Gas, diesel, hybrids vie for U.S. future

Yasuyaki Sando surprised many 2006 SAE World Congress attendees by saying that Honda is exploring HCCI combustion for gasoline engines, rather than diesel.

No single type of powertrain will provide solutions to U.S. vehicle fuel consumption, emissions, and performance challenges during the next two decades, according to an expert panel discussion at April's 2006 **SAE** World Congress.

Gasoline and diesel internal-combustion engines, operating in conjunction with traditional drivelines and also combined with various types of hybrid-electric drive, will dominate the U.S. powertrain landscape through 2020, concluded the experts from **BMW** Group, **AVL** Powertrain Engineering, Robert **Bosch**, **Honda** R&D, **Toyota**, and the U.S. **EPA** (Environmental Protection Agency).

When asked by panel moderator Anthony Pratt, Global Powertrain Forecasting Director at **J.D. Power and Associates**, to predict the U.S. powertrain mix for light-duty vehicles at the turn of the next decade, the panelists agreed that gasoline engines will dominate. Most said they expect gasoline engines to have at least 50% market share at that time. There was disagreement, however, on the shares of diesel and hybrid vehicles.

Jeff Alson, Senior Policy Advisor at the EPA's Office of Transportation and Air Quality, predicted that diesels and hybrids will each capture a 25% share by 2020. John Moulton, President of Bosch's Powertrain division, concurred with Alson.

However, Dave Hermance, Toyota's Advanced Vehicle Technology Executive Engineer in the U.S., called the 25% prediction of diesel and hybrid penetration "optimistic."

Hermance also predicted there will be multiple types of hybrid drives, from micro (stop/start function) to full systems that can propel the vehicle on battery power alone, depending on cost and complexity.

A steady increase in vehicle miles traveled, along with other factors such as global fuel demand, competition for existing petroleum reserves, political instability in oil-producing regions, and more stringent emissions standards worldwide are forcing greater innovation in all engine types, noted keynote speaker and panelist Klaus Borgmann, BMW's Director of Powertrain Development.

Lean-burn, gasoline direct-injection (GDI) engines, many of them turbocharged and fitted with increasingly sophisticated valve-actuation systems, are under development across the industry, said the panelists. The GDI engines will increasingly compete with diesels in terms of overall efficiency.

Turbocharged GDI engines currently in development are showing brake specific fuel consumption (BSFC) equivalent to diesels. NOx abatement, a common issue with all lean-burn engines, could be less of an issue with GDI than with diesels, particularly in meeting the U.S. Tier 2 Bin 5 standards being phased in from 2007 to 2009.

"The diesel tech map for the future is based on cost efficiency," said Chris Cowland, Technical Director at AVL's Plymouth, MI, facility.

He noted that, although some diesels have exhibited potential to meet Bin 5 without aftertreatment, it is likely Bin 5-compliant diesels will require some level of the technology, such as selective catalytic reduction (SCR) or de-NOx catalysts.

Honda's Yasuyaki Sando surprised many with his presentation, which was completely devoid of any mention of light-duty diesels for the future U.S. market. Last year at Congress, Honda executives stated that diesels were in the works.

Sando's presentation focused on homogeneous-charge compression-ignition (HCCI) strategies for gasoline fuel, rather than diesel. However, he explained that HCCI research still has a long way to go to overcome transient control issues, among other challenges.

Lindsay Brooke

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Diesels face many challenges

The challenges of meeting tight U.S. emissions levels for diesel engines are quite complex, forcing diesel specialists to take a full systems approach to powertrain design. Compounding the issue are varying requirements for different vehicle classes, which may result in different solutions.

Participants in the "Diesel Emissions Management Status Report" session at the 2006 SAE World Congress in April did not tip their hands on production decisions, but they did detail the many choices and tradeoffs that engineers face.

Ricardo's Adrian Greaney (second from left) answers an audience question on diesel emissions.

"Ideally, one size fits all, but when you start looking at the different applications, that's difficult to do," said Kevin Duffy of **Caterpillar**. The pending Tier 2 legislation, specifically the stringent Bin 5 requirements, is a key factor driving diesel development.

Adrian Greaney of **Ricardo** focused on light-duty vehicles, but he spoke for others when he said, "There are clearly significant challenges ahead. We need to take a holistic approach to solve them."

Reducing particulate matter and NOx require different solutions. Keeping both of them low begins by minimizing emissions that leave the engine cylinders. The levels of these emissions determine what type of filters will be used to further clean emissions.

"One of the important things is what the engine delivers. Is it at 50% or 85%?" said Andrew Walker of **Johnson Matthey**. Tradeoffs such as this will determine whether manufacturers pick selective catalytic reduction (SCR) or NOx adsorption catalyst technologies.

Another challenge for developers is to find techniques that work as well on roads and worksites as they do in research labs. That will probably mean using electronic controls to constantly monitor the engine's performance. "Managing real-world variabilities is a key challenge. It will require a closed-loop system," Greaney said.

Though engine developers make costs one of their top priorities, the cleaner diesels still carry a hefty price tag. "On medium-duty trucks, there will be a $5000 premium in 2007," said Alan Karkkainen of **International**.

Another factor for diesels that use SCR is infrastructure support. Engines must have technology that ensures the supply of urea in the vehicle's tank, and it must be accessible. "Urea can freeze. In Japan, they use water from the cooling system to keep it from freezing," said Timothy Johnson of **Corning**.

Another factor is that controls must make sure the vehicle will not run if there is not enough urea to filter exhausts. That means an infrastructure must be in place so drivers can add urea when the tank runs low. Most vehicles will carry enough urea so refills on oil-change intervals are unnecessary, but many service stations will have to carry urea for instances when the on-vehicle supply runs low.

Panelists feel they are on track to meet the regulatory time frames, which kick in in 2010. "In 48 months, we'll all be talking about how well we did," Karkkainen said.

They are already looking at the next set of challenges. "Fuel economy will be a considerable issue going into 2010 and beyond," Johnson said.

Terry Costlow

Technologies spin new driveline designs

Insights into a variety of current and near-future transmission and driveline technologies engaged an overflow audience at the **FEV** Powertrain Innovation Forum during the 2006 **SAE** World Congress.

The Transmissions and Drivelines seminar discussed hybrid-electric vehicle (HEV) transmissions, all-wheel-drive systems, friction material research, and development of a new six-speed automatic. Keynoted by Larry Nitz, **General Motors** Executive Director of Global Powertrain, the panelists hailed from **Magna Powertrain**, **Timken Automotive**, **BorgWarner Automotive**, and **Toyota**.

Nitz, who directs GM's HEV program, provided more detail on the transmission the entire auto industry is waiting to see—the "two-mode" hybrid system set to debut next year on GM's full-size trucks.

Originally developed by GM Allison for city bus use, the dual-mode design has been downscaled for use in light vehicles. It is being developed for high-volume applications by a consortium of GM, **BMW**, and **DaimlerChrysler**.

The GM two-mode system offers a power split capability for greater efficiency. Nitz explained that this differentiates the unit from Toyota's current single-mode HEV transmission.

"You don't have to have a power split with a full hybrid," said Nitz. "But the two-mode split allows us to use fewer gearsets, smaller electric motors, and gives a smaller overall package."

The two-mode design features two 60-kW electric motors and three

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GM's Larry Nitz explained the new two-mode transmission debuting on full-size trucks.

planetary gearsets. Nitz explained that adding a third gearset "reduces the amount of electricity needed to flow through the power path, allowing a significant downsizing of the electric motors."

From Nitz's excursion into hybrid power, the discussion turned to driveline torque vectoring, which distributes torque not only front-to-rear but also right to left, depending on available traction.

Sankar Mohan, Director of Advanced Engineering at Magna Powertrain, and Mircea Gradu of Timken, jointly presented a look at new processes and technologies for next-generation torque vectoring systems. The aim, said Gradu, is enhanced vehicle performance, agility, and safety.

"The rear differential is capable of providing 'yaw authority' to improve steering," he said.

Timken is developing a torque-vectoring unit that uses magnetic powder (particle size in the 0.5 to 0.8 micron range), which, when energized, is able to send drive torque to all wheels very rapidly. Magnetic coupling technology is an alternative to friction clutches and visco-based units.

The system provides "linear controllability, low hysteresis, and low drag," said Gradu.

The trend toward higher transmission torque inputs; continuous-slip clutches; dual-clutch operation; and six-, seven- and eight-speed gearsets, requires new friction material solutions, explained Robert Lam, an advanced research director with BorgWarner Transmission Systems.

Lam outlined BorgWarner's R&D in friction materials with unique fiber structure and orientation to not only handle the demands of these new gearbox designs, but also improve durability and reduce operating noise.

The seminar was concluded by Daisake Kasamoto, a design engineer at Toyota. He presented the technical details of the new U660E close-ratio six-speed transmission now entering production for front-wheel-drive (FWD) vehicles.

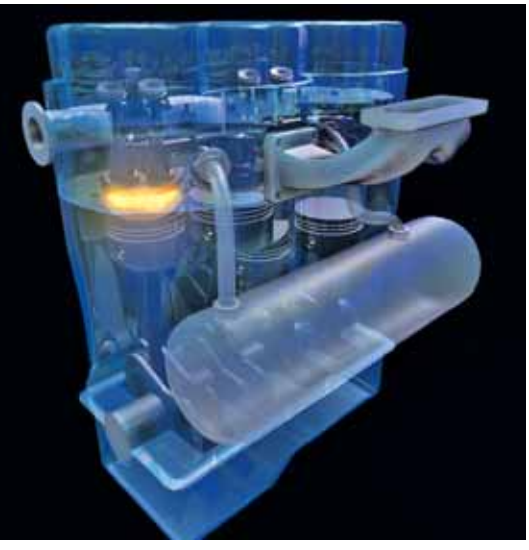
The U660E breaks new ground for Toyota in maximum torque capacity (400 N·m; 295 lb·ft.) for FWD applications. It also improves on Toyota's already quiet and efficient five-speed. Gear noise was reduced through tooth-form refinement and optimized case design using 3-D methods.

The U660E features 21% fewer components than the previous five-speed. The 3-D design process helped Toyota reduce the program lead times by six weeks, Kasamoto said.

Lindsay Brooke

Scuderi's split-cycle solutions

Split-cycle engines—with separate cylinders for compression and power—have been around since the early 1900s, but until now have had much worse thermal and volumetric efficiency than a conventional Otto-cycle engine. The big innovation of the **Scuderi** engine is solving those two problems, said Sal Scuderi, President of the Scuderi Group, at the 2006 **SAE** World Congress.



The split-cycle engine being developed by the Scuderi Group can operate as a gas-air hybrid.

The volumetric efficiency problem was found to be a matter of poor engine breathing due to trapped air in the compression cylinder. The engine could not breathe as well as a conventional engine, making the power density lower. "We are using a unique valve design developed in the early 1980s to solve the problem of trapped air in compressors," said Scuderi. "When you look at our engine, one side is pumping air, and fuel is introduced only on the other side. Using technology from the compressor industry solved the breathing problem."

Traditional engines are designed to fire before top dead center (TDC) so the combustion process can keep up with the piston and pressure builds up enough to deliver the power. The solution on thermal efficiency was to fire after TDC. Scuderi engineers discovered that high-pressure air going into the power cylinder creates a lot of turbulence, and then that combination of high pressure and turbulence causes the fuel to atomize very rapidly and produce a very fast flame speed.

"Our engine breathes well—it has very good volumetric efficiency—and has an efficient combustion process," said Scuderi. "The base engine is higher in efficiency and performance than a conventional engine, but the beauty is that once we figured out how to [make it work] we had all kinds of design flexibility. A lot of features are built in."

Supercharging is done simply by increasing the diameter of the compressor piston so that extra air is pumped into the power cylinder on each cycle. The stroke of the power cylinder piston can also be varied independently of the compression.

"We can offset the cylinders in opposite directions for better friction conditions, one to favor compression and one for power; a conventional engine can't do that because they are both the same," said Scuderi. "This small offset reduces friction on the rings and provides a little extra mechanical advantage to deliver slightly more torque to the crank."

One unique product of the firing after TDC is a mechanical cooling of the expanding flame so the temperatures do not get high enough to produce much NOx. The drop in emissions was not anticipated, and it only came out of a detailed study performed by an independent laboratory.

"The big thing is that we can turn this into a hybrid system by adding a tank to store energy as compressed air instead of electricity," said Scuderi. "The pressure will be high enough to run in 'air-motoring' mode, but we think it might be more effective to still use the combustion process. We can feed in a small amount of air from the reservoir, gaining a big advantage from shutting off the compression cylinder stroke." This is labeled high-efficiency mode, because on any engine the compression stroke is negative work.

Regenerative braking will use vehicle momentum to drive the engine as a pure compressor and charge up the reservoir, saving brake wear at the same time. Cruising mode will use only some of the compressed air for the power stroke, and store the rest. When the reservoir reaches a certain pressure, the engine will switch into high-efficiency mode and use just stored air. Hybrid-electric vehicles offer regenerative braking efficiencies but do not have any advantage over conventional power at cruising speeds.

The 700-psi (48-bar) air storage tank will also be available for other uses. It could supply compressed air to inflate tires or start the engine if the battery dies. Portable power for pneumatic tools has great potential for the military and other commercial users.

"Transfer of the air from the compression cylinder to the power piston requires critical timing of valves and piston motion," said Scuderi. "The valve on the power cylinder must move very quickly. Design of that valve and the actuation mechanism are the design issues we are currently dealing with. The existing design uses cams for valve actuation, but we are also looking at pneumatic operation. On the compression side we don't need cams, because the compressor valve technology operates strictly by pressure differential." Fewer cams mean another slight reduction in engine friction and complexity.

"Our prototype gasoline engine will be a two-cylinder, and our first diesel will

be a six," said Scuderi. "Because of the offset cylinder design we have the compactness of a V but the better wear of a vertical straight six. So far everything has been done with computer modeling. We've analyzed the combustion process, balancing, valves, *etc*. Once we complete the designs we will build prototypes and then go through six months of endurance testing. The first engines for testing are expected to be ready mid-2007."

"We think the diesel engine market has the greatest potential because we have such a big cost advantage," said Scuderi. "Typical diesels today have turbochargers and high-cost, high-pressure fuel injectors. And soon considerable aftertreatment cost. We can eliminate the turbocharger because we have a built-in supercharger, and we only need half the number of injectors. And because of the high turbulence, we can go to lower-cost, low-pressure injectors. Soot and NOx emissions are reduced by lower temperatures and more complete combustion due to the high turbulence.

In January, the **Department of Defense** agreed to provide $1.2 million of development funding for the Scuderi engine. Private investors have since come up with an additional $6.8 million.

David Alexander

FEV shows diesel-electric hybrid concept

An innovative diesel hybrid-electric vehicle (HEV) concept aimed at crossover SUVs and light trucks was showcased by **FEV** at the 2006 **SAE** World Congress.

The powertrain R&D and systems engineering specialist has participated in numerous HEV concept programs for both gasoline and diesel engine applications for a number of years. The fully functioning concept displayed at Cobo Center was developed in conjunction with **Ssangyong Motor** of South Korea and is based on the automaker's Rexton midsize crossover SUV.

FEV and Ssangyong also presented a technical paper on the diesel-HEV system development at the SAE Congress.

Pairing a hybrid-electric drivetrain with diesel internal-combustion engine (ICE) power offers significantly reduced fuel consumption over gasoline HEVs. But for many drivers, a diesel-hybrid offers the prospect of enormous driving fun.

FEV's diesel-hybrid is based on the Ssangyong Rexton crossover.

"This is a fuel-saving concept with great opportunity for niche vehicles," said FEV's Bob Last.

Torque-plus is the result when engineers add an electric motor to the diesel's already prodigious torque output. And it is a further bonus when the system achieves reduced exhaust emissions by employing the hybrid transmission to optimize the engine's speed and load range.

"This is a fuel-saving concept with great opportunity for niche vehicles," explained Bob Last, Vice President of Operations at FEV's Auburn Hills, MI, facility. "The hybrid system gives extremely elastic performance when combined with Ssangyong's 2.7-L inline five-cylinder turbodiesel."

The collaborative program was launched in 2004 on an accelerated schedule. The completed concept Rexton began testing at FEV in 2005.

Optimizing carryover componentry to save cost and speed development time was a key goal of the program. A standard Ssanyong automatic transmission was converted for hybrid duty by replacing the torque converter with a 34-kW synchronous electric motor. The system provides parallel hybrid operation.

The Rexton hybrid's diesel engine is unchanged from standard Ssangyong configuration, except for minor calibration tweaks.

FEV engineers based at the company's Aachen, Germany, headquarters tackled layout of the hybrid system components using a variety of simulation tools. The team created vehicle and drivetrain models that helped it understand the interplay of e-motor, ICE, and transmission.

FEV accelerated hybrid control system development by using software- and hardware-in-the-loop system development. This allowed development of control strategies and algorithms based on simple models of the drivetrain early on.

The process significantly reduced development times of the full hybrid drivetrain, according to FEV.

The team assessed model accuracy for vehicle and drivetrain with the conventional non-hybridized vehicle.

When the hybrid vehicle setup was completed, full-load acceleration and fuel consumption in the European driving cycle were evaluated. NOx emissions were also simulated, but this was found to be less accurate due to the influence of dynamic combustion effects not detailed in the model. But simulation techniques were sufficient to define all major hybrid-system functions for the concept vehicle.

According to Last, the program's second development phase began early this year. He indicated that Ssangyong is considering production. The concept Rexton currently meets Euro 4 emission standards.

Lindsay Brooke

The search for energy

Chart after chart pointed to a change in lifestyle as a succession of speakers spoke about the impending demise of oil production at a 2006 **SAE** World Congress session on the future of transportation energy sources.

"The rate of discovery [of oil] is decreasing at the present time, while consumption is increasing," said Nigel Gale, panel moderator and Vice President of **Southwest Research Institute**.

The flow of oil is projected to be dramatically lower over the next 20 years. Wolfgang Warnecke, Global Manager of Fuels Development for **Shell** Global Solutions, said alternatives—such as biofuels made of food crops and by other processing techniques—continue to receive ample attention, yet fossil fuels will continue to dominate the market for years.

Ray Corbin, President of **AVL** Powertrain Engineering, referenced a litany of automobile energy sources—gasoline, methanol, propane, compressed natural gas, hydrogen, *etc*.—but singled out biomass as a worthy choice. "It can be and is renewable," he said.

Southwest Research Institute's Nigel Gale noted that discovery of oil sources is on the decrease, consumption on the increase.

President George W. Bush's biofuels initiative aims to replace more than 75% of oil imports from the Middle East by 2025, according to Larry Russo, Technology Coordinator, Biomass Program, for the U.S. **Department of Energy**. Almost all ethanol in the U.S. produced today is from corn. Wood chips, stalks, and switch grass are targeted for being "practical" ethanol sources by 2012.

Grain crops presently account for about 5 billion gal (19 billion L) of today's biofuel. The plan is to increase that to 15 billion gal (57 billion L) by 2030 while another 45 billion gal (170 billion L) of biofuel will be from non-corn sources, Russo said.

David Baldwin, Senior Vice President, Energy Group for **General Atomics**, said a change toward a different energy source "has to be done in steps and needs to build on the existing infrastructure. For instance, hydrogen-produced using MHR (modular hydrogen reactor) could provide a transition to a full hydrogen economy," he said.

Christoph Huss, Senior Vice President of Science and Traffic Policy for the **BMW Group**, said if the world saw $100-a-barrel oil, an alternative energy source would "come hurriedly into the game." He spoke about the potential of a hydrogen internal-combustion engine and pointed out that in the next couple of weeks, BMW will pilot hydrogen-powered vehicles in locales in the U.S. and Europe.

Kami Buchholz