotive camera market. It is expected to expand at a compounded annual growth rate (CAGR) of 26.3% through 2020, tops among global regions and representing $11.2 B, according to **Research & Markets**. Magna currently has over 45% of the North American market in rearview cameras, Gary said, and 27% of the forward-facing camera market. Competitors include **Aisin Seiki**, **Autoliv**, **Bosch**, **Continental**, **Delphi Automotive**, **Denso**, **Mobilieye**, **Panasonic**, **Valeo** and **ZF TRW**.

Checking a sheet of assembled image sensor boards prior to camera assembly.

A recent example of the state-of-the-art in backup-system integration is **Ford**'s Pro Trailer Backup Assist in the 2016 F-150 (see https://www.youtube.com/watch?v=fyQIRR56t-o). The system features a Magna rear-view camera that measures the angle between truck and trailer and uses a Magna image-processing algorithm to calculate trailer angle by detecting target decals on the trailer. The system earned a technology award at CES 2016.

## Moving to 2 megapixels

Magna's increasing investment in forward-looking camera production at Holly is a glimpse of things to come. The company's recent announcement that it is supplying its new Eyeris Gen 3.0 camera system to **FCA** for the 2016 **Jeep** Grand Cherokee and 2017 **Chrysler** Pacifica shows the near-term application of ADAS. But to support vehicle automation at and above SAE Level 3 will require faster and more precise integration (fusion) of inputs from the multiple sensor technologies noted above.

Such capability requires ADAS to be 100% robust under all driving conditions and provide 360° coverage to detect vehicles, pedestrians and objects that "come out of nowhere."

Next-generation ADAS will incorporate machine learning, providing the ability to "read" traffic signs and "decide" when to override driver control, or when to give the human a benefit of the doubt.

Imaging systems will feature "smaller form factor with increased resolution—we'll be seeing cameras with up to 2 megapixels in volume," said Jeremy Carlson, an electronics and vision systems analyst at **IHS Automotive**.

Magna experts envision future vehicles with eight to 12 vision sensors, two long-range radar sensors and four LiDARs at the corners with V2X connectivity. They say development challenges and integration issues include how to reliably employ V2X and cloud-based solutions, whether control should be centralized or decentralized and the role of cloud-based data. ■

# MULTI-MATERIAL BODY SOLUTIONS: Possibilities and manufacturing challenges

**The body-in-white is a prime target for lightweighting and many automakers are pursuing unique and effective multi-material approaches, but improved design tools and processes may yield greater gains.**

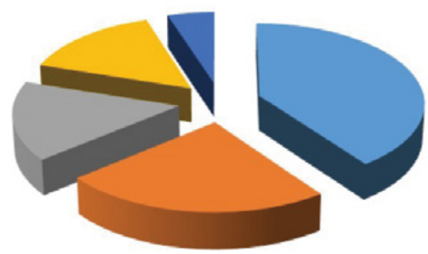



**Figure 1: Vehicle mass divided per subsystem.**

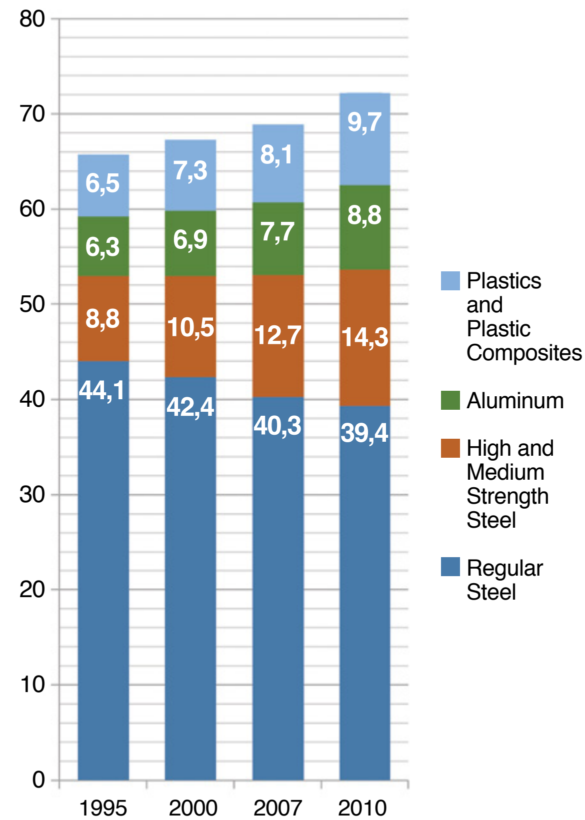



**Figure 2: Material distribution (in %) of an average American vehicle by year (adapted from Transportation Energy Data Book, editions 28 and 31, Oak Ridge National Laboratory, Department of Energy, 2009 and 2012).**

In the automotive industry, mass reduction and lightweight design is a continuing trend that does not show signs of declining. When examing where to reduce weight in a vehicle, the body is a preferential subsystem due to its large contribution to overall mass and the stability of body composition over a specific model range. The automotive industry is moving toward a greater differentiation in materials, as can be seen in the different multi-material vehicle bodies recently introduced. But while mixing materials may contribute to a good compromise between weight reduction and vehicle cost, it also proposes a number of challenges.

## Introduction

At the moment, considerable industrial attention is focused on reducing energy consumption and this is especially true in the automotive industry. A vehicle's energy consumption can be divided into three discrete phases: production phase, use phase and end-of-life phase.

While development is not mentioned anywhere in these three phases (and occurs before the first phase, production, is initiated), decisions made during the development of a vehicle will affect energy consumption in the production, use and end-of-life phases.

Mass reduction of the vehicle clearly will affect energy consumption. But which parts of the vehicle contribute necessary mass and which can be lightweighted?

A vehicle can be divided into five different subsystems based on functionality; body, chassis, powertrain, interior and electrical system. Figure 1 shows that the body is the largest mass contributor to the finalized vehicle, with 40% of the total mass attributed to this subsystem.

This makes the body a most interesting target for mass reduction. Also, since the body is more or less standardized throughout a model range, mass reduction in the body will contribute to a mass reduction to all trim levels of that model, whereas a mass reduction in interior or powertrain components might apply only to a select number of vehicles.

There are other ways of dividing the vehicle into subsystems; one is to look at the mass as primary, secondary and tertiary mass. Here, the body is the primary mass; engine and drivetrain, suspension, wheels and fuel is secondary mass; all other mass (as from glass, electrical systems and interior) is tertiary mass. Primary mass reduction will enable a secondary mass reduction without affecting functionality, performance or vehicle characteristics—and this further emphasizes the vehicle body as a focus area for mass reduction, since it can be

MULTI-MATERIAL BODY SOLUTIONS:

# Possibilities and manufacturing challenges

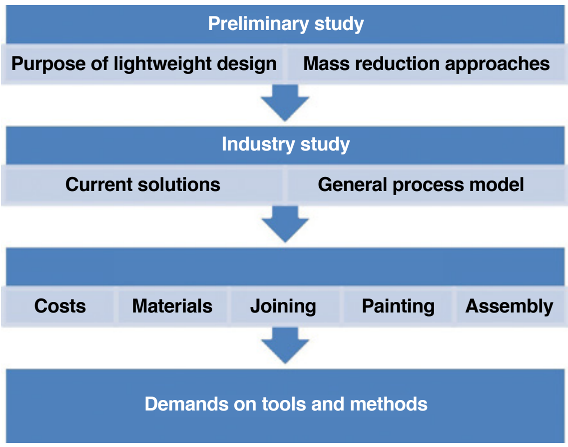



**Figure 3: Process model for the research project.**

seen as an enabler for further mass loss on the vehicle.

Mass generally can be attributed to two factors: geometry and material density. In the application of vehicle design, material density could be translated into material selection. Usually, these two factors are combined, since material qualities other than density have to be considered. A vehicle is composed of a large number of different materials, but again, the body contributes to a significant part of the mass of the finalized product. Therefore, material distribution trends even on finalized vehicles can indicate what is happening with automotive bodies, as shown in Figure 2.

Also shown in Figure 2 is that further material differentiation is a continuing trend. Notably, the plastic and plastic composites as well as aluminum content have grown with time (from around 6% to 9-10%), while conventional steel each year comprises a smaller portion of the materials.

Body-material composition also varies throughout vehicle types and makes, with the upper segments of the market showing more differentiation than lower-priced markets. The sports and supercar segments, with cars like **McLaren** MP4-12C and **Lexus** LF-A, can be used as an example of this larger material composition diversity in the upper market segments.

Since no single material is best suited for all body components, a multi-material approach seems to be the best way to find an optimal compromise between requirements. However, existing design tools and methods have issues handling material properties and multi-material solutions because many tools have been developed strictly for one type of material and/or manufacturing method.

In turn, this suggests that different concepts might need different evaluation methods, making it hard to compare qualities between concepts if they are too dissimilar. Also, component geometry will need to differ between different material concepts in order to have an honest comparison. Adding the possibility of path dependency—

**Figure 4: BMW 7-Series "Carbon Core."**

and the fact that some solutions might be favored by existing manufacturing capability— the engineering task becomes extremely complex.

## Method

This paper aims to show the need for integrated product and production development when looking at lightweight design in the automotive industry. These two research topics interact with the industrial result and the context to create a basis for this work.

In this project, study developed according to the process described in Figure 3. First, a preliminary general study was made to research the purpose of lightweight design and possibilities for mass-reduction approaches. Subsequently, an industry overview was performed to investigate current multi-material solutions. In parallel, a general process model for vehicle car bodies was created from empirical findings. This process was split into a number of sub processes based on value-adding activities, each for which different challenges with multi-material solutions were investigated via literature research. The material families selected were the same as have been investigated in earlier research found by the authors, while general material properties were taken from CES EduPack 2015. These challenges were then analyzed and put into demands on product development tools and methods.

In this paper, different approaches to the multi-material design body-in-white (BIW) are presented. General studies or studies not implemented in large-scale production are presented under the heading "Academic examples and research projects." Designs that have been or will in the near future be implemented in large-scale production are presented under the headline "Industry examples."

## Academic examples and research projects

Different research projects point to a possible significant mass reduction from increasing polymer composites as structural material in vehicles and an increased use of aluminum in structural components.

Peterson and Peterson have shown that a significant mass reduction can be achieved, with the same unit manufacturing cost as existing designs, if the whole vehicle is designed for these changes. Other research projects also have shown that a multi-material approach can reduce body mass by more than 40% at a 35% cost increase—using only current technologies.

Industrial research projects show that a light-duty pickup truck can be lighweighted by as much as 33% by switching to an aluminum body, while a passenger car can be lightweighted by 23% and the BIW by 21% employing existing manufacturing and a multi-material design approach. Another project points to a 31% mass reduction by

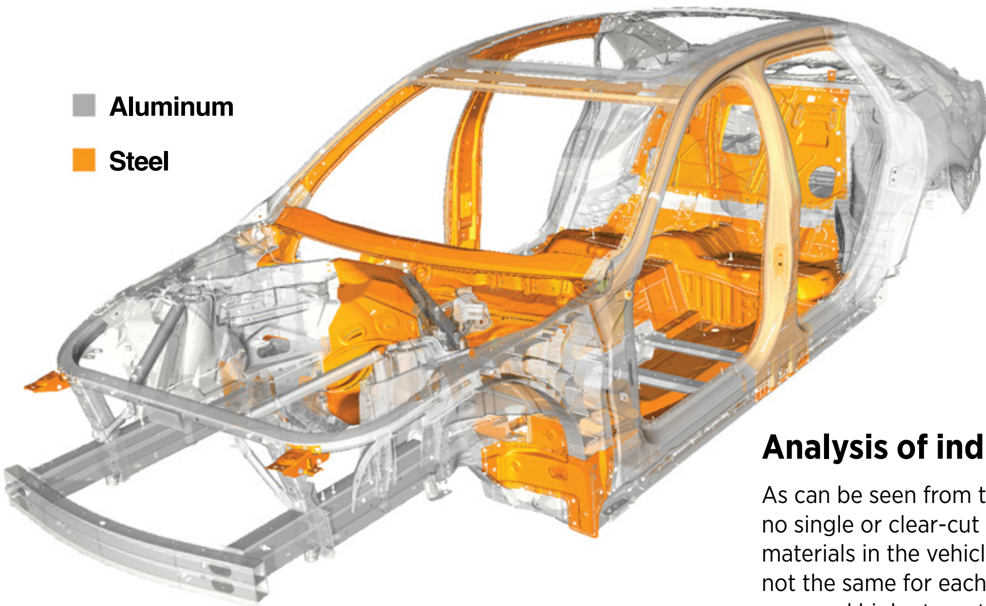



Figure 5: Cadillac CT6 "Fusion Frame" architecture.

transitioning from steel to aluminum and composite body panels. Projects focusing on magnesium-intensive structures have shown that this material family also is promising for mass reduction without significantly increasing unit costs.

## Industry examples

Some stakeholders in the automotive industry believe in increased usage of hybrid or multi-material designs. Different polymer-based materials have long been used for hang-ons such as hatches, hoods and fenders, while more recently, fiber-reinforced polymer composites have been used in roofs. Currently, a number of vehicles are being released with different multi-material solutions even further integrated into the bodies. A few are presented as follows:

**BMW 7-Series:** The body of the G11/G12 BMW 7-series is designed for lightweighting via a combination of steel, aluminum and carbon-fiber reinforced plastics (CFRP) in what the company calls the "BMW Carbon Core" approach. A number of components—among them door sills, B-pillars and roof beams—are either reinforced or replaced with CFRP panels shown as the darker body portions in Figure 4.

**Cadillac CT6:** The 2016 Cadillac CT6 (Figure 5) is built around what General Motors calls the "Fusion Frame," a concept in which a steel center section is clad with aluminum panels for everything visible. Aluminum also is used for components such as crash bars.

**Volvo XC90:** Volvo's XC90 utilizes several different high-strength steel grades as well as aluminum parts for a lightweight but strong body. Within the body structure, joints between these different steels and aluminum are present throughout, as can be seen in Figure 6. Aluminum also is used in the strut towers and the front crash bar, along with the hood and front quarters.

**Mercedes-Benz C-Class:** For the 2016 Mercedes-Benz C-Class (Figure 7), the company developed a body with all hang-ons (doors, hood, fenders, trunk lid) in aluminum, an aluminum roof and a body with an increased use of aluminum and high-strength steel (hot-formed as well as conventional).

## Analysis of industry examples

As can be seen from these industry examples, there is no single or clear-cut method for integrating newer materials in the vehicle body. The chosen materials are not the same for each manufacturer (though aluminum and high-strength steel are widely used by all) and the position and design of the non-steel panels is not identical. This could suggest that this technology step has not yet matured, but also that there are internal factors within automotive manufacturing organizations that may affect the gains from design choices.

## Manufacturing challenges

Based on study visits at automotive manufacturers, the authors developed a simple overview of the production process: the production plant is split into three different factories: A, B and C. In this breakdown, the A factory is the body manufacturing and welding facility, the B factory is the paint shop and the C factory is the main body shop where the vehicle is assembled.

Within the A-factory, two major groups of processes can be separated: forming and joining. In the B-factory, three major process steps can be performed: pretreatments, painting and curing. In the C-factory, many different types of assembly are performed.

## Cost

Mårtensson has shown that to find a suitable compromise between performance and cost, the question of integrating versus differentiating structures must be addressed when looking at composite lightweight structures. This could also be transferred into multi-material solutions, where differentiating also could indicate different materials in two or more components.

When comparing different materials and different manufacturing techniques, the task of comparing manufacturing cost becomes increasingly more complex. Because tooling costs depend on the component geometry, this needs to be addressed in cost estimations.

# Possibilities and manufacturing challenges

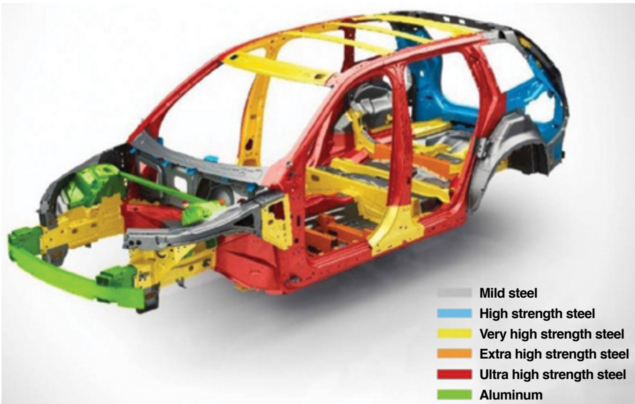



Figure 6: Volvo XC90 empolys various high-strength steel grades and aluminum hybrid structure.

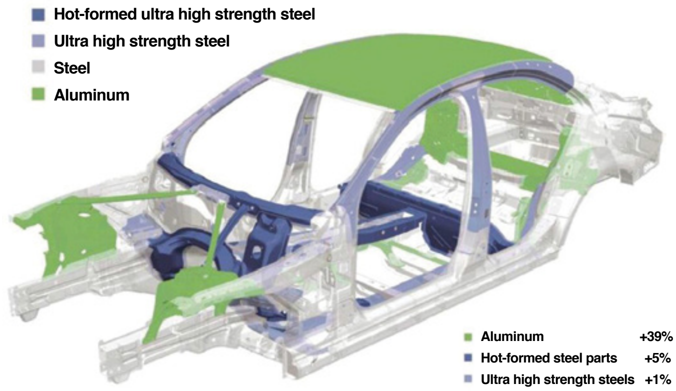



Figure 7: Mercedes-Benz C-Class body showing significant aluminum integration into the body-in-white.

## General material properties

Materials can have very different qualities and many different properties. Two important factors in the A-factory, where body panels are formed and joined, are tensile strength and yield strength. These parameters explain how much force is needed to permanently alter the shape of the material at room temperature and how much force can be added before the material breaks.

Although there are outliers, metals in general are stronger than polymers in both tensile strength and yield strength. This means that the metals can withstand higher loads before deforming plastically and before rupture. This will affect both forming and joining in the A-factory and assembly in the C-factory.

Two relevant properties when looking at effects on the B-factory are maximum service temperature and coefficient of thermal expansion, due to the painting process. Although all metals have a relatively low thermal-expansion coefficient, the maximum service temperature differs greatly: from under 200°C to over 1000°C.

Looking at polymers, it becomes even harder to draw any conclusions that involve all materials in the family. Some materials have both maximum service temperature and thermal expansion coefficients similar to some metals, while others have very low service temperatures or reasonable service temperatures but relatively high thermal expansion coefficients compared to metals.

## Joining

There are four types of joining processes; mechanical, chemical, thermal and hybrid processes.

Traditionally, car bodies have been manufactured in steel and resistance-welded. But when transitioning to joining dissimilar materials, as with a multi-material body, the number of design parameters increases due to an increase in number of relevant material properties. This means the joining process type could need to be revised, for example from welding to flow drill screws or adhesive joining technologies.

Often, there are multiple joining-process types that are possible, although only a few processes are preferable or realistic. The selection of joining method becomes interlinked with material selection and component geometry.

## Painting and curing

The whole-surface finishing process, including pretreatments and painting, means that the body is heated for curing several times. The curing occurs by transporting the body through an insulated tunnel, where hot air is used to heat it. Since the body is constantly moving through the tunnel and minimal tunnel time is desired, this process is not guaranteed to heat the entire body to uniform temperature.

## Mixed-model assembly lines

It is common to assemble several models or variants of a vehicle on the same line. This is defined as a mixed-model assembly (MMA) line and is characterized by its ability to utilize multi-skilled workers and automated tool changes between different variants of products. Since the variants of vehicles increase with the trend of customization, MMA-lines are required in order to increase capacity utilization.

## Conclusions

To cope with new manufacturing challenges related to mass reduction via multi-material design, product development tools and methods need to help design engineers find solutions to previously unknown issues—or issues that have earlier been solved by clear-cut standards or design rules. Product development tools and methods need to be evaluated and possibly improved to identify potential manufacturing issues and solve them early in the design phases. ■

**This article was adapted from SAE technical paper 2016-01-1332 authored by Fredrik Henriksson and Kerstin Johansen of Linköping University.**

## Second time a charm for Honda's unibody Ridgeline pickup?

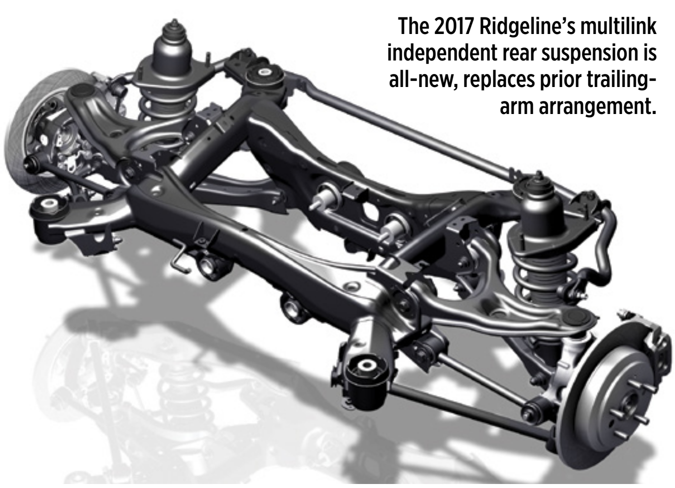
**The 2017 Ridgeline midsize pickup truck is longer overall and has a larger cargo bed, but is somewhat lighter, thanks largely to a body of 60% high-strength steel.**

**Ridgeline body structure stiffer than before, makes for noticeable ride-and-handling benefits.**

Although its best-ever sales year was barely more than 50,000 units and many critics questioned the buying public's desire for a midsize pickup based on a unibody structure instead of the tried-and-true body-on-chassis layout, **Honda** remained faithful to the concept it introduced with the first-generation Ridgeline pickup, producing it for ten years from 2005-2014.

Even through the recession and auto-industry downturn, Honda insisted it was keen to develop a second-generation Ridgeline, to continue to press the idea that if many in pickup-crazed America took an honest look at what they want from a pickup—and equally important, how they actually use a pickup—a unibody-based design would be the most satisfying choice.

So here's Honda with the 2017 Ridgeline and it seems the conditions are more favorable than ever for the company to prove its point: the U.S. market remains in a highly absorptive mood for pickups, new midsize models such as **General Motors**' **Chevrolet** Colorado and **GMC** Canyon have reinvigorated demand in a segment recently decreed as stagnant—and not of inconsequential importance, the 2017 Ridgeline also happens to be a pretty convincing effort.



**The 2017 Ridgeline's multilink independent rear suspension is all-new, replaces prior trailing-arm arrangement.**

### Non-issue styling

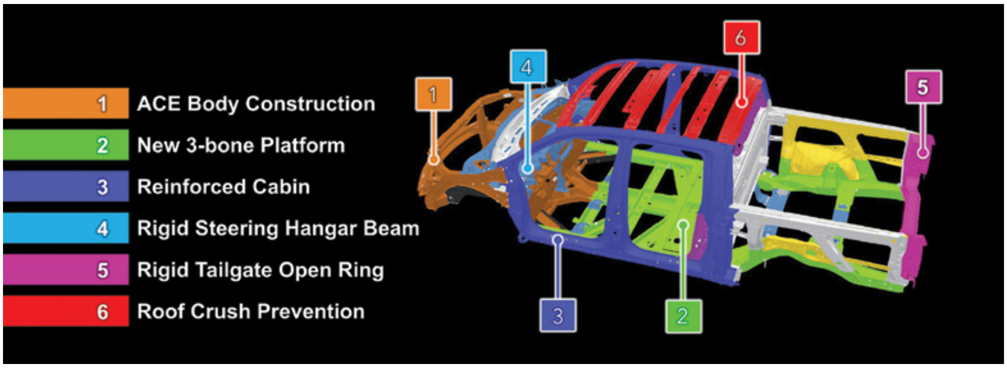
The big news for the 2017 Ridgeline is that it no longer looks wacky. Gone are the previous model's thick side buttresses aft of the cab that blended into the bed, giving the truck a distinct "hybrid" appearance—a look Honda believes was another "avoidance" factor for comparison shoppers that already needed convinced why they shouldn't just buy a conventional pickup from the established players.

So although the new Ridgeline isn't the same as its body-on-frame competitors, it's been deliberately styled to look the same, particularly in that crucial area where the cab meets the cargo bed. Apart from not scaring off customers, the straightforward look has another advantage: the Ridgeline's bodyside no longer needs to be a one-piece stamping, a part that caused assembly-plant fits. The new Ridgeline now is the only Honda made in North America with bolt-on rear fenders. And one further advantage: if a rear fender is damaged, the new design makes for easier and less-costly repair.

### Pilot-related structure

The 2017 Ridgeline utilizes a well-modified variation of Honda's Global Light Truck architecture, which also underpins the Pilot and **Acura** MDX crossovers; for example, 50% of the Ridgeline's suspension is reengineered compared with the Pilot, while the big takeaway in size difference is overall length and wheelbase: the new Ridgeline, at 210 in (5335 mm) overall, is 3.1 in (79 mm) longer and wheelbase grows at subsequent 3 in to 125.2 in (3180 mm). Bed length is a handy 64 in, almost 4 in longer than before and a couple inches longer than the Colorado and **Toyota** Tacoma "short" beds. The former Ridgeline's innovative in-bed cargo trunk is here again, as is the useful swinging or folding tailgate. Honda's proud of a new sound system that reverberates the bed walls for a big-time tailgating experience; to us it seems superfluous but only comes on the two top-trim models, at least.

Used to be the talk about unibody pickups often centered on




**Optimized body structure is nothing new, but Honda said it helps the Ridgeline attain an expected 5-star safety rating, something body-on-frame rivals have yet to achieve.**

a presumed weight-saving potential, but that's not so much the case here: the base AWD configuration weighs about 4431 lb (2010 kg), said Honda—that's 73 lb (33 kg) lighter than before, but not much lighter than a comparable Toyota Tacoma (4480 lb) and a touch heavier than the 4390-lb Chevy Colorado. No, the distinct payoff from the Ridgeline's structure is refinement and on-pavement dynamics; it's smoother and quieter inside, steering is more direct and there's a noticeable lack of body movement and shudder. Honda said the new-generation Ridgeline is 28% more torsionally stiff—and the previous Ridgeline already had class-leading bending performance.

The unibody structure also enables a much larger storage area under the rear seats and class-leading cargo volume with the rear seats folded, said Kerry McClure, chief engineer and development leader who also was a member of the original Ridgeline's engineering team. He also said Honda expects a 5-star safety rating for the new Ridgeline, a score no body-on-frame midsize pickup has yet achieved. But it's not as if there isn't lightweighting going on, Honda body and manufacturing engineers told *Automotive Engineering*. They said the new model is larger and has more content, yet weight nonetheless was reduced. One factor, they said, was markedly increased use of high-strength steels, where HSS accounts for about 60% of the 2017 Ridgeline's body in white, compared with just 5% before.

The MacPherson strut front suspension and multilink rear suspension are up-fitted from the Pilot's design, with several crucial pieces, particularly knuckles and subframe mounts, suitably beefed for pickup duty. The layout makes for immensely satisfying on-road behavior and doesn't seem an impediment for hauling, towing and medium-rough off-roading.

## Two-spec powertrain

All 2017 Ridgelines are powered by a new version of Honda's 3.5-L DOHC V6 that develops 280 hp and 262 lb·ft (355 N·m) of torque, increases of 30 hp and 15 lb·ft compared with the previous 3.5-L V6 and right on the 278 Toyota's Tacoma gets from its 3.5-L V6, while the Colorado gets 305 hp from its 3.6-L engine.

The Ridgeline bucks the broad industry's transmission trend, though, in sticking with just six forward speeds for its planetary automatic. Engineers said they're satisfied with performance

**The 3.5-L V6 is the Ridgeline's sole engine, revised with more hp and torque and with variable-cylinder management to operate in fuel-saving 3-cylinder mode.**

and fuel-efficiency with the 6-speed unit and it appears for now that margins and caution have kept any automakers from making the leap to more ratios for midsize pickups. We suspect Honda's forthcoming 10-speed automatic could be a future upgrade, particularly if the much-discussed mid-term review of federal fuel-efficiency regulations doesn't yield any rollbacks.

Meantime, though, there's other driveline interest. The 2017 Ridgeline offers a 2WD variant for the first time (in this case, that means front-wheel drive). The company said it can't ignore the interest in 2WD from fair-weather markets such as California, Texas and Florida and the 2WD option presents the opportunity to hit showrooms with a base price under $30,000. All-wheel-drive models are fitted with the i-VTM4 differential that incorporates torque vectoring. It's 22 lb (10 kg) lighter than before and is 40% faster in sending torque to the rear axle, while either rear wheel can be over-speeded by as much as 2.7% to influence cornering.

The i-VTM4 also collaborates with the Ridgeline's new Intelligent Traction Management system that permits toggling between normal, snow, mud and sand settings for AWD models

**The fold-or-swing tailgate that became a Ridgeline hallmark returns for the second-generation truck. Opens to a bed with class-leading payload capacity.**

**Ridgeline interior is the antithesis of "trucky," raft of available electronic safety features is uncommon for the segment.**

and normal and snow for 2WD. A button gets the driver between the settings; we think a console- or dash-placed rotary knob would be more in keeping with the Ridgeline's mission.

## Yeah, but is it a 'real truck?'

The 2017 Ridgeline seems like enough truck for most needs. The AWD models' 5000-lb (2268-kg) standard tow rating, as derived from **SAE** standard J2807, is enough for 95% of towing that midsize-pickup buyers require, according to a third-party survey conducted for Honda, while the Colorado and Tacoma are rated to tow up to 7000 lb with special upgrades.

With 8 in (203 mm) of ground clearance, the Ridgeline is near the Colorado's 8.2 in, but a little afield of the Tacoma's 9.4-in ground clearance. Honda didn't supply off-road approach and departure figures, but given the comparatively minor differences in the major comparison points, the Ridgeline appears capable of standing toe-to-toe with its body-on-frame competition in most measures—particularly, as Honda's always noted, when real-world use of midsize pickups is the baseline consideration.

The 2017 Ridgeline "is not an exercise in compromise," summarizes Jeff Conrad, senior vice president and general manager of the Honda Division. "It's an all-new pickup for a new generation."

Honda tried once and it didn't quite fit. But the Ridgeline developers' realistic appraisal of how most pickups actually are used may find a more receptive audience this time around. High refinement and a "plenty capable" approach to utility could make unibody pickups a concept whose time has come. Anybody remember how the Toyota RAV4 and Honda's CR-V changed how the world looked at SUVs?

**Bill Visnic**

# Jaguar puts a brave Pace on testing its new crossover

Rarely does an automaker choose the world's most dangerous roads to introduce a new vehicle to the media. So **Jaguar**'s recent launch of the all-new 2017 F-Pace sports crossover in the mountains of Montenegro—where poor surfaces, unguarded sheer drop-offs and narrow, unexpected hairpin bends are routine—was a brave decision indeed.

Such take-it-to-the-limit testing is typically reserved for vehicle development teams, but the route and sensational topography clearly gave *Automotive Engineering* and other select media good insight into F-Pace's dynamic capabilities and its four-year development.

"We call it our practical sports car," explained Andy Whyman, the Vehicle Program Director. Clearly F-Pace marks a whole new direction for a company whose basis is sports cars and luxury sports sedans.

It might seem more logical for this aluminum-intensive, road-biased SUV to wear a **Range Rover** badge—the majority of production, after all, will be all-wheel drive (AWD). But rear-drive-only versions will be offered in some markets and dynamically, F-Pace feels like a taller, more commodious sibling of Jaguar's XF and XE sedans. There is a "Jaguaresque" balance of ride, handling and steering in this vehicle that is immediately apparent.

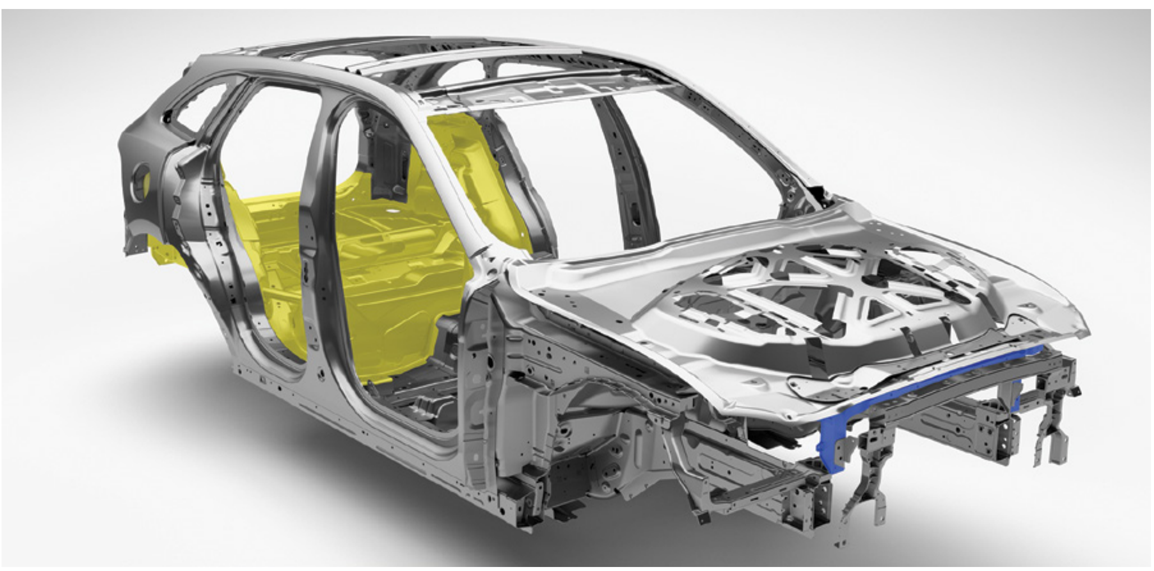
## Adaptive chassis control

Although not in the Land Rover league for off-road adventuring, the F-Pace has been designed to tackle some rough stuff. It has aluminum double wishbone front suspension, with lower arms designed to protect against accidental grounding. And anti-rollbar bushings are bonded to give added protection against dirt or sand ingress.

Rear suspension is an integral-link system with high lateral stiffness. Said Whyman: "It allows us to separate vertical and lateral compliance to give much

Jaguar's F-Pace uses JLR's aluminum architecture but the 2874-mm wheelbase and specific front and rear track are not shared with any other model. Overall length is 4731 mm.

The F-Pace has a high-definition virtual 12.3-in instrument cluster with four visual themes and full-screen 3-D navigation display supported by a laser head-up display.



The aluminum body structure of the new Jaguar F-Pace weighs less than 300 kg.

better performance than conventional systems." Passive monotube dampers are tuned for on-road performance, and for smooth progressive response on rutted or broken surfaces.

The F-Pace is available with Jaguar's adaptive dynamic chassis system. It measures driver inputs and vehicle responses up to 500 times per second taking data from 18 sources. It is driver-configurable. Optional 22-in wheels are available with road tires specially developed to give what Whyman claims is the largest rolling diameter and radius of any current sports crossover.

"They have deep sidewalls for ride quality. Also, we have double the curb protection of our key competitors," he added.

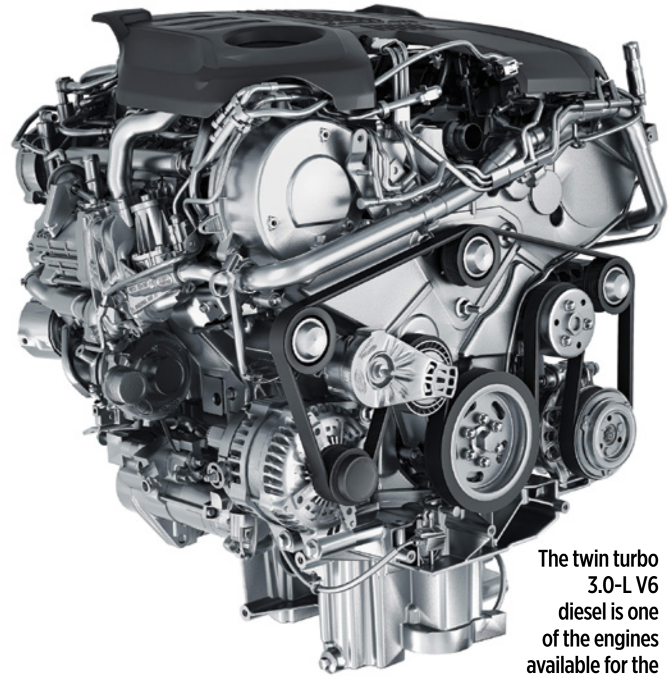
Traction technology includes adaptive surface response (AdSR) to optimize traction on ice, gravel, sand or snow. All Surface Progress Control (ASPC), utilizing the car's cruise control to set low speeds on both very steep up and down slopes. Low Friction Launch (LFL) provides smooth pull away in challenging conditions.

## 1400 N·m front diff capability

The heart of the F-Pace's rear-wheel-biased AWD is a compact, chain-driven, wet-clutch transfer case that is "10% more efficient and 16% lighter than previous generations," explained Whyman. The front differential is capable of handling 1400 N·m (1032 lb·ft). Torque-on-demand is controlled by driveline dynamics software developed in-house from the F-Type sports car. The algorithms provide RWD-like agility and help counter the understeer that is inherent in AWD set-ups. The system transitions from 100% rear-bias to a 50:50 torque split in a claimed 165 ms. If there is already a proportion of torque being sent to the front axle, additional torque transfer takes place in 100 ms.

Many of the F-Pace's safety features employ the forward-facing stereo camera. Autonomous Emergency braking is standard and incorporates pedestrian protection, spotting people in the vehicle's path, alerting the driver or if necessary, stopping the vehicle.

Aerodynamics played a significant part in the creation of the F-Pace, providing an added challenge for Director of Design, Ian Callum, charged with making the SUV "immediately recognizable as a Jaguar." Height is 1652 mm excluding antennae. Cd is 0.34.



The twin turbo 3.0-L V6 diesel is one of the engines available for the Jaguar F-Pace.

Andy Whyman, F-Pace Vehicle Program Director: "My team and I have engineered a completely new type of Jaguar."

The new Jag offers a wide choice of powertrains, including a twin-vortex supercharged 3.0-L gasoline V6 also used in the F-Type. It provides 0-100 km/h acceleration in 5.5 s (280 kW version). There are also two diesels: a 3.0-L twin turbo V6 with 700 N·m (516 lb·ft) that is claimed to be capable of 0-100 km/h in 6.2 s, and a 2.0-L "Ingenium" 4-cylinder unit producing 132 kW (177 hp), with 430 N·m (317 lb·ft) available from 1750 to 2500 rpm.

A 6-speed manual gearbox is available with the RWD driveline, with 129 g $CO_2$/km emissions claimed for the 2.0-L diesel; V6 models use the same **ZF** 8HP70 8-speed as the sedan and F-Type.

## Recycled aluminum target by 2020

The F-Pace is being built at Jaguar's new purpose created flexible Solihull manufacturing center (70 new robots in the bodyshop) alongside the Jaguar XE. Use of modular aluminum architecture is a major element of F-Pace design, allowing the company to increase "the breadth of products we can introduce and reduces the time taken to create them," explained Kevin Stride, Vehicle Line Director.

He added that the vehicle personalization that Jaguar customers demand is another design attribute that is not possible to engineer using a high degree of bill-of-material commonization with the sedans. Stride claimed that 81% of F-Pace components are not shared with XE or XF. For example, its HPDC (high pressure diecast) aluminum front suspension turrets and the entire front subframe are unique to the SUV and enable greater ground clearance and suspension travel.

Jaguar has its own aluminum grade, RC5754, and the company is "constantly increasing the percentage of aluminum used in our cars through smarter engineering and manufacturing," Stride said. Approximately 80% of the F-Pace's body structure is aluminum; the core body-in-white weighs less than 300 kg (661 lb). One-third of this is recycled material, by weight; Jaguar's goal is to get to 2020 using 75% recycled aluminum. The body is joined using more than 2600 self-piercing rivets, 72.8 m (238.8 ft) of structural adhesive and more than 560 spot welds.

The car's hood is aluminum, doors are steel, the liftgate is composite, and front cradle is magnesium. All contribute to a near 50:50 front/rear weight distribution, Whyman said.

More than 100,000 machine-hours of CFD simulation resulted in a flat underfloor leading from the front splitter and a rear spoiler which contributes to a 50% lift balance between front and rear to achieve a best Cd of 0.34—which is a useful thing to have after you leave the mountain hairpins.

**Stuart Birch**

# Focus RS: Ford and GKN create an AWD masterpiece

If an international TV quiz show had the new **Ford** Focus RS as one of its subjects, Tyrone Johnson would have all the answers.

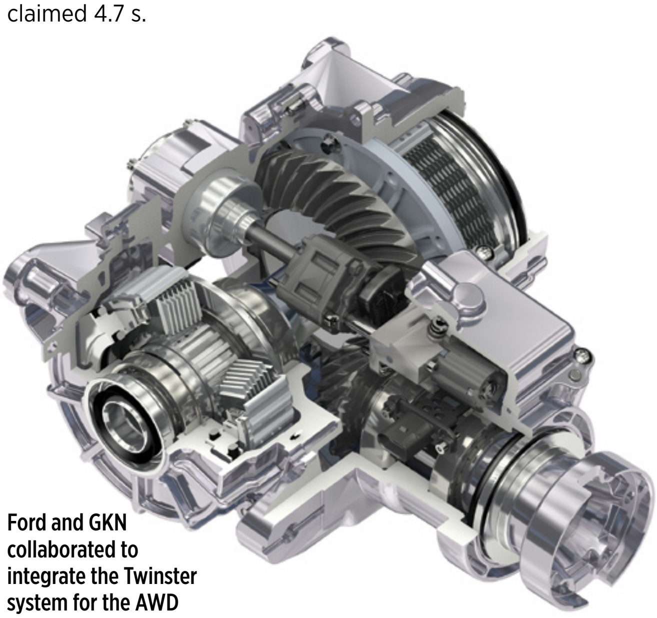
As Vehicle Engineering Manager for Global Ford Performance—and as Chief Engineer for Formula One and rallying before that—Johnson has seen the latest RS mature to become a truly global car. And like the Mustang and a growing number of other models, it is conforming to the company's "One Ford" philosophy.

Despite being a specialized sports model, the RS had to be built on the same line as the regular Focus at Ford's Saarlouis, Germany, plant without causing any hint of a hold up in the output of some 2000 cars per day.

"Stop the line and you get a lot of attention at Ford!" said Johnson. So although the RS is something of an exotic machine, it still contains the essential elements that define a Focus. "It had to be an everyday usable car—not just a one purpose vehicle, even though we planned to introduce some innovative solutions for track and handling, with aerodynamics (achieving zero-lift balance is very difficult for a 5-door car) and chassis systems driving its design," he told *Automotive Engineering*.

## A 'less efficient' intercooler

The new RS packs an impressive specification. Power comes from a **Honeywell**-turbocharged 2.3-L 4-cylinder driving a 6-speed manual gearbox and **GKN** all-wheel-drive system with torque vectoring and drift control. The Ecoboost engine's claimed 257 kW (345 hp) is kept in check with launch control and is capable of propelling the RS to 266 km/h (165 mph) max velocity, with 0-100 km/h (0-62 mph) acceleration in a claimed 4.7 s.



Ford and GKN collaborated to integrate the Twinster system for the AWD Focus RS.


Plenty of air for the new Ford Focus RS; in fact a little too much for one system.

The RS front suspension is by MacPherson struts with semi-isolated subframe. The rear short-long arm suspension features Ford's "control blade" setup designed by former Ford vehicle-development boss Richard Parry-Jones. First used in the Focus ST, this unique trailing arm multilink system offers the packaging benefits of a trailing arm suspension with the geometry of a double wishbone system.

The thin stamped-steel control-blade trailing arm handles two degrees of freedom—longitudinal wheel movement and brake-torque reaction. So only three lateral links are needed to fully control toe and camber, with the added benefit of good anti-dive geometry.

Braking the 1599-kg (3525-b) RS is handled by **Brembo** 4-piston Monobloc calipers clamping 350 x 25-mm ventilated rotors in front, and solid 302 x 11-mm discs in the rear. Claimed fuel consumption on the combined NEDC is 7.7 L/100 km and $CO_2$ emissions of 175 g/km.

Johnson noted that his development teams sweated the details on this car. That's immediately evident to drivers, but in one area the technology developed was just a little too good.

"We had to decide 2½ years ago on air intake opening size. This could not be changed later in the development program so we decided bigger is better, as durability cooling was very important," he said. "However, the intercooler proved to be too efficient; under some specific conditions water vapor was created in the intake system, which is not good. So we made the intercooler a little less efficient by using a blanking plate."

There may be applications in the future for the super cooler, he noted. Peak engine torque is quoted at 440 N·m (325 lb·ft) but Johnson explained that an overboost to 470 N·m (347 lb·ft) is available for 15 seconds. But a driver only need lift off the throttle for a millisecond and back would come the added 30 N·m (22 lb·ft); so effectively it is available all the time.

The sound effects accompanying the engine are supported by an exhaust system "as straight through possible" with an active valve system to balance NVH and power and stay within noise legislation.

"One of our metrics is: 'Rewarding to rev.' Sound in this type of car is incredibly important but it has to be legal."

Achieving just the right balance involved three redesigns to meet what seemed like opposing criteria. "We are legal, including pops and burbles, something that officials looked at very closely, as they are achieved by misfires, not burning fuel efficiently and leaving hydrocarbons!"

## GKN's clever Twinster AWD

The RS features a twin-clutch GKN Twinster driveline, rather than a **Haldex** AWD. Ford and GKN worked closely to integrate the system that can apply torque independently, enabling the vehicle's dynamic torque vectoring functions across its entire speed range.

The GKN system incorporates a PTU (Power Transfer Unit) and an RDM (Rear Drive Module) utilizing the Twinster twin clutch system that can apply torque to one or both wheels independently. The Twinster drives the rear wheels faster than the front.

The overspeeding (2%) at the rear, fundamentally changes the way the car feels and handles. The result is a car of competence and character sampled recently by *Automotive Engineering* on track, frozen lakes, and regular roads. It's fun.

Through corners, the Twinster makes the vehicle turn in more sharply, responding more immediately to the driver's inputs. In the Focus's track-only drift mode, the AWD system delivers even more torque to the rear axle, making it easy for the RS to achieve a controlled drift through corners.

A dedicated ECU controls the hydraulics and solenoid valves to continuously vary the pressure at each clutch pack, redistributing the torque to the wheels.

The software updates the hydraulic control settings 100 times per second to provide quick, accurate torque control, the clutches continuously moving as required anywhere between fully open and fully locked, delivering the required performance.

Johnson explains that the system allows the car to be steered into and through a corner without the usual understeer effect of most AWD setups, facilitating a very fast exit from the corner. "We did not want a fixed input of torque to the rear wheels, typically 70% for other systems," he noted.

The rear-wheel overspeeding means the rear of the car is constantly trying to overtake the front, explained Johnson: "This gives the car its lively feel. That's the good news; the bad is that the back of the car works against the front."

Ford, working with GKN, took more than two years to develop the AWD for the RS, successfully achieving compensating solutions for the forces generated and the systems' "in-fighting."

Said Johnson: "Engineers spent hundreds of hours calibrating every possible drive situation in order to get the reactions we wanted. We experienced extreme situations where we had upwards of 95% of torque going to the back of the RS!"

There is also is launch control for rapid take-offs.

Other chassis technologies for the RS include a unique electric PAS, brake cooling aided by an upside-down airfoil to accelerate airflow, unique dampers, spring and subframe assemblies, and exclusive **Michelin** tires.

The body gets additional stiffening to enhance torsional rigidity.

And all this has been done for a global buyer base, stressed Johnson. "It's probably the most global car we have ever built," he said, "yet I can count on the fingers of one hand the different parts between the U.S. and Europe."

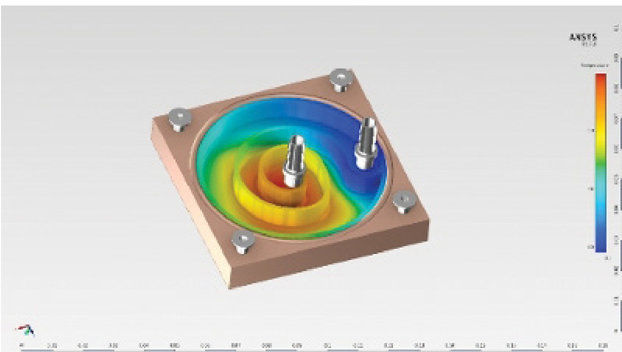
Former Ford CEO Alan Mulally, father of the company's "One Ford" doctrine, might allow himself a satisfied smile at hearing that.

**Stuart Birch**

# PRODUCT BRIEFS

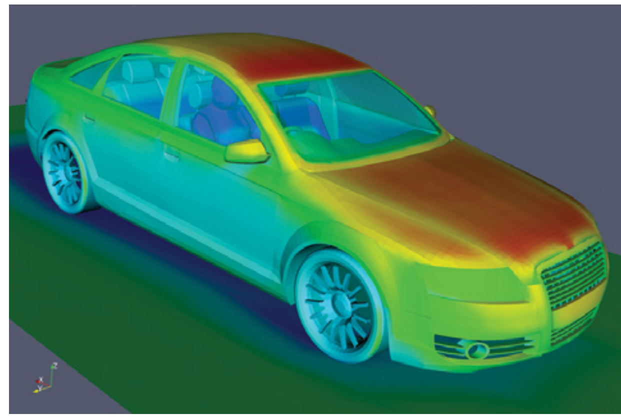
## SPOTLIGHT: CAD/CAM/CAE

### Engineering simulation tool



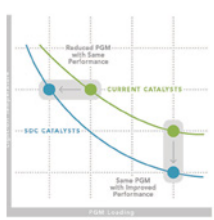
**ANSYS** 17.0 delivers 10× improvements to product development productivity, insight, and performance. Highlights of the release include: a comprehensive chip-package-system design workflow with new capabilities for automated thermal analysis and integrated structural analysis that enables customers to deliver smaller, higher-power density devices to market faster. The fluids suite includes advancements in physics modeling and innovations across the entire workflow and user environment design that accelerate time to results by up to 85% without compromising accuracy. Preprocessing has also improved by an order of magnitude. Using the direct-modeling tools in ANSYS 17.0, users can prepare their geometry for analysis faster than with traditional CAD. Save and load times for complex models have increased by up to 100×. For more information, visit **www.ansys.com/17**.

### Thermal simulation



CoTherm from **ThermoAnalytics** facilitates the flow of information between CAE simulation products to streamline CAE workflow, improve simulation time and reduce test time and cost. Instead of working with complicated scripts, CoTherm allows the customer to construct complex CAE coupling processes with an intuitive user interface, allowing them to graphically monitor and automate a coupled simulation. CoTherm provides the opportunity to use the firm's advanced thermal solver, TAITherm, and efficiently couple it to the world's most advanced CAE solvers, a combination that provides an opportunity to create an effective and accurate thermal-simulation methodology. For more information, visit **www.thermoanalytics.com**.

### Advanced materials for catalysts




**SDCmaterials** will partner with **Car Sound Exhaust System** and supply the company with material for its catalytic converters. SDC's Nano-on-Nano formulation, applied to exhaust-treatment catalysts, requires as little as 40% of the platinum-group metals in traditional catalysts, essentially doubling the efficiency of the precious-metal composition. SDC manufactures its Nano-on-Nano catalyst ingredients via plasma-synthesis technology, which integrates nano-sized precious metal particles onto nano-oxide support particles. When incorporated into traditional catalysts, the ingredients inhibit catalyst-degrading precious-metal migration and agglomeration, creating more stable and predictable emissions control, and allowing the catalyst manufacturer to use substantially less precious metal. **GM Ventures**, an investor in SDC, believes the technology can provide a significant cost savings for customers when applied in broader use. For more information, visit **http://www.sdcmaterials.com/**.

### High-pressure CNG hoses

**Eaton**'s high-pressure 35NG hose and low-pressure NG-TW hose for compressed natural gas (CNG) applications are certified to ANSI NGV 4.2 Class A and D, and ANSI NGV 3.1 Class B and C. Primarily used in dispensing and commercial vehicle applications such as refuse trucks, buses, and delivery vehicles, the certified hose offerings ensure safety requirements and quality standards are met. Featuring a UV-resistant cover, the 35NG hose outlasts competitive alternatives by five-to-one. The hose assemblies are designed to dissipate static electricity for safety. Additionally, the 35NG hose offers low volumetric expansion and available twin-line designs. Constructed with a Teflon resin tube, a stainless steel wire braid, and a fire retardant cover, the low pressure NG-TW hose is built to withstand the high temperatures found under the hood—up to 121°C. The NG-TW hose is also flexible and offers a low permeation rate. For more information, visit **www.eaton.com/CNG**.

## Development kit for gesture recognition

**Microchip Technology** Inc. has introduced a development kit for integrated 2D projective capacitive touch (PCAP) and 3D gesture recognition on displays. The DV102014 kit will provide designers access to Microchip's 2D and 3D GestIC sensing technology, allowing them to integrate 2D multi-touch and 3D hand gesture recognition into their display applications. The use of electric-field based technology enables hand and finger gestures to be tracked, both on the display surface as well as above, at a distance of up to 20 cm (8 in). The development kit requires no code development. Parameterization, diagnostics, and optional settings are done through Aurea 2.0, a free downloadable graphical user interface. For more information, visit **http://www.microchip.com/**.

## Position-control torque arm system


A position-control torque arm system from **Mountz** improves and automates the fastening process while reducing manufacturing costs. The compact position-control device features a touch-screen display that is easy to program. An automation device management system incorporates the latest in screw counting technology. The position-control system reduces the risk of improperly fastened screws, ensuring that every screw is correctly tightened in the correct sequence. Available configurations include a table-mounted articulated arm system and a telescoping arm that is mounted above the assembly area. The ergonomic torque arms reduce repetitive motion injuries as well as providing comfortable tool operation and increased production. For more information, visit **www.mountztorque.com/**.

## 3D laser scanner

The new version of the MetraSCAN 3D laser scanner from **Creaform** is 12 times faster than the previous version and can tackle black, multicolored, and shiny surfaces with metrology accuracy for applications directly on the shop floor. The device is easy to use, ensuring short learning curves and operation by any level of user. Enhancements include volumetric accuracy of 0.064 mm (0.0025 in); rate of 480,000 measurements per second; and sturdy design for enhanced reliability. For more information, visit **www.creaform3d.com**.

## Additive for fluoropolymer coatings

**Carbodeon** has developed a new additive for fluoropolymer coatings, based on its uDiamond NanoDiamond technology. It targets solvent-based coatings used across multiple industries including automotive, aerospace, and industrial. The additive reportedly doubles the wear resistance of standard fluoropolymer coatings without making them abrasive, and maintains or improves the existing low friction properties. The new additive consists of diamond particles smaller than 10 nm in size, which are produced alongside Carbodeon's existing uDiamond NanoDiamond products, but with a newly designed surface chemistry to suit fluoropolymer materials. The surface chemistry enables the particles to disperse into the coatings without becoming agglomerated, resulting in an extremely high diamond surface area. This enables the additive to work at very low concentrations, reducing the cost, and making NanoDiamond applicable to a far greater market spectrum, the company claims. For more information, visit **http://www.carbodeon.net/**.

## UPCOMING WEBINAR – ANTI-FRICTION COATINGS: HOW TO ELIMINATE NOISE FOR THE LIFE OF INTERIOR PLASTIC COMPONENTS

Thursday, June 9, 2016 at 10:00 am U.S. EDT

Today's cars use sophisticated measures to avoid propagation of noise from the engine and gearboxes into the passenger compartment. This 30-minute Webinar explores anti-friction coatings as a preventive solution to reduce certain types of automotive component noise, offering service-life noise protection, compatibility with several plastics, and ease of integration into existing production lines.

**Speakers:**

**Vittorio Clerici**
Senior Application Engineering and Technical Service Specialist, Dow Corning

**Lisa Arrigo**
SAE International

**Registration:**
**www.sae.org/magazines/webcasts**

Sponsored by: DOW CORNING

Hosted by: SAE INTERNATIONAL

## UPCOMING WEBINAR – ACCELERATE DEVELOPMENT OF POWERTRAIN ECUs WITH VIRTUAL HARDWARE

Tuesday, June 21, 2016 at 1:00 pm U.S. EDT

Automotive powertrain ECUs are increasingly reliant on complex MCUs/SoCs and embedded software to achieve fuel efficiency, emission, and safety standards. The combination of complex hardware and software requires developers to face increasing architecture design, software development, and testing challenges. This 60-minute Webinar provides an overview of virtual hardware ECUs and how to integrate them into the automotive system development process to manage these challenges.

**Speakers:**

**Marc Serughetti**
Director of Business Development, Synopsys

**Lisa Arrigo**
SAE International

**Registration:**
**www.sae.org/magazines/webcasts**

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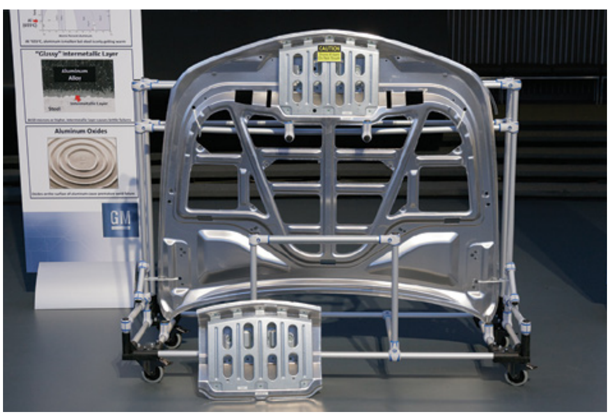
## WHAT'S NEW

### GM prepping industry-first steel-to-aluminum welding process

**General Motors** is poised to pull the trigger on a potentially game-changing manufacturing process to spot weld steel to aluminum. In the first production application for the patented process at GM's Hamtramck, MI, assembly plant, the advanced spot welding eliminates rivets that join an aluminum bracket to a steel framework to form part of the seatback for the **Cadillac** CT6.

Engineers claim GM's steel-to-aluminum welding will be an industry first when it launches later this year. If all goes according to plan with the seatback frame, GM intends to expand the process to the hood of the CT6, a new flagship sedan that currently represents the company's most aggressive use of multi-material construction.

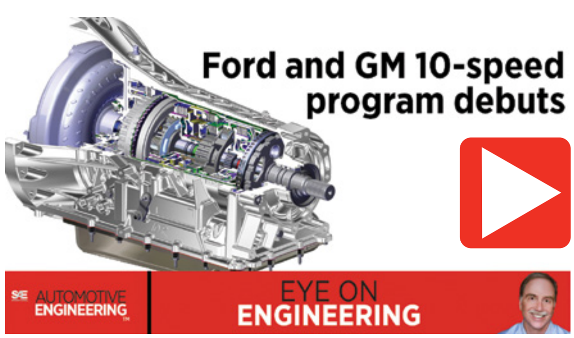
A specially-designed ridged electrode for the welding-gun tip is a key component of the system, said Blair Carlson, lightweight material processing lab group manager at GM Research & Development. In all, there are 19 patents covering hardware and controls for the process.



Read the full story at articles.sae.org/14838/.

## VIDEO

### SAE Eye on Engineering: Ford and GM 10-speed program debuts

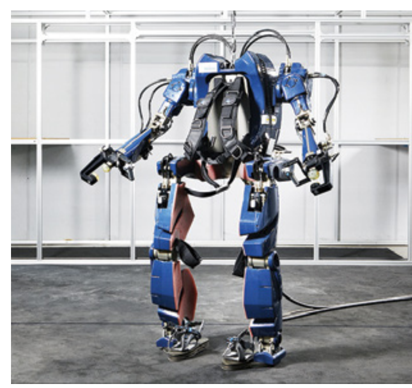



The first fruit of the latest **Ford** and **GM** joint project on transmissions was unveiled recently, and it sure looks sweet. In this episode of SAE *Eye on Engineering*, Editor-In-Chief Lindsay Brooke looks at Ford and GM's new 10-speed automatic transmission. The video can be viewed at http://video.sae.org/12174/. 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.

## WHAT'S NEW

### The race to engineer robotic personal mobility

Innovations in the ever-expanding category of personal mobility technology (PM) have become the norm both in and out of the automotive industry in recent years. Beyond renewed focus on the bicycle, new design concepts for all kinds of novel electric vehicles continue to appear—everything from nimble quad/tricycle city cars, urban runabouts and sidewalk buggies to e-bikes, scooters and self-balancing Segways, hoverboards and even unicycles.



Concept car designers at **BMW**, **Ford**, **Geely**, **GM**, **Honda**, **Hyundai/Kia**, **Renault Nissan**, **Suzuki**, **Toyota**, **VW** and others have incorporated these PM vehicles—often miniaturized, foldable or collapsible—to explore "dual-mode" ways to get passengers that "last-mile" home by providing "total mobility services." Navigating that critical last mile—really, only the last few hundred meters—has garnered greater attention as the world's population ages and interest grows in improving accessibility for the elderly, paraplegics and the mobility-impaired.

So it's little wonder that engineers at some 40-plus companies and research organizations worldwide have in recent years developed strap-on legged/walking PM vehicle designs. In these powered exoskeletons the passenger actually wears a mobile robot.

Read the full story at articles.sae.org/14725/.

# COMPANIES MENTIONED



# UPCOMING FROM THE EDITORS

**June 1:** Aerospace Engineering Technology eNewsletter

**June 8:** Off-Highway Engineering Technology eNewsletter

**June 14:** Automotive Engineering Technology eNewsletter

**June 21:** Vehicle Engineering Technology eNewsletter (all markets)

**June 28:** Automotive Engineering Technology eNewsletter

**July:** Automotive Engineering Digital-only Magazine
- Additive manufacturing (Webinar feature)
- Composites product spotlight

**July 7:** Aerospace Engineering Technology eNewsletter

**July 12:** Off-Highway Engineering Technology eNewsletter

**July 19:** Automotive Engineering Technology eNewsletter

**July 27:** Vehicle Engineering Technology eNewsletter (all markets)

**August:** Automotive Engineering Print Magazine
- Special Lightweighting Issue
- Vehicle lightweighting: What's beyond 2025?
- Composites product spotlight

**August:** Off-Highway Engineering Print Magazine
- Advanced emissions strategies
- Thermal management
- Aerodynamics for over-the-road
- 3D printing
- Hydraulic Components product spotlight

**August 2:** Aerospace Engineering Technology eNewsletter

**August 9:** Off-Highway Engineering Technology eNewsletter

**August 16:** Automotive Engineering Technology eNewsletter

**August 29:** Automotive Engineering Technology eNewsletter

# AD INDEX

Kazuaki Shingo: Showing the world Toyota's capability. (Photo by Lindsay Brooke)

# Pride in engineering the world's most popular electrified vehicle

Kazuaki Shingo's background is in mechanical engineering and internal combustion engines—making him a perfect candidate to develop the world's most popular electrified car! The Assistant Chief Engineer of the 2016 (fourth generation) Prius chuckles when he tells you that, recalling his seven years spent in control-systems design after joining **Toyota** as a university graduate in 1996. Shingo-san then got his wish to enter product planning, with subsequent moves back into development of the second-generation Prius hatchback, and the Auris and Prius V programs. He spoke with *Automotive Engineering* through an interpreter at the 2016 Prius North American media launch.

**Were you excited when the fourth-generation Prius was chosen to be the first vehicle developed on TNGA—Toyota's new global architecture?**
Yes! A lot of new Toyota technologies are incorporated into the latest Prius. The new platform raised the bar way up high for us who were developing the car. In fact, in the beginning I was working on both the new platform and the car. We felt this was a great chance for us to really capitalize on the new structure to make the car better. And that's what happened.

**What challenges did moving to the all-new TNGA present to your development team, and what benefits did TNGA provide?**
There were many challenges. For most of the components we started from scratch. Then it was difficult for team members to integrate the many, many requests for the platform from other departments and projects! But the new global platform created a 'volume effect' that make the vehicle prices more affordable. And it gives us more freedom to engineer different variants.

Also, at the time we were creating the new platform, we faced a number of challenges that came one after the other: first the 'Lehman Bros. shock' then we had a big earthquake in Japan and also Toyota had some quality-related problems. Not only that, the global market was shifting from the developed countries to the developing countries. I felt the crisis was so significant that our company might not be able to keep afloat. So the company decided to 'go back to basics' and create something affordable and with high quality. It was a company-wide decision to focus our efforts on that idea. In order to do that, intra-divisional walls were eliminated. Everybody got together and collaborated. We knew we had something that Japan is very proud of: the ability to manufacture products with very high quality. That spirit enabled us to move forward through the challenges.

**In developing the new Prius, what were the 3 main customer desires for the new model?**
Prius is Toyota's 'hybrid DNA' so we wanted to maintain the world's best fuel economy. That was number one. Second, while the previous model's fuel economy is very good, we also knew that road noise, ride comfort and handling weren't as good. On a long trip the fatigue level was not so good, and the handling needed improvement. So we wanted to rectify those areas. We wanted the new Prius to be a fun car to drive. And third was the interior aspects—some voices we heard said the old interior was too 'plasticky.' So based on those voices we revisited the interior and spent a lot of time on the seat design.

**Was there an aim to reduce the weight of the new Prius compared with the previous one? You did say the lithium-ion batteries contribute to less weight.**
Mass reduction was one of the greatest challenges we had in this development because the fuel economy is very important to us. Making sure the vehicle stays light was one of our most important aims. In addition to that, U.S. collision safety and fuel economy regulations were becoming very stringent; we had to cope with higher collision speeds. Also, to improve ride and handling we decided to install a double-wishbone rear suspension which caused us to raise body rigidity to a higher level. These and other things resulted in an increase in vehicle mass so to compensate we used more aluminum components and high-tensile steel. In the end we achieved a weight level comparable to the older Prius.

**The white body is all steel with aluminum hood and liftgate. Was there ever a plan to make Prius aluminum intensive?**
Yes, we gave consideration to use of aluminum in more areas. Because this vehicle was going to be produced using the TNGA, that meant it had to be designed for production anywhere in the world. It was a business decision that we had to protect. Also, obtaining aluminum for processing is easy in the U.S. and Japan, but not so easy in developing countries.

**What is your greatest achievement on the fourth-gen Prius?**
I'm most proud of developing the new hybrid system and also its new platform built from scratch. It's one way to show the world Toyota's capability.

**Lindsay Brooke**

**LAST CHANCE!** Entry deadline: July 1, 2016

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# "THE BEST WAY TO PREDICT THE FUTURE ...IS TO CREATE IT."

—ABRAHAM LINCOLN

## Making Inroads


**2013 BEST STUDENT ENTRY**

### SELF-DRIVING CAR

Autonomous vehicles have the potential to provide increased mobility for many, including the elderly, the disabled, and the blind. Cars equipped with this technology will also reduce accidents, energy consumption, and pollution, as well as cut costs associated with congestion. The vehicle automatically calculates an optimal route considering traffic congestion, road work, and other road incidents, and can operate without human interference.

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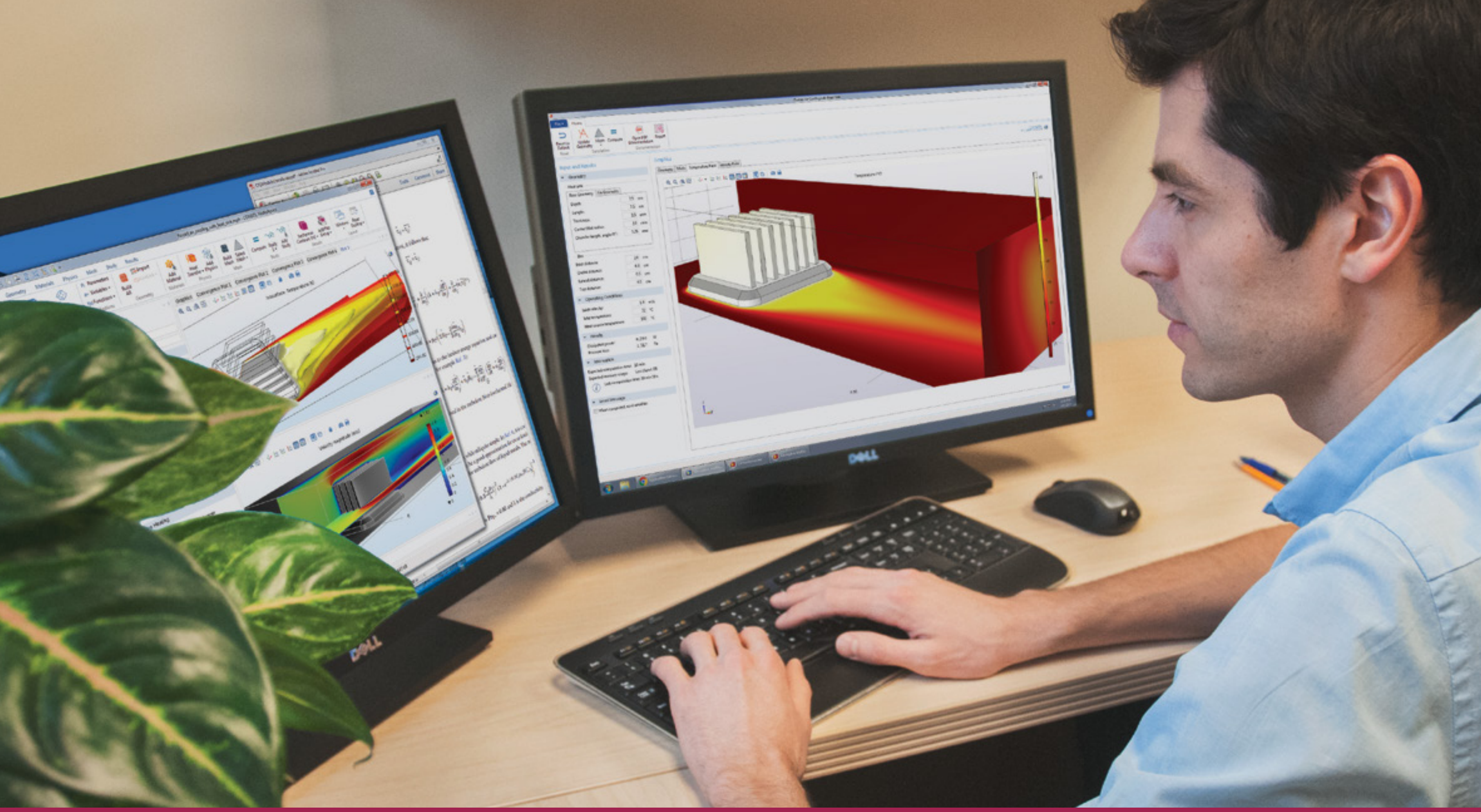

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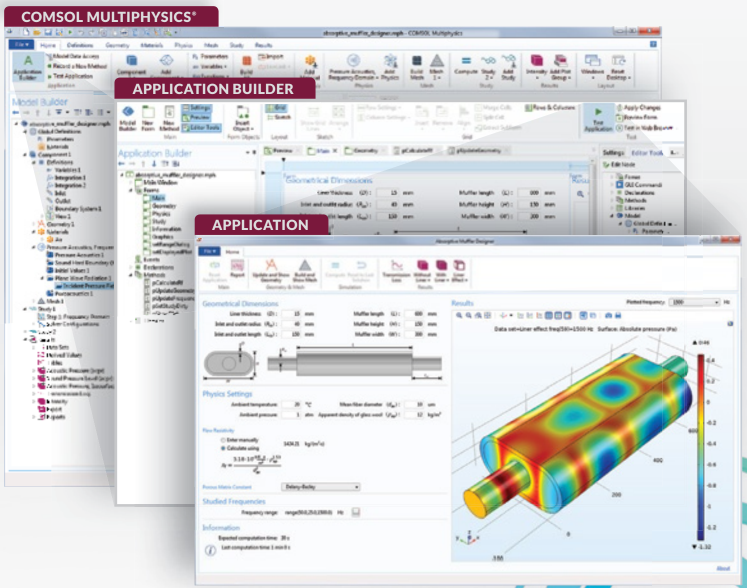


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