

It's a matter of economy



A Bosch plant in Nuremberg, Germany, manufactures many products, including single-cylinder high-pressure pumps for second-generation direct injection systems. The stainless steel pump is suitable for all grades of fuel, including ethanol.

Amidst the auto industry's efforts to satisfy horsepower cravings without sacrificing fuel economy, one solution is poised to gobble market share in double-digit abundance.

"We forecast that gasoline direct injection technology will make up 25% of light-duty vehicle production in North America by 2015," said Sujit Jain, Senior Vice President of the Gasoline Systems Division for **Robert Bosch**. The North American light-duty passenger vehicle market share for the industry presently is less than 5%, according to Jain.

Bosch engineers point to the **Cadillac** CTS luxury sport sedan as an example of how gasoline direct injection (DI) technology can help increase power without costing fuel consumption. The 2008 CTS

same whether the engine uses PFI or DI technology.

"We have the tools to get fuel economy improvement when employing gasoline direct injection (GDI) and the synergies of engine downsizing and turbo boosting. For instance, a Cadillac CTS powered with a 3.6-L V6 GDI engine—when retrofitted with twin-turbo boost enhancements—has the performance equivalent of a V8 with PFI, but with a 14% fuel economy benefit in city mpg and a 10% combined mpg fuel economy benefit. We're also getting a significant improvement in low-end torque," said Gottfried Schiller, Director of Engineering for Engine Management Systems at Bosch.

While direct injection can help improve fuel economy in gasoline-fueled vehicles, direct injection also could improve the fuel economy of ethanol-fueled vehicles. Since 2003, Bosch has reigned as Brazil's market leader in ethanol-suited components for PFI. "Brazil is the largest user of ethanol, so that provided us with a customer base for ethanol-compatible components," Jain said.

If ethanol becomes a popular fuel choice in other world markets, the lessons learned in designing ethanol-capable fuel injectors, fuel pumps, and other fuel-system components could net a hefty payback. "Using DI and the synergies of turbocharging and VVT, we want to optimize the effective compression ratio to the ethanol blend. Today's engines are optimized for gasoline," said Schiller.

The end result of achieving an optimized direct injection ethanol-fueled passenger vehicle is better mpg. "Bosch, **Ricardo**, and the **University of Michigan** are involved in a three-year collaborative program—sponsored by the U.S. **Department of Energy**—that will take a gasoline-optimized engine with DI and turbocharging and make the necessary modifications to build an optimized flex-fuel vehicle. We're hoping to get ethanol mpg to match what gasoline mpg is today," said Schiller.

Kami Buchholz



By using a flex-fuel management system from Bosch, an engine can run on gasoline, ethanol, or any mixture of those two fuels.

3.6-L V6 engine is available with either port fuel injection (PFI) technology or DI technology. Using DI technology, the variable valve timing (VVT) engine improves horsepower (304 hp [227 kW] at 6300 rpm vs. 263 hp [196 kW] at 6200 rpm) and torque (273 lb-ft [370 N·m] at 5200 rpm vs. 253 lb-ft [343 N·m] at 3100 rpm). The estimated 26 highway mpg is the

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New powertrain enhancements from Valeo

"It is our role as a supplier to create the new car which does not pollute as much," began **Valeo** Chairman and CEO Thierry Morin, speaking at the Frankfurt Motor Show in September. Morin illustrated the point with projected annual global automobile production figures for 2014—88 million compared with an expected 68 million in 2008, rising to 1.2 billion by 2030. The pressure by governments to reduce carbon dioxide emissions is therefore irresistible, he thinks.

However, by using a combination of technologies, Morin believes that Valeo can reduce carbon dioxide emissions from a 2.0-L 125-kW (168-hp) turbocharged engine by up to 40%. The drawback is that the cost of this technology would add between €1000 and €1500 to the powertrain cost by 2012. "But," added Morin, "OEMs have no choice."

To achieve Valeo's claimed 40% reduction in carbon dioxide emissions, the company calls on a range of powertrain technical solutions, some already available, others under development. The largest single reduction is derived from replacing the conventional cam-driven valvetrain with an electromagnetically actuated valvetrain (e-valve). The system, which won the Gold Award in the "Engineering and Advanced Technology" category at October's Equip Auto Show in

Paris, requires a 42-V power supply produced by a voltage inverter from the vehicle's 12-V system.

The e-valve system can provide cylinder deactivation and infinitely variable valve timing, which can deliver up to 15% more torque at low engine speeds. Each valve is controlled by two magnets and a pair of opposing springs. The magnets, which are placed above and below an armature plate attached to the valve stem, catch the armature plate as the



Valeo says that its StARS starter/alternator stop/start system can start diesel engines with displacements as large as 2.0 L and gasoline engines with displacements over 3.0 L.



Valeo claims carbon dioxide emissions reductions of between 15 and 20% with the addition of its electromagnetic valvetrain.

plate moves toward the magnet. When the valve opens, the upper magnet releases the armature. The valve opens as the upper spring uncoils and the lower magnet catches the armature plate, compressing the lower spring in the process.

Valve opening is controlled by the valve control unit (VCU), according to operating requirements. The VCU is cooled by the engine cooling system. Closure is a reverse of the opening process. Valves remain closed when the engine is not running. Valve opening and closing can take place more quickly than with a cam drive, which helps to reduce pumping losses, while a throttle air valve is not needed.

The system can be applied to gasoline and diesel engines, with or without turbocharging and with direct or indirect fuel injection. Valeo claims efficiency gains and subsequent carbon dioxide emissions re-

ductions of 15 to 20%. A vehicle equipped with this e-valve technology is scheduled to reach the market in 2012.

Valeo's StARS starter-alternator, as fitted to the **Citroën** C2 and C3 and due to be used on the **Smart** Fortwo microhybrid drive, can deliver efficiency improvements of between 6 and 15%. According

to Valeo, the familiar belt drive system is currently capable of starting gasoline engines with displacements as high as 3.0 L, and even up to 4.5 L in the Valeo tests. The system can also start diesel engines with displacements of up to 2.0 L.

Smaller efficiency gains can be achieved by using a dry double-clutch system, which can provide smooth shifts for automated manual transmissions without increasing fuel consumption. Double-clutch systems such as the **BorgWarner**-based **Volkswagen** DSG rely on wet clutches with a consequent loss of efficiency compared to a manual gearbox. A dry double-clutch system should be capable of providing smooth automatic gear changes without the losses associated with a torque converter automatic. Valeo claims a 4 to 6% improvement in efficiency.

Similar reductions can be provided by an electronically operated coolant flow control valve and a cooled exhaust-gas recirculation system.

John Kendall, with contributions from Ryan Gehm

The bombardier beetle and the challenge of emissions reduction

The bombardier beetle (*Brachinus Carabidae*) must be the most unlikely collaborative partner ever to become involved in an advanced automotive technology research project. However, this amazing little insect's ability to spray a stinging 100°C (212°F) cocktail from its internal "combustion chamber" over a distance 10 times its own length has concentrated the minds of a team at a leading British university.

The 2 cm (0.8 in) long beetle uses its toxic irritant exothermic spray as a protection against ants. The insect creates the spray by reacting hydroquinone with hydrogen peroxide, stored in its fuel glands, to produce a blast of steam. It is an ability that may contribute to greater fuel efficiency, and subsequently to reducing emissions in the fuel-injection systems of production automobile engines.



Leeds University's "bombardier beetle" test rig demonstrates the potential for linking nature and automotive engineering.



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The bombardier beetle: it may play a part in the development of more efficient automotive fuel-injection systems.

Andy McIntosh, Professor of Thermodynamics and Combustion Theory at **Leeds University**, explained: "The beetle's capability has direct applicability to fuel injectors due to its ability to tune the size of the droplets down to as little as 2 μm . This greatly increases the burning efficiency of the fuel, since the surface area (with respect to volume) increases greatly and consequently, less fuel is burned, and thus pollution is reduced."

The bombardier beetle's capability was revealed in *AEI's* sister magazine, *Aerospace Engineering*, four years ago. At that time, work by a research team under McIntosh had just begun at Leeds, with the project title, "Learning from controlled explosion in nature—modeling the catalytic explosion device of the bombardier beetle." At that time, the team focused on the extrapolation of the beetle's spray "technology" to support research into the re-light procedure for aircraft gas turbine engines at high altitudes.

Now, the list of potential applications

of the beetle's forceful personality has expanded to include automotive fuel-injection systems. Said McIntosh: "We have built a rig which simulates the physics of the bombardier beetle. It has the capacity to eject a very fine mist with 2 μm droplets as well as large droplets up to 100 μm . The maximum throw ratio (distance thrown divided by chamber dimension) is 200—the same as that of the beetle itself—striking confirmation that we had got the physics right!"

The beetle's 1-cm (0.4-in) diameter "combustion chamber" works rather like a pressure cooker. As the liquid in the chamber is held under pressure, a valve is opened, and flash evaporation occurs. The valve closes, the chamber refills, and heating brings the liquid to above atmospheric boiling point again—although this is not achieved until the chamber valve is opened once more. The beetle does this at 400 to 500 cycles/s. "Essentially, it is a high-force steam cavitation explosion," said McIntosh.

The experimental rig built by the McIntosh team (Novid Beheshti, Andreas Prongidis, and Steve Caddick) generates a slower frequency of 10 to 20 cycles/s, and rather than heating by catalytic chemistry like the beetle, achieves heating electrically. "But the principle is the same," explained McIntosh. "The great advantage of such a device is that the delivery is not through a high-pressure atomizer, but the small droplets are achieved with minimal damage to the environment. This has direct applicability to automotive fuel injectors due to the ability to tune the droplet size down to less than 10 μm ."

The beetle-based technology developed at Leeds has been given the trademark name, μMist . The research work was funded originally by the UK's **Engineering and Physical Sciences Research Council** (EPSRC) and subsequently by **Swedish Biomimetics 3000**, a virtual venture philanthropic inter-sectional organization founded in Sweden in 2004 by Lars Uno Larsen to fund translational research of biomimetics concepts to the point where they are considered commercially viable. At that point, corporate partners are sought for the technology's further development.

The μMist spray technology enables droplet size, temperature, and velocity to be closely controlled. The dynamic electronic tuning capability of the mist's properties presents what McIntosh regards as "the unique potential to sense the optimal mist characteristics required and then adjust accordingly, in real time". He added: "Nobody had studied the bombardier beetle from a physics and engineering perspective as we did—and at first, we did not appreciate how much we would learn from it."

The work at Leeds was inspired by entomologist Tom Eisner of **Cornell University** in the U.S. Swedish Biomimetics 3000 has signed a worldwide exclusive licensing agreement for the development and commercialization of μMist technology and potential application opportunities arising from the work have been filed for intellectual property rights, stated the EPSRC.

Stuart Birch

Ecology inspires new hybrid drivetrain options

Transmission manufacturer **Getrag** unveiled its new concept in hybrid drivetrains—a dry dual-clutch transmission linked to an electric rear axle—at the Frankfurt Motor Show this September.

In tune with the environmental undercurrent of the show, Getrag launched the concept, developed jointly with **Bosch**, under the banner of "Ecology Needs Dual Power." The company also announced the latest transmissions in its PowerShift range, introducing variants with both wet and dry dual-clutch systems.

The agreement between Getrag and Bosch is designed to launch a range of parallel hybrid systems using Getrag PowerShift dual-clutch transmissions and Bosch electrical architecture for the alternator, electric drive system, and power electronics. Designed around a six-speed PowerShift transmission, the resulting systems will feature modular designs that offer flexibility in the hybrid drivetrain.

For instance, the system can be arranged as a conventional parallel hybrid, with the e-machine as a combined alter-

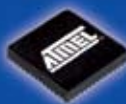
nator/drive motor positioned between the internal-combustion engine and the dual-clutch mechanism.

Alternatively, the e-machine can exploit the dual-clutch transmission's capabilities by mounting an alternator/motor separately and axially parallel to the transmission. Drive is then taken via an electromagnetic shift unit from one side of the split transmission (either the "odd" or "even" gear sets). The alternator/motor can be driven from one side of the transmission or switched from one to the other

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Getrag and Bosch will introduce a range of cooperatively developed parallel hybrid drive systems such as this one, which incorporates a Getrag dry dual-clutch six-speed transmission, Bosch alternator/motor, power electronics, and electric drive rear axle.



Due for delivery to Volvo this fall, the first PowerShift dual-clutch transmission will feature wet clutches and six speeds for front-wheel drive.

as needed. The electromagnetic shift unit can also disengage the alternator/motor drive completely. Getrag has named the system "Torque-Split"

The principal advantage of the system is that the internal-combustion engine and alternator/motor can be operated at different speeds. As a result, the alterna-

tor/motor can operate at its optimum speed—between 14,000 and 20,000 rpm—while the internal-combustion engine operates over the conventional diesel or gasoline speed ranges.

Getrag claims that lighter and less-complex electric components are applied and many parts are common to the

PowerShift transmission used with non-hybrid powertrains.

An alternative arrangement is to add an electrically driven rear axle. Since no further modification of the drivetrain is needed, the electric rear axle can be used either as an add-on to the "Torque-Split" hybrid or with the front-drive internal-combustion engine to provide all-wheel drive by switching in drive to the electric rear axle as required.

Used in place of a torque-converter automatic transmission with a conventional internal-combustion-engine drivetrain, Getrag claims that its PowerShift transmission will deliver a minimum fuel consumption reduction of 4 to 8% for both diesel and gasoline engines.

First to market in the revised PowerShift range will be wet clutch systems with production beginning this year.

Volvo will be the first customer for the six-speed 6DCT450 transmission with a torque rating of 450 N·m (332 lb·ft), and a maximum ratio spread of 6.5, when it appears this fall, followed by **Ford**. The transmission will be used in conjunction with a 2.0-L diesel engine. A 470-N·m (347-lb·ft) variant is also due this year. Seven-speed variants with torque capacities of 600 to 750 N·m (443 to 553 lb·ft) are due to follow in 2008, and the first PowerShift dry clutch transmissions will appear in 2009.

John Kendall

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Eyes on diesel research

Using quartz and sapphire components, high-powered lasers, and scientific cameras researchers are able to see inside an operating engine, and that vision is proving to be a valuable aid for finding ways to reduce diesel emissions.

"We can use the optical engine as a tool to get visual data, to get quantitative data, and to better understand the physical processes that are occurring in a standard metal engine," said Julian Kashdan, Research Engineer in the Energy

Application Techniques Division at IFP (**French Institute of Petroleum**) in Rueil-Malmaison, France.

An optical engine—essentially akin to a standard, all-metal engine but with certain parts fashioned in quartz and sapphire—has been a part of the research community since the 1980s. The transparent engine of today, however, is serving a vital role in the development of greener diesel engines.

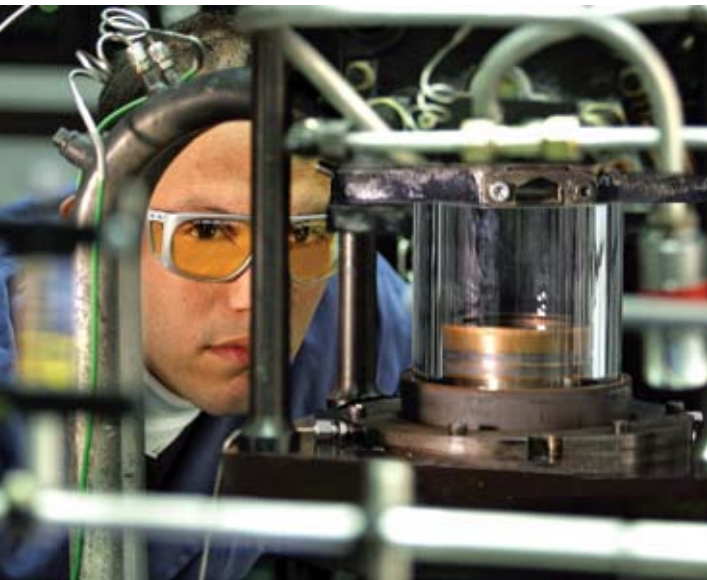
"We're trying to solve the NOx and soot emissions problem with diesel engines using low-temperature combustion strategies, and so we want to understand what's happening in-cylinder," said Kashdan. In one set of tests currently being conducted in the engine laboratory, an optical

diesel engine is fitted with a quartz cylinder and quartz piston bowl. "Using laser-spectroscopy techniques, we are able to visualize the physical processes occurring in-cylinder," Kashdan said.

Researchers can observe a range of operating conditions, including the time span from the injection of fuel into the cylinder on through engine combustion. "This is very important because it has a big effect on emissions formation. The data that we obtain is useful in terms of understanding what is happening physically so that we can try to optimize the designs of the combustion chamber. We can also provide this important data to the numerical modelers—meaning the people who perform CFD calculations for three-dimensional simulations. The data also can be used to validate those models," said Kashdan.

In the past few years, the homogeneous-charge compression-ignition (HCCI) diesel engine has received optical attention. "In order to get an HCCI diesel engine on the market, we need to look at increasing the low-load operating range limitation in order to really maximize the benefits of low-temperature diesel combustion. But when combustion temperatures are reduced, hydrocarbon and carbon monoxide emissions are problematic, which is why it is so important to see and understand what is happening in-cylinder in order to get to the source of the problem," Kashdan said.

Information gleaned from optical engines and other forms of analysis techniques are valuable discovery tools for companies involved with diesel technology. For instance, **Delphi** has been involved with diesel fuel injection technology for 50-plus years, and new products are always on the road map. "Compared to today's diesel engines, the injection nozzle that would be used in conjunction with an HCCI engine might need to have a larger number of holes. It could also have different spray angles, smaller hole size, and a more sophisticated injection pattern, which is why Delphi engineers are helping IFP researchers interpret what will be needed," said Pascal Dutfoy, Strategy and Planning Director for Diesel at Delphi's Powertrain Division in Blois, France.



Technician Jerome Cheral sets up an experiment on the optical engine, which shows the quartz cylinder liner and piston.



Looking inside the combustion chamber of the optical engine via a 45° mirror, which is housed inside an extended piston. The bluish light corresponds to combustion luminosity.



A full view of a single-cylinder diesel optical research engine within the IFP engine lab.

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