Powertrain progress at GM

Fuel efficiency gains and emissions reductions are the primary benefits that **General Motors** wants to deliver with its forthcoming product releases. "We'll have nine new or significantly revised engines and transmissions for North America in the 2006 model year," said GM Powertrain Group Vice President Tom Stephens. Among the products slated to debut in 2006: new variants in the Gen IV small-block V8 engine family, six-speed automatic transmissions, and the Belt Alternator Starter (BAS) hybrid system.

The new Vortec engine variants include 6.0- and 6.2-L displacements for next-generation full-size SUVs. In all, there are eight new variants of the small block V8 engines for the 2006-2007 model years.

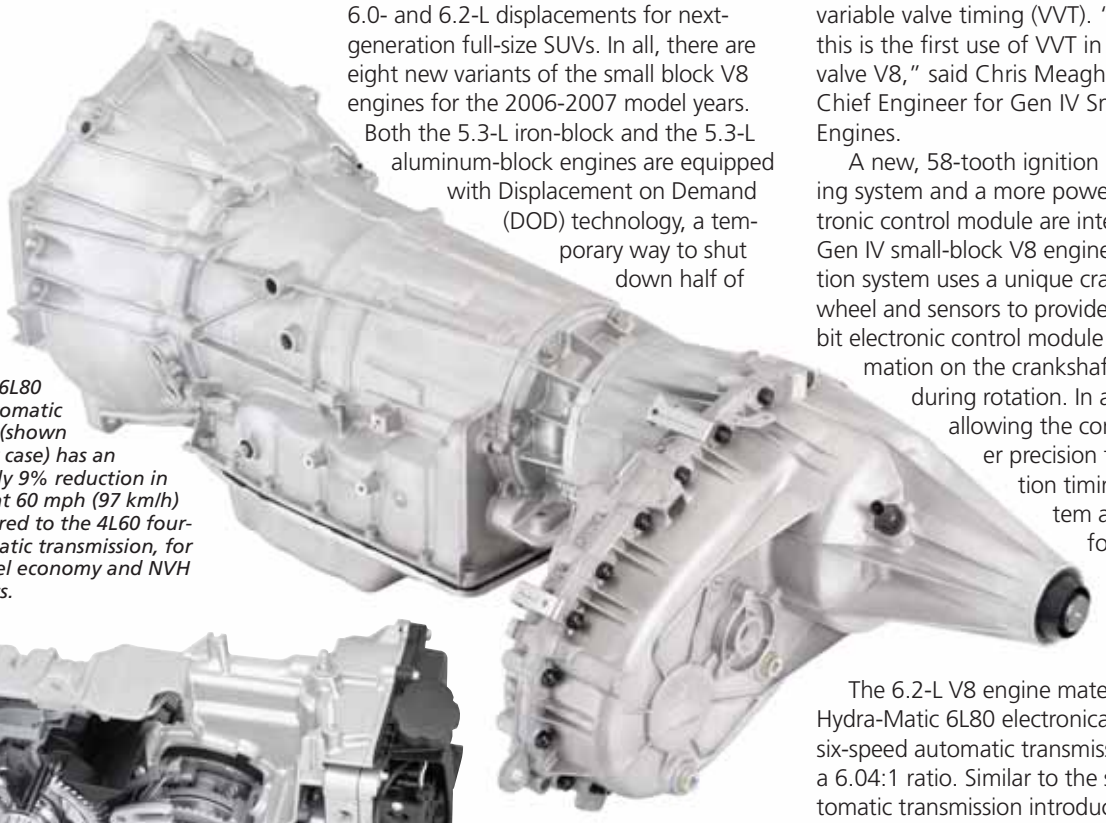
Both the 5.3-L iron-block and the 5.3-L aluminum-block engines are equipped with Displacement on Demand (DOD) technology, a temporary way to shut down half of an engine's cylinders to save fuel. Some 5.3-L engines are capable of running on E85 ethanol-based fuel. The 5.3-L aluminum- and iron-block engines, as well as the 6.0-L aluminum-block with DOD, can provide up to 7% fuel efficiency improvement when compared to the non-DOD 5.3- and 6.0-L engines.

Three variants—a 6.0-L iron block rated at approximately 350 hp (261 kW), a 6.0-L aluminum block rated at approximately 355 hp (265 kW), and a 6.2-L aluminum block capable of an estimated 380 to 400 hp (283 to 298 kW)—feature variable valve timing (VVT). "We believe this is the first use of VVT in an overhead-valve V8," said Chris Meagher, Assistant Chief Engineer for Gen IV Small Block V8 Engines.

A new, 58-tooth ignition position sensing system and a more powerful electronic control module are integrated on all Gen IV small-block V8 engines. The ignition system uses a unique crankshaft wheel and sensors to provide the new 32-bit electronic control module with information on the crankshaft's position during rotation. In addition to allowing the controller greater precision to adjust ignition timing, the system also "provides for clean and more consistent starts," said Meagher.

The 6.2-L V8 engine mates to the new Hydra-Matic 6L80 electronically controlled six-speed automatic transmission that has a 6.04:1 ratio. Similar to the six-speed automatic transmission introduced on the 2006 **Chevrolet** Corvette, the 6L80 was tailored for the heavy-duty requirements of SUVs and pickup trucks. "This transmission is the first of a four-variant family of six-speed rear-wheel-drive automatics," said Jeff Baran, Chief Engineer for Rear Wheel Drive Six Speed Transmissions. The transmission debuts on select 2007 model year full-size SUVs from GM.

GM Powertrain's first front-wheel-drive six-speed automatic transmission



The GM Hydra-Matic 6L80 six-speed automatic transmission (shown with transfer case) has an approximately 9% reduction in engine rpm at 60 mph (97 km/h) when compared to the 4L60 four-speed automatic transmission, for enhanced fuel economy and NVH characteristics.

The Hydra-Matic 6T70 six-speed automatic provides packaging convenience for either front- or all-wheel-drive vehicles with transverse-mounted powertrains.

The 2007 Saturn Vue hybrid uses an advanced nickel-metal hydride battery pack capable of delivering and receiving more than 10 kW of peak power, and a Belt Alternator Starter. Hybrid Vue's 4T45-E electronically controlled overdrive transaxle includes an auxiliary oil pump and unique hybrid controls to ensure seamless hybrid operation.

debuts on the 2007 **Saturn** Aura mid-size sedan. Co-developed with **Ford**, the transmission provides advanced clutch-to-clutch operation and a wide 6.04:1 overall ratio spread, which helps enable a performance improvement of up to 8% and a fuel economy improvement of up to 4% vs. the current front-wheel-drive four-speed automatic transmissions. The transmission has a torque capacity of 280 lb·ft (380 N·m) and shift speeds up to 7000 rpm. GM's Hydra-Matic 6T70 is applicable to front- and all-wheel-drive layouts. "The front-wheel differential can be taken out and an all-wheel-drive differential put in," said Robert Vargo, Assistant Chief Engineer for Transmission Engineering at GM Powertrain.

Saturn is also the first brand to debut the BAS hybrid system via the 2007 Saturn Vue Green Line SUV that enters the market in mid-2006. "The BAS system does engine start/stop, early fuel cut-off when the vehicle is decelerated, regenerative braking, intelligent hybrid battery charging, and hybrid electric power assist during vehicle acceleration as needed," said Steve Tarnowsky, GM Powertain Assistant Chief Engineer for the Vue's hybrid powertrain system.

A unique aspect of the system relates to the accessory drive's dual tensioner assembly. "It's two tensioners on a common, pivoting arm. One tensioner is hydraulic, and the other is a conventional tensioner with friction damping," said Tarnowsky. GM has a pending patent on the technology. Saturn Vue Green Line's hybrid system will mate with a 2.4-L VVT Ecotec engine and a Hydra-Matic 4T45-E electronically controlled overdrive transaxle. The BAS hybrid system will provide customers with "about 80% of the full hybrid experience," said Larry Nitz, Executive Director of GM Powertrain's Hybrid Program.

A two-mode full hybrid system, co-developed by GM and **DaimlerChrysler**, will launch in 2007 via two full-size SUVs, the 2008 Chevrolet Tahoe and the **GMC** Yukon. Chrysler will first use the system in the **Dodge** Durango. The system is based on the **GM-Allison** diesel-electric hybrid propulsion system operating on 364 transit buses currently servicing 25 cities in the U.S. and Canada, as well as Yosemite National Park in California.

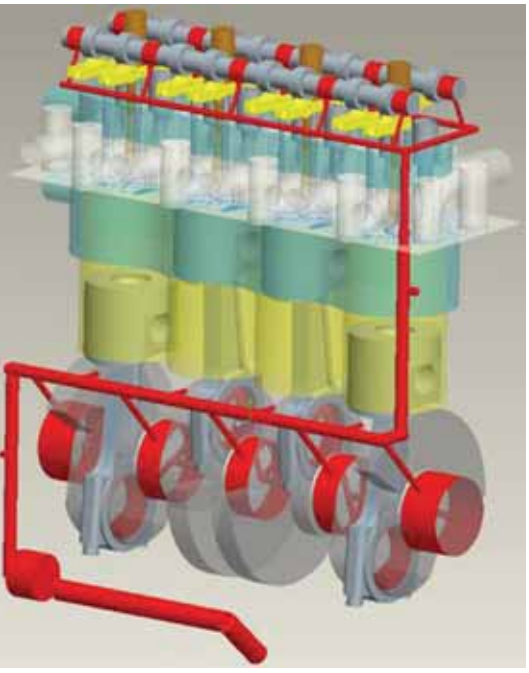
Engineers will be doing substantial development work in the coming months. "The electric motor torque needs to be balanced with the engine torque to produce the proper output torque. Any errors in the calculations or in the control of the torque will produce output torque disturbances, which is unsatisfactory to customers. This [integration work] is where most of the development work is being focused in 2006," said Tim Grewe, Chief Engineer of Rear Wheel Drive Hybrids at GM Powertrain.

Since April 2005, the two-mode full hybrid system has undergone proving ground testing via about 30 SUVs and pickup trucks. Laboratory and math-based testing is also part of the mix. "It takes tools like the road-to-lab-to-math method to develop the hybrid system. It's necessary to reduce this complex system to a manageable execution task," said Grewe. GM officials expect that when combined with DOD technology, the hybrid SUVs with V8 power will result in a composite fuel economy improvement of 25%.

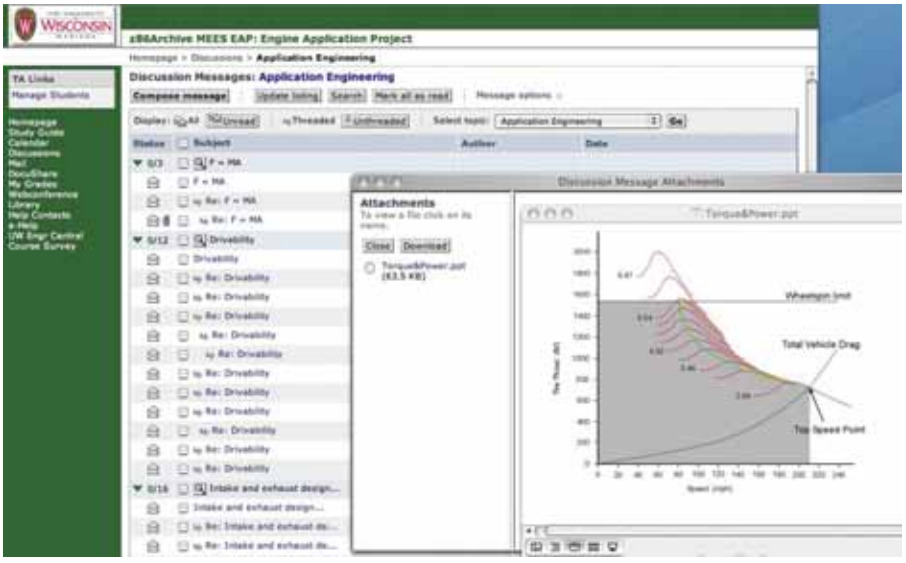
Kami Buchholz

Developing engine engineers

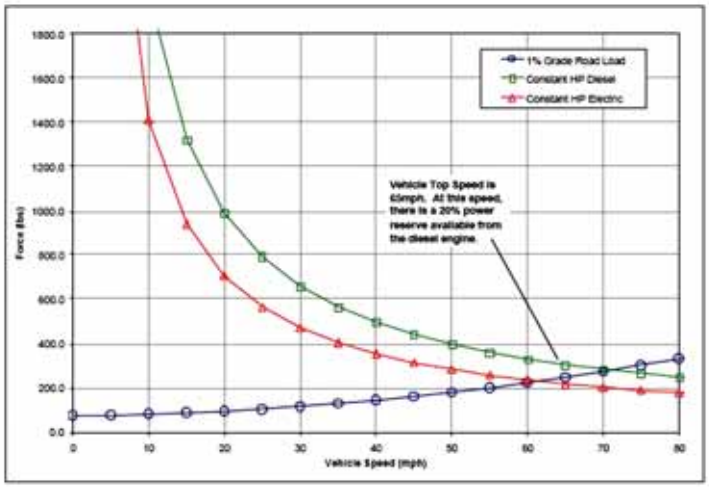
The idea for a new type of engine engineering qualification came from a meeting on campus at the **University of Wisconsin-Madison** (U of W-M) in 2000 between the academic staff and industry customers. The meeting was called to evaluate demand for short courses for the engine industry, but it became apparent that all the participants had a greater need to fill. Feedback came from executive engineers at companies such as **DaimlerChrysler**, **Caterpillar**, **Cummins**, **International**, and **Harley Davidson**.



A recent Master of Engineering in Engine Systems (MEES) design class project was to develop a lubrication system for a four-cylinder engine.



The MEES program at the University of Wisconsin-Madison relies on distance-learning tools such as threaded online discussions.



MEES students undertake detailed engine design projects in small groups, with output such as this analysis of a hybrid powertrain for a postal delivery truck.

"All were experiencing similar challenges in their organizations," said Kevin Hoag, Director of the Master of Engineering in Engine Systems (MEES) program at the University of Wisconsin-Madison. "Career progress for engineers tended to be down either a thermal/combustion or structural/vibration path. Few get technical expertise in both disciplines. A new engine program at any company would like to have a chief engineer with significant technical background in both, in addition to electronics, controls, and manufacturing." All companies have the same challenge—a breadth of technical background is needed to be able to integrate the different disciplines into a successful program.

The first MEES class started in 2003. Wayne Pferdehirt, Program Director for Engineering Distance Degree Programs, had already developed a Web-based master's course that won awards for excellence in distance education. The new model is Web-based—all specially designed course modules with no classroom—which makes it very compatible with the engine research approach.

Key to establishing the MEES was the existing large engine research facility at U of W-M, with 50 graduate students focusing on engines, plus six full-time faculty staff. The graduate school had already generated a master of engineering option.

"An advantage of distance learning is that it can focus on a particular industry regardless of geography," said Hoag. "The potential audience is anyone working on engine development. Our objective is to produce people with a breadth of technical skills who know enough to be able to understand the experts."

Student teams take on a major project that extends over several semesters. Each team consists of three or four engineers who help to define their responsibilities. Each member is employed in the industry,

and they take responsibility for learning the general methodology and working on how it is applied in their own company's products. The project is an in-depth engine design, and each individual does a "deep dive" on one aspect.

"I feel that the distance learning approach encourages more student-to-student interaction with online study than through the traditional classroom learning environment," said Hoag. "The class has progressed as a group, and cross-learning has been critical."

One key tool used is the threaded online discussion. Students can post questions and experiences and share answers and results. Being online means it is available 24/7. At the start of each semester a ring binder is supplied containing a study guide with a CD. Lectures are developed using Camtasia software from **TechSmith**, which allows the presenter to include sound and video. Students can work ahead if they want to.

Ricardo was involved early on, volunteering student licenses of WAVE. During the course on engine fluid dynamics, WAVE models were built by each student. Other software companies are also involved. **ReliaSoft** has provided Wiebull++ for reliability prediction. Student licenses of Matlab and Simulink from **The MathWorks** are used for engine control development.

Scope of the degree course is deliberately kept as broad as possible, with a focus on fundamentals. Students come from many industries, with backgrounds in small and large engines, marine and automotive, two- and four-stroke, diesel and spark ignition. Understanding the governing equations and fundamental physics is the goal, and how these principles are applied across industries is the contribution from the students themselves. Because of its ubiquitous popularity, the internal-combustion piston engine does get most of the focus.

Instructors are drawn from the university faculty and from industry. Harley Davidson, **GE**, **Southwest Research Institute**, **Toyota**, and **GM** have all provided instructors, who are hired as adjunct faculty. Guest lecturers from **Ford** and **Honeywell** have also been featured, and others are always welcome. Bill Hancock is the President of **Arrow Racing Engines** in Auburn Hills, MI. His shop does many of the aftermarket parts for the Mopar performance catalogue, and all of the warranty work on the **Dodge** Viper V10 engines, and his background includes being factory engineer for Richard Petty's **NASCAR** team. Hancock has been involved with MEES from the very beginning and has done several guest lectures on engine design considerations for racing.

David Alexander

Enabling compression ignition

A chemically controlled combustion process that lasts only milliseconds could change the emissions and fuel economy landscape for light-duty passenger vehicles. Gasoline engines could become 20% more fuel-efficient and diesel engines could realize near-zero NOx emissions if researchers successfully supply the missing links to achieving a flameless combustion ignition.

The catalyst for change is HCCI (homogeneous charge compression ignition). Researchers and engineers are now challenged with how to control the combustion process because of the extreme sensitivities to changes in temperature, pressure, and fuel type. But researchers and engineers with **General Motors**, key suppliers, and select universities are pushing to make the process a commercially viable endeavor.

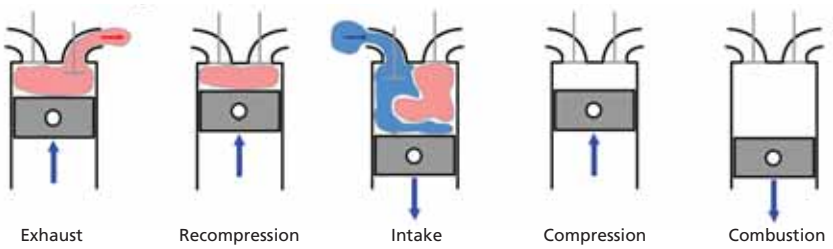
An HCCI engine means that fuel is uniformly mixed with air, although there is a higher proportion of air to fuel. The air-fuel mixture is piston-compressed until spontaneous combustion occurs. Because of the low temperature combustion and a high air-to-fuel ratio, there are virtually zero NOx emissions. And because of reduced throttling losses in a gasoline engine, there is a fuel economy boost.

If the HCCI combustion process can be successfully transferred from laboratories to commercial applications, specific content will play a major role. "An HCCI engine will have cylinder pressure sensing, a very sophisticated variable-valve actuation system, direct injection, and sophisticated controls," said Paul Najt, Group Manager, Gasoline Engine Research at GM.

Two recent initiatives—a five-year, $13 million technology program with the **U.S. Department of Energy**, and a three-year, $2.5 million cooperative program with **Robert Bosch** and **Stanford University**—will focus on developing advanced control systems. "Stable and satisfactory operation of an HCCI engine is not possible without further development of sophisticated sensors, actuators, and feedback control systems. The end goal is to develop an engine-controls solution that is both robust and cost-effective," said Rolf Leonhard, Executive Vice President of the Engineering Gasoline Systems Division at Bosch.

Gary Smyth, Director of the Powertrain Systems Research Lab at GM, said a significant amount of the automaker's research and development budget is going toward HCCI and other technologies that potentially can increase a vehicle's fuel economy. "We've increased our head count. Most researchers are now working on the technologies that will enable HCCI," said Smyth.

To understand the physics of the combustion event, researchers are employing a variety of analysis tools, including advanced laser diagnostic techniques. Using the resulting information, GM technology



The HCCI process includes a recompression event.

specialists are working to devise a way to have HCCI cover the entire drive cycle of a gasoline engine as well as a diesel engine.

"Using sophisticated controls, we can do highway cruise and below with HCCI combustion. However, we cannot do full load with HCCI. But stay tuned. The focus of our research is to push up to the highest engine load possible where we can run HCCI," said John Pinson, Group Manager, Diesel Engine Research in GM's Powertrain Systems Research Lab. "The sensing capability is what's enabling us to take this HCCI technology forward."

While HCCI is not new technology—HCCI combustion in a four-stroke engine was demonstrated in 1983 at the **University of Wisconsin**—the technology is moving closer to becoming a possible production reality. Even if a commercially viable HCCI application falls short, there are still positive by-products because "the pieces and parts that go into the [HCCI] system have an intrinsic value on their own," said Najt.

GM's HCCI engine would not require a special fuel type, so all current diesel and gasoline blends are part of the engine operation strategy. "HCCI can be applied to a variety of fuel types due to the sophistication of the components that will be on the HCCI engine. In effect, the engine components will enable a large degree of control over the in-cylinder temperatures," said Pinson.

As envisioned, the HCCI concept would boost fuel efficiency on a gasoline engine and reduce emissions on a diesel engine. Use on a hybrid vehicle would give even greater fuel efficiency gains. "In the next two years, we'll know whether HCCI is an 'if' or a 'when,'" said Smyth.

Kami Buchholz

Efficient gasoline engine development gains support

The need for better engine fuel efficiency and low emissions with less cost and industry changeover complication is reflected in the fast-growing number of major firms cooperatively funding development of a high efficiency dilute gasoline engine (HEDGE) at **Southwest Research Institute** (SwRI).

HEDGE technology is expected to reach parity with the thermal efficiency of many diesels at the U.S. Bin 5 emissions level, and offers the potential to help reverse the developing diesel fuel shortage and petrol fuel glut forecast for Europe and wherever middle distillate refinery capacity is falling behind market demand, including the U.S.

Illustrating the level of industry interest in HEDGE, consortium sponsors at deadline for this report are: **Corning**, **Cummins Engine**, **Hino Motors** (51% owned by **Toyota**), **John Deere**, **PSA Peugeot Citroën**, **Volvo/Renault** (trucks), **Renault** (car), **Volkswagen**, **Ford**, **Nissan**, and **Valeo**, with "more expected to sign on" according to HEDGE Program Manager Tom Ryan.

Ryan explained that HEDGE technology is based on very high exhaust gas recirculation (EGR) rates to minimize pumping losses and engine-out NOx emissions. The resulting lower specific engine power is offset by turbocharging. The system employs a new ignition system termed "intelligent high energy delivery." Ryan identified a number of advantages and characteristics of HEDGE:

- HEDGE system engines operate with stoichiometric air-fuel ratios, and so meet all emissions requirements with common three-way catalyst technology, and in fact may need lower catalyst loading due to low engine-out NOx. No costly particulate filter is needed.
- Low-cost port fuel injection is used, which provides a major cost advantage compared with high-pressure fuel-injection systems for diesels and medium pressure for direct-injection gasoline engines.
- The system will need variable-valve technology, precise-charge motion control, and turbocharging, but the needed boost pressure is expected to be less than planned for high-EGR diesels. This likely translates into single- rather than dual-stage turbo systems for HEDGE engines.
- The current U.S. typical $5000 premium price for 6.0-L diesels vs. gasoline engines for the large end of the light vehicle category is expected to increase at Bin 5 to an even higher premium due to emissions control requirements, which is why some diesel makers now serving this market are sponsors of HEDGE. Another reason is that turbocharged HEDGE engines for the larger vehicles will benefit from diesel-like robustness, and so are a good fit with core diesel design and manufacturing.

Early interest in HEDGE was related to the 6.0-L diesel vehicle market but has since expanded into the smaller vehicle/engine market. By the same token, Ryan said there are reasons to believe HEDGE may in time move up into the heavy vehicle categories.

Adding a note of caution to the outlook for HEDGE, **University of Wisconsin** engineering professor and past SAE President Phillip Myers said: "It can be very difficult to achieve misfire-free combustion at high EGR rates; hence, this aspect must be looked at with great care."

The noted MIT (**Massachusetts Institute of Technology**) authority on engine combustion, John Heywood, spoke at a recent University of Wisconsin symposium on combustion technologies. With respect to very high gasoline engine EGR rates, "Ignition is not the issue. Burn rate is the problem," he said.

Asked how development work in this respect is progressing at SwRI for the HEDGE engine, Ryan said it is "very promising." Such confidence may explain recent consortium member additions.

Ryan said that while consortium members are asked to commit to the program for four years, a first working multi-cylinder HEDGE engine is planned for demonstration at the end of the first year, which would mean by the beginning of 2006.

As for the expected diesel fuel shortage and petrol glut in Europe, this was reported by the **Financial Times** and attributed to a study by **Wood Mackenzie**. The study explains the diesel vs. petrol supply imbalance (diesel shortfall one fifth of demand by 2015) with characterization of diesel engines as "more fuel-efficient and can be cleaner than petrol engines." HEDGE sponsors hope to alter this general assumption and cut engine cost as well.

Bob Brooks

HVAC for hybrid electric vehicles

Toyota's THS-II hybrid system in the Prius, Highlander Hybrid, and **Lexus** RX 400h employs a "beltless" engine that many Japanese automotive engineers agree is an effective path to improve internal-combustion engine efficiency and fuel economy. In the THS-II configuration, all engine ancillaries and the HVAC compressor are electrically driven. Steering effort is lowered by EPS (electric power steering); in the case of the RX 400h and Highlander Hybrid it is a 42-V system, with voltage stepped down from the 288-V hybrid battery.

The RX 400h and Highlander Hybrid compressor is a scroll-type unit, controlled by an inverter integrated within the compressor body and driven by a brushless dc motor. The control logic employed in the system is a neural network, a complex and sophisticated program simulating input and output information modeled after human neurons. The neural network comprises three layers—input, intermediate, and output—that control target output temperature, correction to solar heat, blower speed, and outlet choice.

Honda's IMA (integrated motor assist) in the Accord Hybrid employs a torque-converter, stepped-gear-type five-speed automatic transmission with ratios optimized for IMA. The IMA features include "idle-stop" function when the engine has reached its operating temperature. An electric rotary-type pump is employed to constantly pump fluid through the transmission's torque converter to preclude a lag when restarting from an idle-stop.

Honda employs a hybrid compressor in the Accord Hybrid.

The Accord Hybrid is equipped with dual-zone, hybrid automatic climate control. The air-conditioning compressor is a hybrid unit with two scrolls; one 75-cm^3 (4.6-in^3) scroll is belt-driven by the engine and the other 15-cm^3 (0.9-in^3) scroll is electrically driven. Either of the compressors can be used to cool the interior individually depending on cooling requirements and engine status. On extremely hot days, cooling is provided by both the mechanical and electrical scrolls.

Senior Manager Hiroaki Yoshida, Advanced Vehicle Department, **Mitsubishi** Motors, says that his company's forthcoming pure electric vehicle (EV) program is fully supported by suppliers. "Be it an EPS or a compressor for such application, the OEM must first indicate clearly its serious intention and planning. The suppliers will respond with development of such equipment. **Denso** and **Mitsubishi Heavy Industries** are both keen to participate. They are our strategic partners in product development."

Fuji Heavy Industries is another OEM seriously pursuing EV development, as demonstrated by its R1e concept. The car is based on the production gasoline-engine R1 2+2 seat light runabout. A **Subaru** engineer explained that its rather crowded "engine bay" was "because we are using existing ancillary equipment. Take a 12-V battery driving the accessories: It does not have to be so large. Obviously, optimized EV equipment will have to be developed."

The Subaru concept EV uses an electrically heated "hot-water bottle" in the heating system. For the production model, an appropriately sized inverter-type compressor would adequately supply heated or cooled air without water.

Jack Yamaguchi

The VCR picture develops

MCE-5 Development has launched a variable-compression-ratio engine block that it claims is ready for volume production.

Variable-compression-ratio (VCR) technology has been considered passively or actively by most major OEMs as a contribution to solving fuel consumption and environmental issues. In France, **MCE-5 Development** has just launched its VCR engine block, which it describes as a mechanical solution to VCR technology and regards as making volume production of VCR engines viable.

The VCR block is described by the company as an all-in-one unit that combines power transmission and compression ratio control, integrating a special long-life piston design that is not subject to slap or radial stress. The company claims that the piston's durability meets high load and high mileage requirements.

The engine block is described by MCE-5 as having no negative effects on other engine components or on the vehicle. Initially designed in 1997, the MCE-5 VCR engine block has been tested and improved in successive stages, explained the company in a statement. The strength of the engine block results from the rigidity of its crankshaft and of its main structure, which are described as giving its hydrodynamic bearings an optimum geometrical environment and long life span.

MCE-5 Development, based in Lyons, was established five years ago by a small group of engineers, and has the support of **PREDIT**, a French program for energy and transportation; **ADEME**, the French agency for environment and energy management; **ANVAR**, the agency for innovation; and the French ministries of research and of industry.

Stuart Birch