

A pro vote for anti-idling

Fuel cells used to be the catch-all when it came to possibilities for power systems that would in the future essentially emit only water. But as observers began to notice that their viability in off- and on-highway mobile applications perpetually seemed to be ten or more years away, hybrids began to grab most of that attention. This change in focus could be attributed to the fact that while fuel cells were mainly seen in print (*i.e.*, magazine and newspaper articles), a hybrid could be in front of you in stop-and-go morning traffic or even parked in your own driveway.

Not that work on fuel cells stopped while hybrids were being driven in real time. **Delphi** in particular has never given up on the technology. "We were working with PEM [proton-exchange membrane] fuel cells when we were part of **General Motors**," said Bruce Moor, Business Development Manager, Fuel Cells & Reformers, at Delphi Energy & Chassis. "When we were spun off of GM [in 1999], GM continued with its PEM activity."

But Delphi changed strategy to take better advantage of its internal resources, and ended up focusing on solid oxide fuel cells (SOFC).

Delphi was able to take advantage of in-house talent during the design of its solid oxide fuel cell. The heat exchangers are from Delphi's Thermal & Interior division, the fuel injectors used for the reformer come out of Delphi Diesel Systems, and the electronics are courtesy of Delphi Electrical, Electronics, & Safety.



While Delphi has targeted from the start transportation applications for its SOFC, "The goal is to get to high volume, so we're designing in commonalities for both stationary and mobile applications," said Bruce Moor, Business Development Manager, Energy & Chassis, Delphi. "If you had one of these in your home, you could run it on natural gas to supply electricity to your house."

"In the near term we're looking at anti-idle applications for heavy-duty trucks in which the [SOFC auxiliary power unit] would negate the need to run the diesel engine for things such as the air conditioner, heater, radio, *etc.*," he said. "There's payback in two to three years just in fuel savings alone." Moor added that Delphi's process is about 35% efficient, whereas diesel gensets, for example, are about 15-17% efficient.

"The cell uses the same fuel as the vehicle and is itself made up of three main elements: the anode, cathode, and the electrolyte," said Moor. "When we say 'solid oxide,' we're really referring to the electro-

lyte, which is a ceramic material. You could just as easily call this a ceramic fuel cell."

The ceramic material allows oxygen ions to pass through it. Air is blown through the cathode to provide the oxygen. A fuel reformer inside the SOFC vaporizes the system fuel and a catalyst breaks the fuel into hydrogen and carbon monoxide. That gaseous mix is then fed through the porous anode, where it comes into contact with the electrolyte. The carbon monoxide combines with the oxygen ions to form carbon dioxide and the hydrogen combines with the oxygen to form water, and those are expelled out of the anode. Electrons are produced in the process, creating a voltage across the cell. Cells are stacked, generating an output of about 40 V that can be converted to another voltage, including 28 or 12 V, or even ac, for use as an auxiliary power unit.

Delphi is currently contracted with the **Department of Energy** (DOE) in a partnership with **Volvo Truck North America** and **PACCAR** to determine how to integrate the device into a truck for anti-idle applications, but "in the longer term, we'd like to have this [SOFC] take over all the electrical power for the vehicle," said Moor. "That step would mean we would off-load all the mechanically driven devices on the engine, such as pumps, fans, *etc.*, and run those electrically so you'd only use the engine for propulsion." The DOE has shown that an 8% improvement in fuel economy can be achieved if all the mechanical accessories are unloaded from the engine.

The third-generation Delphi SOFC now in development is about the size of an airline-authorized piece of carry-on luggage and capable of about 3 kW, which would satisfy trucks today. But that will change. "In the future, the power will need to grow; we don't know yet to where," said Moor. "Maybe 10 kW will be suitable."

Moor uses refrigeration trucks as an example. Running the compressors electrically could make the system more fuel efficient by a power of about two. "Today's truck refrigeration units run at about 10 kW," he said. "We're not quite sure yet whether we need all that power because those are thermostatically controlled, kind of like your refrigerator at home. It comes on for a while, then it turns off. This fuel cell runs continuously, so in the future we might be better off powering the system down a little bit."

Besides heavy-duty trucks, Moor also cites uses for the 80-kg (176-lb) SOFC in recreational vehicles, construction and agricultural equipment, boats, military and utility vehicles, and aircraft. "The biggest adaptation problem for the different industries is the fuel itself," he said. "We have to change the reformer formulation of the catalyst for the different fuels, which include gasoline, natural gas, diesel, and JP8 for the military."

Jean L. Broge

A partnership based on aftertreatment

Tenneco will be supplying **International Truck and Engine** with exhaust aftertreatment systems for its 2007 medium-duty diesel vehicles powered by VT 275, VT 365, DT 460, and DT 570 engines. **Ford** will also use the system on the International engines it uses for its line of medium-duty trucks.

International and Tenneco have been working together for 12 months on the system, which is being developed "to make the addition of the emissions-control system as transparent to the driver as possible," said Lois Boyd, Vice President and General Manager, Global Commercial Vehicle Systems and Specialty Markets.



Shown is the complete exhaust aftertreatment system Tenneco is supplying International for its 2007 inline six, V6, and V8 engines used on International and Ford trucks. The hanging system takes advantage of elastomer technology developed through Tenneco's Clevite division for reduced NVH characteristics.

The system includes a diesel particulate filter (DPF), diesel-oxidation catalyst (DOC), and air gap pipe. "The DOC requires a specific temperature to function properly," said Boyd. "The air gap pipe preserves the heat from the engine exhaust to bring the DOC to that temperature more rapidly. This element of the system contributes to improved emissions control, especially during cold-start applications."

Soot particles captured in DPFs are essentially a product of incomplete combustion of the diesel fuel. To maintain proper



The aftertreatment system includes the diesel-oxidation catalyst, diesel particulate filter (DPF), and air gap pipe, which work together to minimize thermal losses while enabling more efficient and effective DPF regeneration events. Tenneco is conducting extensive component and system-level tests to ensure the system meets all design requirements, while International is "exhaustively testing" the systems in a variety of real-world driving conditions.

system functioning, the filter needs to be regenerated, a process in which accumulated soot is burnt off. In Tenneco's system, NOx in the exhaust gases passively regenerate the filter when the vehicle's duty cycle allows for the specific gas temperatures needed to burn off the soot.

"When soot is collected at a rate greater than the system can passively regenerate, it allows for active regeneration," said Boyd. "Fuel is dosed into the exhaust to increase the exhaust gas temperature so that the soot can be oxidized."

While soot in DPFs can be eliminated through a combination of passive and active regeneration, removing the ash that results because of that process involves actual human intervention, if, in Tenneco's system, only once about every 150,000 mi (241,400 km).

Its latest-generation DPF system "allows the DPF to be removed, cleaned, and reinstalled in less than 30 minutes," said Boyd. "Compressed air will be used to remove the accumulated ash from the filter."

The contract is Tenneco's first in North America for diesel-emissions-control technologies for this vehicle segment. The development and engineering for it is being done at Tenneco's engineering center in Grass Lake, MI. Production will be at its exhaust manufacturing facility in Seward, NE.

Jean L. Broge

Cat moves operator training into the classroom

In a cost-effective approach to equipment training, **Caterpillar** has introduced a series of PC-based simulators to orient and train inexperienced and prospective operators in basic machine operation and application skills.

The Cat Virtual Training System moves operator trainees through increasingly difficult tasks, ranging from basic operation of the boom and carrier to trenching and truck loading. Instant feedback is generated, detailing the time spent performing the task, its accuracy, and undesirable actions during the task. The trainee's skill level is measured, reported, and compared to performance criteria so that strengths and weaknesses can be quickly identified.

The system consists of software, a chair base assembly—designed to fit any five-caster office chair—and a joystick control module. The software for the system was developed in conjunction with simulation specialist **Simlog**, and the Cat Technical Center designed the chair base assemblies and the

components for the levers and controls. A menu allows operators to switch between an excavator-style **SAE** joystick pattern and a backhoe-loader joystick pattern. The boom and stick are controlled by opposite joysticks on the excavator and backhoe loader.

"We've had customers asking us for a safe, cost-effective way to train someone from having no experience to having at least a familiarization or an understanding of the controls of the machines," said Marty Dains, Cat Marketing Development Consultant and Certified Instructor. "These simulators are an introduction to the machine controls and their functions, preparing the operators for the next step, which would be into the field with an instructor or onto a large motion simulator."

The system currently available for hydraulic excavator operation retails for \$7500. Systems for wheel loaders, off-highway trucks, and track-type tractors will follow later this year, and motor graders and skid steer loaders are planned for 2007.



Cat's Virtual Training System consists of software, a chair base assembly, and joystick control module. The simulated image can be viewed on a computer screen or connected to a LCD television or projection screen.



The simulated training system can also be used as a tool for screening new employees, offering an objective method to assess the skill of potential employees.

The system's main advantage is reducing the time spent in the field with an instructor on the machine. By moving training to the classroom, both cost and time savings result.

"It will accelerate the learning process that it takes an instructor in the field right now to get a guy familiarized with the controls and how they work," said Dains. "The other part of it is, you're burning no fuel. You're losing no production from a machine within the company. No manpower hours are lost because you're not taking a machine and an experienced operator out of production to do this training."

Inherent in classroom learning is an added safety benefit as well.

"You're sitting in a classroom in a chair," said Dains. "You're not talking over the noise level, you're not standing on

the side of a machine with it moving and having the possibility of the instructor slipping or falling off the machine."

The system, targeted toward smaller contractors, is not intended to take the place of the actual field operator/instructor.

"The simulators are designed to familiarize someone with the controls and what they do and how to operate," said Dains. "I don't think you can ever get a true replication of the machine moving and digging the dirt or rock or rocky conditions. You actually have to go into the field with an instructor to understand that part."

Matt Monaghan

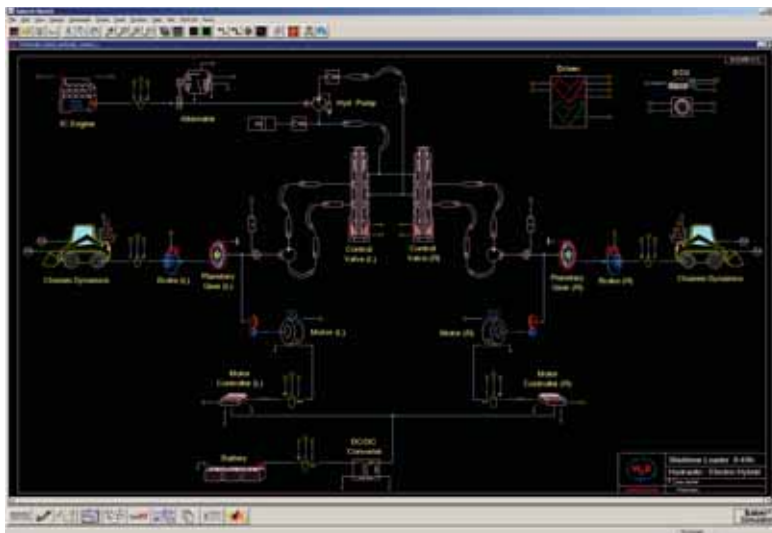
Design challenges of off-highway hybrids

Hybrid vehicles in general are very complex systems requiring unprecedented integration between control and the electrical, mechanical, and hydraulic systems. Add to this the rigors of off-highway environments, and design teams are challenged to produce hybrid vehicles that are cost effective to build yet reliable to operate.

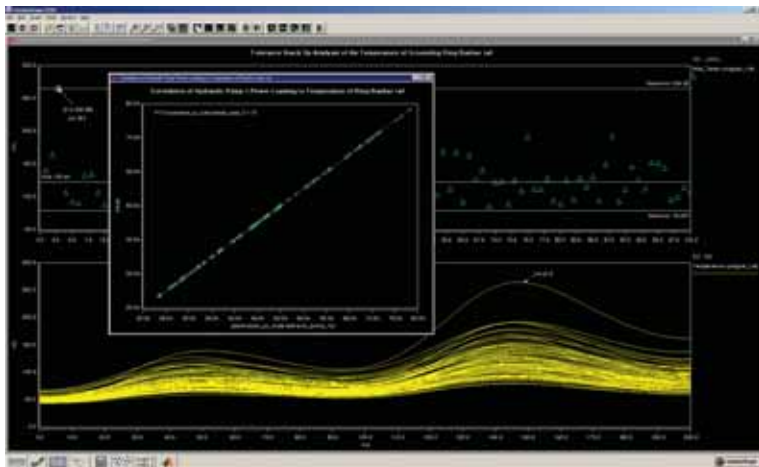
To meet these challenges, design teams such as those at **Synopsys** are increasingly turning to the use of Robust Design practices for off-highway hybrid vehicle design. Robust Design compensates for significant sources of variation that can affect a design, including manufacturing tolerances, environmental conditions such as temperature, and product wear.

The goals of a Robust Design process are to produce the simplest and least expensive product that still meets customer satisfaction goals throughout the product's life under all specified use conditions, which can be extreme for off-highway vehicles. Accounting for all conditions that affect vehicle performance can be a formidable design challenge.

A Robust Design methodology provides a systematic framework that design teams can use to meet reliability objectives. A typical Robust Design process includes the following steps:



An example of virtual hydraulic-electric off-highway vehicle design; as new systems such as hybrid vehicles are introduced into the off-highway industry, designers have seen a sharp increase in the need to run more simulations for virtual prototyping.



Robust Design methods are normally referred to as Taguchi methods or Six Sigma methods, which involve iterative analyses such as Monte Carlo or Pareto analysis. The objective of Robust Design is to compensate for all significant sources of variation that can affect a design.

- Creation of a nominal case design that operates according to base specifications, but does not include behavior due to variability or operational conditions
- Identification of all relevant sources of variability with respect to a particular design
- Structured design testing (typically using simulation)
- Analysis of the effects of variability upon measures of performance
- Modification and tuning of the design to meet overall design goals.

Design teams can implement these steps using the traditional techniques of design, prototype, and test. Building numerous prototypes for an effective Robust Design flow, however, can be both cost and time prohibitive. These critical restrictions create the opportunity to use virtual prototyping. Virtual prototyping involves using software to create the system design, and employs behavioral simulation and analysis to replace physical prototyping and measurement. Once a virtual prototype has been created, a series of simulations are run to analyze and verify system performance.

Because of the need to analyze system performance across a broad range of manufacturing tolerances and environmental conditions, an effective design process built on Robust Design principles is simulation intensive, particularly true during the statistical analysis stage, where thousands of simulation runs are frequently required to get meaningful results. Often the only way to handle this amount of simulation is through the use of grid computing, where statistical simulation runs are distributed among CPUs on

a compute grid.

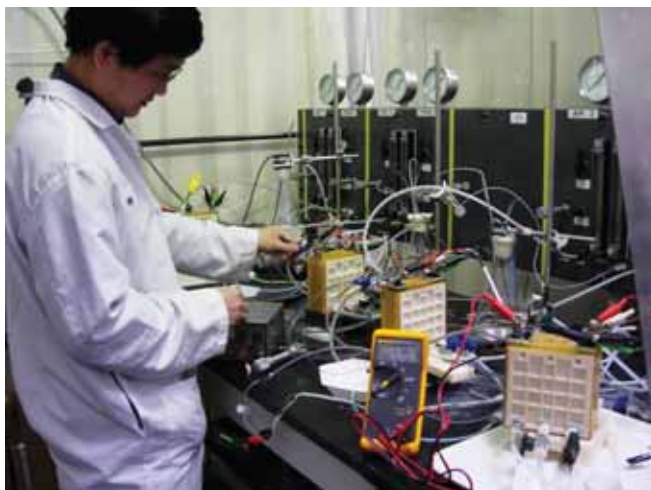
The combination of virtual prototyping and Robust Design techniques help insure increased reliability, at a reduced cost, of off-highway hybrid vehicles. High-performance design tools support key analyses and simulation techniques used at all stages of the Robust Design process for the design, simulation, and verification of multi-domain systems—essential aspects of reliable off-highway hybrid vehicle development.

This article was written for *SAE Off-Highway Engineering* by **Nils Johnson**, Saber Corporate Applications Engineer, Synopsys.

A fuel cell with a dual purpose

An atypical fuel cell would use metal hydride as a substitute for precious metals. The design would employ injection-molding equipment, and the system would function as its own energy storage unit. But is the resulting fuel cell ready for prime time?

“It is difficult to get new concepts accepted, particularly when there is a mainstream movement in place, which is the proton-exchange membrane (PEM) fuel cell for low-temperature applications such as automotive propulsion. But we think the Ovonc metal hydride fuel cell has more promise for a lot of applications, including automotive,” said Dennis Corrigan,



Hong Wang, Senior Research Scientist, tests fuel-cell stacks in a laboratory at the Ovonc Fuel Cell Company.

President and Chief Operating Officer of the **Ovonc Fuel Cell Company**, a subsidiary of **Energy Conversion Devices**.

Designed as a low-cost alternative, Ovonc’s fuel cell bypasses precious metals usage. Instead, metal hydrides that consist of disordered multi-component alloys of transition metals and rare earth elements as well as graphite powders and Teflon are the main materials. No proprietary membranes or bipolar plates are part of the package, but plastic meshes and nickel screens and tabs outline the landscape. The hydrogen electrode active material is an electrochemical catalyst layer—made of the metal hydride, carbon powders, and Teflon.

The fuel cell operates with hydrogen entering on the metal hydride side, while air passes through the metal oxide side. In between the catalyst sheets is an alkaline electrolyte. “It’s a simple three-part design with the electrolyte being sandwiched between metal hydride catalysts and metal oxide catalysts,” said Corrigan. Ovonc’s fuel cell has received more than 12 patents, and there are 20-plus pending patents covering aspects ranging from fundamental use of hydrogen storage and oxide materials to construction and design aspects.

In the prototype presentations, fuel-cell stacks are encased in an epoxy-sealed ABS housing, but injection-molded containers welded by laser or vibration technique are envisioned for production application. “Instead of a Silicon Valley type of approach where manufacturing is done in an environmentally controlled area, we plan to produce and seal the pieces together using conventional automotive manufacturing methods,” said Corrigan.

One aspect that really differentiates the Ovonic metal hydride fuel cell from other fuel cells is its ability to store energy, thus eliminating a separate storage battery for startup and for capturing regenerative braking energy. "It's the first fuel cell that can run backwards and store electricity in the fuel-cell stack with the potential also to replace the hybrid battery in a fuel-cell vehicle," said Corrigan.

Because the unit also functions as an energy storage portal, there is instant startup without hydrogen. Early testing has shown that the initial operational state can continue at peak power without hydrogen for approximately five minutes. The Ovonic metal hydride fuel-cell stack also can operate below -20°C (-4°F). Early product prototype in-house testing demonstrated that an eight-cell stack lasted more than 2000 h at constant power. Single electrode tests showed the potential for more than 5000 h.

Ovonic's present prototype fuel cell is still well shy of the 1000 mA/cm² output of typical PEM fuel cells. "We feel with continued engineering that a substantial power boost is possible by optimizing the gas flow patterns, improving the

current collection, establishing better spacing of the electrodes, and designing more efficient packaging," said Corrigan. Ovonic researchers have realized a 250 mA/cm² power output, and the prototype has exceeded 500 mA/cm² in pulse mode operation.

Company officials recognize that the near-term production application is centered on the stationary market. "We have a good technology for UPS (uninterruptible power supplies)," said Corrigan. Several potential customers have indicated an interest in Ovonic's metal hydride fuel-cell technology. "We're working to provide prototype samples over the next several months," said Corrigan.

Although an automotive production application may be years away, Ovonic officials have an optimistic view about what they consider game-changing technology. "We offer a way to eliminate the battery and associated weight, volume, cost, and complexity penalties from a fuel-cell vehicle while offering key advantages in efficiency and heat rejection," said Corrigan.

Kami Buchholz

Better standards for diesel fuel sought

As regulations requiring cleaner-burning diesels take effect, developers are focusing on improving the quality of fuels available. That is of particular importance in the U.S., since much of the diesel fuel used in America is fairly low in quality.

"The U.S. fuels have an average cetane number of 44. That's the world's worst, including emerging countries," said Loren Beard, Senior Manager at **DaimlerChrysler** Environmental and Energy Planning.

Improved fuels will be needed to help engine makers meet pending U.S. regulations for both on- and off-highway vehicles. The **EPA** has mandated a move to low-sulphur fuels in 2006 and lower engine emissions in 2007. This will reduce particulate matter and oxides of nitrogen emissions from heavy-duty engines by 90% below current standard levels, according to the EPA.



International Truck and others hope global specifications will provide a single diesel fuel standard for future engines.

Many presenters at the recent 11th Diesel Engine Emissions Reduction Conference, sponsored by the U.S. **Department of Energy**, called for completion of fuel standards linked to the EPA requirements.

"We need to do more work to get a spec in place so the hardware folks can feel good about warranties. A key issue is stability," said Wendy Clark, Group Manager at the **National Renewable Energy Laboratory**.

If these standards are matched with those emerging in other countries, it will simplify engine design for global manufacturers. "We need harmonization worldwide so we can design a single engine for all markets," said Rodica Baranescu, Chief Engineer at **International Truck and Engine**.

Upgraded standards are also needed for alternative fuels such as biodiesel. The biodiesel B100 specification will not assure problem-free usage in advanced engines, so it must be upgraded. "A standard that assures us biodiesel fuels meet quality standards is critical. We need a B20 specification; we can't just look at B100 and say, do 20% of that," Beard said.

While the key focus of new fuel specifications is lower emissions, there will be side benefits. Many presenters noted that improved fuels will remove some of the negative aspects that have slowed the adoption of diesel by U.S. car buyers, which could increase its acceptance here.

"As diesel fuel is around us more and more, its sociability characteristics like noise, white smoke, and odor are more important. They don't impact emissions but they do impact people's view of diesel fuel," Baranescu said. Gains in fuel efficiency will also improve the likelihood of increased market acceptance, she added.

Though some presentations discussed the introduction of premium diesel, at least one automaker feels that it is not a good idea. The availability of diesel remains an issue for American consumers, and vehicles that require premium diesel could have a very limited market.

"We are not particularly interested in premium diesel fuel. We don't want to tell customers that of the 30 to 40% of stations that have diesel, only a few have premium diesel," Beard said.

Terry Costlow

NexxtDrive's space-saving CVT


Transmission technology specialist **NexxtDrive** has developed a new continuously variable transmission (CVT). Called DualDrive, it includes an electric drive capability and can be packaged in less space than a conventional automatic gearbox with torque converter. NexxtDrive believes that the technology will facilitate a fast, low-cost integration of a hybrid-electric system and make a significant contribution to meeting lower CO₂ requirements.

The DualDrive system, which allows manufacturers to use a single transmission for both hybrid and non-hybrid vehicle variants, incorporates an epicyclic geartrain to combine the drive from the vehicle engine with two electric motor/generators. In normal use, one of them operates as a generator while the other functions as a motor. Power from the engine is split between a mechanical drive path (through the epicyclic geartrain) and an electrical path from the generator to the motor. By altering the way the transmitted power is routed between the electrical and mechanical drive paths, the speed and torque at the output shaft can be precisely controlled.

Frank Moeller, NexxtDrive Director and Chief Engineer, said: "A critical advantage of the DualDrive approach compared to those of alternative electrical/mechanical power splitting devices, is that a larger proportion of the power is transferred through the highly efficient mechanical gearbox, while control is achieved using the smaller electrical power path. In this way, overall system efficiency is high—on average, only 10% of the power is transferred electrically. The relatively small electrical generator/motors also help to ensure the cost of the system is lower than alternative approaches. The system works without the need for clutches, torque converters, or any form of mechanical gear change."

Mechanically and electrically transmitted power is recombined by the epicyclic gearbox and transmitted to the vehicle propshaft. Moeller explained that although electrical power transfer is less efficient than that transferred mechanically, the design of the epicyclic gearbox allows electric power transfer to be minimized for the highest overall efficiency. Controlling the relative speed of the two electric generator/motors gives full control of the gearbox ratio and allows the vehicle's engine to operate at its most efficient speed in all conditions.


"This facilitates potential fuel and CO₂ emissions savings of up to 20%," said Moeller. For further efficiency improvements, battery storage can be integrated into the system for full hybrid operation, without altering the DualDrive gearbox in any way. The electric generator/motors can also replace the vehicle's conventional starter motor and alternator to deliver a stop-start function for added fuel savings in city traffic, plus a further reduction in total package cost. According to Moeller, in full hybrid applications, CO₂ reductions are expected to be at least 35% compared to conventional car designs.




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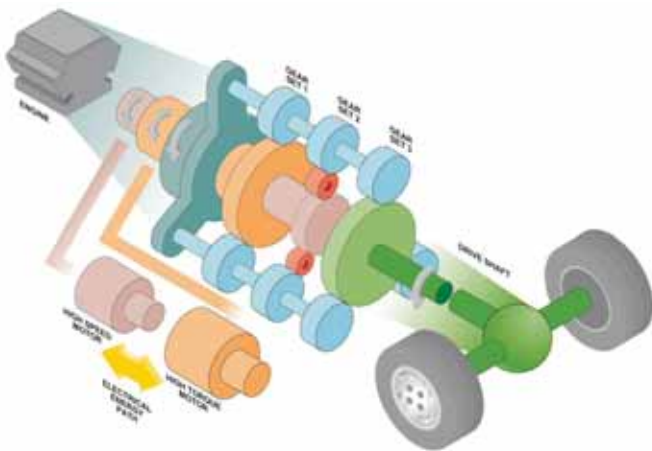


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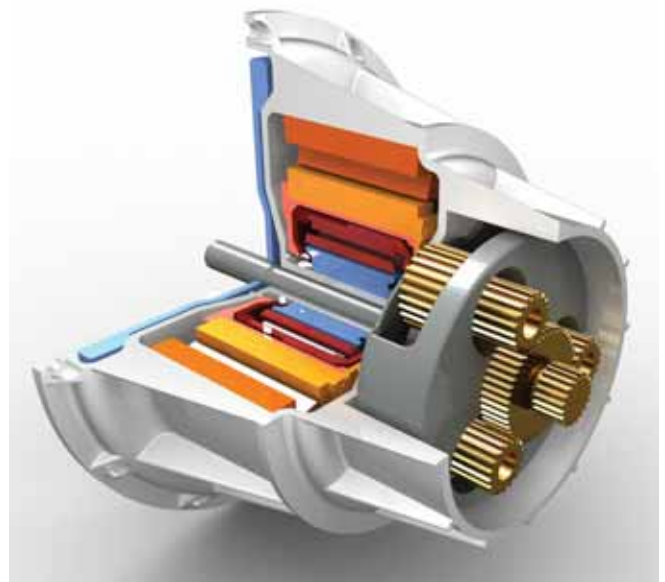


Core of the DualDrive system is an epicyclic gearbox to combine torque from the vehicle's engine and from one of two electric motors.

The use of a twin generator/motor system is said by Moeller to markedly improve packaging compared to that of other single-motor hybrid solutions. The two motors are assembled concentrically, which, combined with the compact epicyclic transmission, allows the whole system to be engineered into a drivetrain with minimal changes to the vehicle configuration.

NexxtDrive has announced that it has completed a detailed program of prototyping and simulation of the DualDrive system. Among its portfolio of designs are a robust solution for rear-wheel-drive passenger vehicles of up to 200 kW and "extremely compact" solutions for front-wheel-drive vehicles. As part of studies now under way for an OEM, NexxtDrive stated that it has demonstrated that DualDrive can provide automatic transmission capabilities in vehicles where it had previously been impossible to package such a system. DualDrive can also be scaled up for use in four-wheel drive, truck, and bus applications.

"With a similar unit cost to conventional automatic transmissions and straightforward integration into existing



The space-saving DualDrive can operate as part of a hybrid power system or as a totally self-contained application with no hybrid capability.

vehicle platforms, DualDrive can eliminate the daunting costs associated with development of vehicle-specific hybrid transmission solutions," said Rod Keech, NexxtDrive's Chairman.

The technical innovations underlying the DualDrive system may find applications in light electric vehicles, construction and agricultural equipment, and renewable energy generation. Keech revealed that SuperGen2, an automotive pressure-boosting technology using NexxtDrive's core intellectual property, is already under development in a program with the company's joint-venture partner, **Integral Powertrain**, based on an option agreement with "a major global Tier 1 supplier."

Stuart Birch

Scientists see 3-D nanostructures

An international team of scientists affiliated with the **University of Wisconsin**-Madison Nanoscale Science and Engineering Center has coaxed a self-assembling material into forming "never-before-seen," three-dimensional nanoscale structures, with potential applications ranging from catalysis and chemical separation to semiconductor manufacturing.

Led by UW-Madison chemical and biological engineering professors Paul Nealey and Juan de Pablo and colleagues at **Georg-August University** in Germany and the **Paul Scherrer Institute** in Switzerland, the team has discovered that materials known as block copolymers will spontaneously assemble into intricate 3-D shapes when deposited onto particular 2-D surface patterns created with photolithography.

The result demonstrates a promising strategy for building complex 3-D nanostructures by using standard tools of the semiconductor industry, said Nealey. Those tools, particularly lithography, already allow the making of devices with dimensions substantially smaller than 100 nm (4 μ m). But photolithography is also limited because it is essentially a 2-D process, he noted.

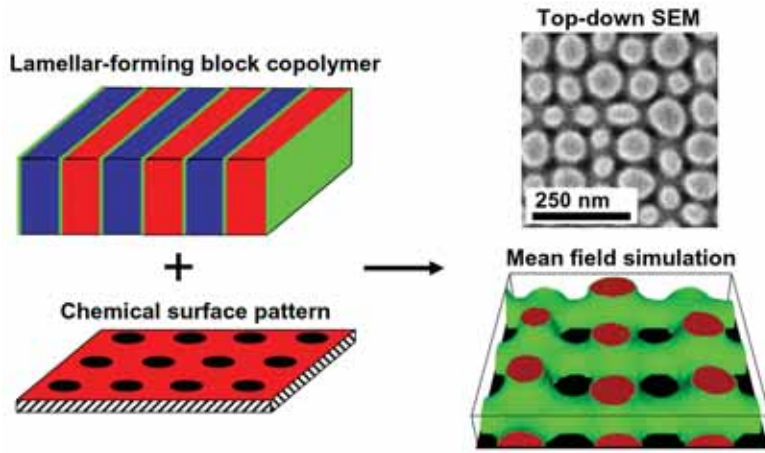
"What we've done by using self-assembling block copolymers is to extend photolithography to three

dimensions," said Nealey. "And the structures we've fabricated are completely different from the same block copolymer materials in the bulk."

Also important to manufacturing, the new 3-D nanostructures are said to be stable, well-defined, and nearly defect-free over large areas.

"This research shows that lithography combined with block copolymers is more versatile and powerful than we thought. We can now create completely new structures that will no doubt have new properties and new applications," said de Pablo. "Exactly what those structures will be is anybody's guess ... The important thing is they open up a new field of exploration, both for these materials and this technology."

The specific structures the team produced were composed of two tightly interwoven, yet independent, networks of channels and passages—all at the atomic scale. The networks are in perfect register with the photolithographic pattern underneath, which allows scientists to know exactly where each channel ends and gives them ready access to channel openings. A gas, for example, might be introduced through the openings to react with a catalyst deposited on the walls of



Thin films of a block copolymer that assumes a layered (lamellar) morphology in the bulk (top left) form complex 3-D nanostructures when deposited onto 2-D surfaces patterned with a square array of spots (bottom left). Top-down scanning electron micrographs (top right) show that a series of spots arise on the surface. Results from a mean field simulation (bottom right) indicate that both copolymer domains (the blue domains were removed from the image for clarity) of the self-assembled morphology are continuous and align with the lithographic pattern. The black spots indicate the position of the underlying surface pattern and the green represents the interface between the blue and the red domains.

the network. Nanoscale materials have massive surface areas compared to their volumes; thus, catalysis would be extremely efficient, according to the researchers.

Another use would be chemical separation of substances of different sizes. "This process gives us exquisite control over the dimensions of pores," said de Pablo. "So, we could easily make membranes that are permeable to substances smaller than the length scale of the material."

The researchers study specific block copolymers consisting of long chains of two different types of molecules, which alternate with each other in blocks. At high temperature, block copolymers are molten and randomly mixed. But when cooled down, the material spontaneously assembles into alternating layers of molecules.

The **National Science Foundation** Nanoscale Science and Engineering Center at the University of Wisconsin and **Semiconductor Research** supported this research.

Ryan Gehm

Innovation at speed

The development of innovative vehicle applications, as well as increasing customer and legal demands, combine to increase the complexity of contemporary automotive engineering applications. Conventional engineering methods have trouble coping with the resulting complications. This helps to explain why nearly all the major automobile manufacturers have independently adopted **The MathWorks'** Model-Based Design for their development process.

In Model-Based Design, engineers use an executable specification that lets them iterate quickly through design concepts and simulations without needing to build physical prototypes. Later, they can use these executable specifications as the basis for real-time simulation and hardware-in-the-loop testing, as well as for automatic code generation.

Most new features in next-generation automobiles are based on the development of new hardware and software. Traditional text-based specifications are difficult to manage over frequent design iterations and are often ambiguous, resulting in more meetings between system and implementation teams, and, potentially, products that do not meet their requirements. With this type of hand coding, the design must be respecified, recoded, and reverified at each iteration. Moreover, engineers cannot perform full functional tests until the prototype hardware becomes available, which usually isn't until quite late in the design process. Then when testing is carried out, and errors are discovered, it is difficult to determine which subset of the verification testing is needed to confirm that change. As a result, many hardware design



DaimlerChrysler re-engineered a cruise controller for Mercedes-Benz trucks using Model-Based Design to develop, test, and implement the software on an ECU.

changes require such an extensive recoding effort that it is often easier to start from scratch.

Model-Based Design enables a hierarchical approach in which the design is initially defined at a very high level and blocks are added as necessary to provide more functional details. The model of the embedded system being designed becomes an executable specification that designers can rapidly modify and evaluate by simulating it on development hardware and viewing the results immediately. Engineers can quickly evaluate the performance of a wide range of design concepts, selecting the best one. Continuous testing and verification makes it possible to identify problems up front so that only minor changes are required during the prototype stage,

reducing both time to market and engineering costs.

Major automobile OEMs and Tier 1 suppliers have demonstrated successfully that the code engineers generate automatically from models is as good as the code produced by experienced hand coders. More importantly, once the configuration of the code generator for a given model is done, generating new iterations from that model is as simple as pushing a button.

Lastly, complete functional verification is greatly accelerated. Instead of manually testing thousands of possible combinations

of hardware on vehicles, engineers can develop scripts to do automatic functional tests of all possible combinations in parallel, and in a greatly reduced time frame, using computer simulations. Because the model is developed independently of an embedded hardware target, it can easily be retargeted to different platforms and reused in future systems.

For example, engineers at **DaimlerChrysler** recently re-engineered a cruise-control system for **Mercedes-Benz** commercial vehicles, including heavy-duty trucks, delivery trucks, and coaches. The vehicle's complex cruise-control

software controls drive and brake torque, regulates distance, and limits speed. The systems and software engineers on the DaimlerChrysler project team had already developed a C-code module for this application, but needed to redesign it for a new target ECU. DaimlerChrysler began by developing a design model consisting of 3900 blocks with 140 input signals, 40 output signals, and 340 parameters.

Engineers conducted tests throughout the development phase using an interactive, automated test tool based on a test database with predefined tests and a control interface. They performed processor-in-the-loop testing using a closed-loop simulation of the model communicating over CAN bus with the automatically generated production code. Then they automatically generated code, tested it in the target ECU, and tested the ECU in a hardware-in-the-loop simulator consisting of a vehicle model working on VME systems and all vehicle ECUs, including hardware sensors.

The automatically generated code required about 16% less RAM than the previous version's handwritten code, and met all project requirements for efficiency and structure. Debugging the control software on the desktop instead of in the vehicle enabled the DaimlerChrysler team to reduce the time and cost associated with resolving software problems. The entire project, including analysis, restructuring, modeling, and testing, took just 18 months. It would have been nearly impossible to achieve this project deadline without Model-Based Design.

This article was written by **Jon Friedman**, Automotive Industry Marketing Manager at The MathWorks.

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