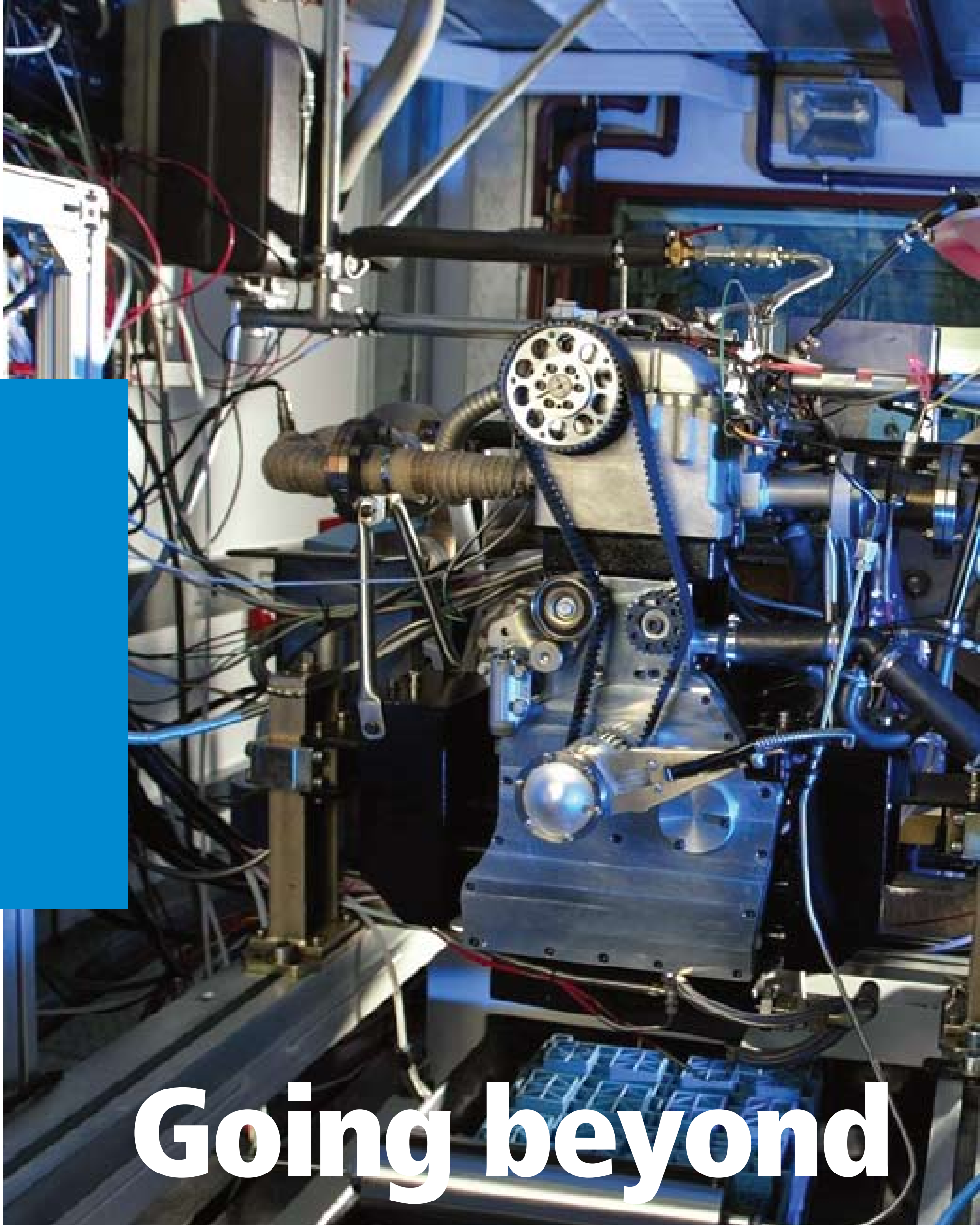

Going beyond

An early look at some of the emissions-control and aftertreatment technologies and tools aimed at helping automakers meet future U.S. and European regulations.

by ***Lindsay Brooke***

Improving vehicle fuel efficiency, with its direct impact on reducing CO_2 emissions, has become the battle cry of powertrain engineers worldwide. But that doesn't mean efforts to reduce oxides of nitrogen (NOx) and other "traditional" greenhouse gases, as well as exhaust particulates, have abated.

On the contrary, R&D teams are looking beyond the current regulatory horizon to develop new emissions-control and exhaust aftertreatment technologies for the 2010 decade.

Having driven tailpipe emissions to levels so low that measurement equipment is challenged to keep pace (see sidebar), engineers are anticipating the next rounds of U.S. and European standards, predicted to be more stringent in some aspects than the current Tier 2 Bin 5, and Euro 5. They're devising technology solutions for downsized, turbocharged, direct-injected gasoline engines; advanced combustion strategies for gas and diesel; further reduction of NOx and particulates; and the unique emissions-control challenges of extended-range electric vehicles (E-REVs).

"The desire of every powertrain engineer and car company is to do as much as possible to clean up emissions within the cylinder. That approach usually costs the least and has us quite busy," explained Dr. Dean Tomazic, Vice President of **FEV**'s Engine Performance and Emissions Division.

Aftertreatment systems will remain essential next decade, experts agree. However, absorbing their increasing cost on the light-duty diesel side is "turning the focus back to the gasoline engine in Europe," noted Andrew Fulbrook, Senior Manager of European Powertrain Forecasts at **CSM Worldwide**.

But the CO_2 vs. emissions balance is precarious. Regulations are pushing Europe's OEMs toward full lean-burn gasoline solutions, which will require some NOx aftertreatment, Fulbrook noted. Likewise, discussion of particulate traps for gasoline engines possibly late next decade has risen above a whisper.

To reduce cost, chemists and systems engineers are focusing on minimizing the use of precious metals in catalysts while boosting durability. For example, the Euro 6 standards currently in guideline form and slated for 2014 are expected to require dramatically greater catalyst durability, said Dr. Marius Vaarkamp, Global Product Manager for Mobile Emission Systems at coatings supplier **BASF**.

"Engine oil consumption over time, and issues with biodiesel, are areas we're addressing with new materials," he said. "And there is a possible need to develop scavengers for absorbing the poisonous materials before they meet the reactive elements."

While breakthroughs in non-precious-metals R&D continue, their properties do not yet offer the high-temperature stability, poisoning resistance, and overall robustness of traditional platinum and palladium, Vaarkamp said. Also, OEMs' interest in new catalyst applications, including "pre-turbo" installations directly ahead of the turbocharger intake, bring new mechanical challenges.

An IAV technician prepares an advanced development engine for test.

Managing airflow

Increasing rates of exhaust-gas recirculation for both gasoline and diesel engines, with a priority to improve fuel efficiency, is also spurring innovation. "The challenge will be digesting higher rates of EGR without affecting driveability," explained Pete Hradowy, Vice President of Engineering and Program Management at **Pierburg** Inc.

Hradowy said his company is developing new approaches to disbursing EGR within the engine.

"Delivery on a cylinder-by-cylinder basis, versus single-point ingestion, is one way to enhance driveability while raising the percent of EGR," he said. New packaging solutions for the EGR cooler are also under study, including possibly integrating it with other heat exchangers on the vehicle.

OEMs also are requesting development of new air pump technologies to optimize catalyst performance—including the use of pressurized air to purge particulate traps of accumulated soot.

"They're asking us for air pumps that run continuously for longer cycle times, possibly for up to twenty minutes," Hradowy said. Such pumps would function separately from the secondary air pumps currently used for a few seconds to heat the catalytic converter during the initial start-up cycle.

Elevated exhaust-gas temperatures—1000ºC (1832ºF) and higher—are characteristic of downsized, turbocharged gasoline engines. The higher temps are driving exhaust-system component and materials development. Gary Grimm, Vice President of Engineering with **Hitachi Metals America**, projects "significant growth" in the use of cast stainless steel for turbocharger housings, exhaust manifolds, and integrated turbo/manifolds.

He said the stainless-steel castings provide greater thermal resistance for improved durability, compared with ductile iron. European OEMs experienced in turbocharger systems are requiring cast stainless steel, Grimm noted.

Enabling E-REVs and HCCI

Advanced hybrids and E-REVs bring unique emissions challenges. "What happens with a car like Volt where you have a lot more engine-off time?" asked Audley Brown, Director of Advanced Propulsion Systems Control at **General Motors**. He suggested that an E-REV's emissions-control system may have to be "primed" (warmed) automatically before starting to ensure its effectiveness.

"The vehicle might have great efficiency, but we can't afford to have any problem with the emissions system, whether during one cold start per trip or many cold starts on a long trip," Brown asserted.

Without revealing Volt's specific after-treatment strategy, Brown echoed engineers' concerns that tapping into the vehicle's stored electric power to heat the catalyst could reduce its range.

"If we very precisely control the heat so we're not doing a cold start every time, then there's the possibility to use electric

Development of the Volt E-REV powertrain is teaching GM much about advanced catalyst controls, said Audley Brown, GM's Director of Advanced Propulsion Systems Control.

GM's new turbocharged 1.4-L gasoline engine slated for 2011 features a cast-ductile-iron integrated turbo/exhaust manifold. The D5S iron material contains 35% nickel for greater thermal resistance. Experts expect to see lower-grade stainless-steel alloys gain popularity in similar applications.

power to add heat to the emissions-control system without consuming power that could be used to propel the vehicle," he said.

Indeed, controls sophistication will be key to greater emissions-system effectiveness, noted Utz-Jens Beister, President of **IAV** Inc. "Controller development and simulation is proving to be one of our biggest growth areas over the next decade," he said.

Advanced combustion technologies offering potential for lower engine-out emissions, and thus less aftertreatment, are developing rapidly. Although the

Stringent standards bring new measurement tools

Engine-test and vehicle-certification engineers also face challenges in meeting the more stringent mobile emissions regulations coming next decade.

"We're to the point where ambient air quality inside the test cell is often dirtier than the exhaust of the vehicle being tested," noted David Kulp, Assistant Director, Sustainability, Environment, and Safety Engineering, at **Ford**. "Getting good, repeatable data as we certify closer and closer to zero emissions will require even more precise and faster analytical equipment."

The trick for every OEM is to pass the required standards without having to overkill on emissions-control and aftertreatment technologies, explained Dr. Mike Akard, Analytical Product Specialist at **Horiba**, a major supplier of emissions-test instruments and equipment.

Akard said throughout the industry, older test cells are being upgraded to provide more capable and sophisticated sampling and analysis at the super-clean SULEV and Bin 2 levels. One piece of equipment gaining popularity in North America is the Horiba bag-mini diluter (BMD). This partial-flow sampling system allows testers to do constant-dilution ratios, which offer better accuracy and repeatability, according to Akard.

"We think it's a very strong tool for the more stringent exhaust regulations coming below U.S. Tier 2 Bin 5," he said. "It allows testers to hit the lowest possible dilution ratio by sampling the exhaust gas hot, and diluting the exhaust [using air] right away. This prevents condensation in the bags."

Another claimed advantage of the BMD's partial-flow dilution is it allows testers to use very clean, purified air. Akard likens it to preferred test methods in Japan, where the dilution air is pre-scrubbed. The BMD's limiting factor is it requires a direct exhaust-flow measurement.

Emissions testing differs among the global regions due to different emissions-test cycles. Europe generally favors constant-volume sampling (CVS). This process takes all of the exhaust and dilutes it, while maintaining a constant total flow.

To instantaneously capture and measure soot and particulate matter in a transient environment, **AVL** developed the Micro-Soot Sensor, which uses acoustic laser technology. "The advantage is that it performs on a real-time basis," explained Greg Hopton, AVL North America President.

His company's Fourier Transform InfraRed (FTIR) high-speed gas measurement and analyzer measures organic substances in engine exhaust, including alkehydes in urea aftertreatment.

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A BASF Catalysts technician sets up a catalyst long-term stress test in the laboratory. Future emissions regulations are expected to require greater catalyst durability.

Exhaust test cell showing a Horiba BMD-1000 (at right), the collection bags (center), and the MEXA-7000 (left). In the foreground is the heated sampling pipe coming from the vehicle and entering the EXFM exhaust flow meter. Its measurement determines correct dilution.

specific deployment strategies are not yet clear, production applications are expected to arrive around the middle of the 2010 decade.

According to Dennis Assanis, Director of the Automotive Research Center at the **University of Michigan** and a globally recognized expert on advanced combustion systems, the most promising strategies emerging are full-time homogeneous-charge compression-ignition and premixed compression-ignition (HCCI and PCI for gasoline and diesel, respectively), and mixed-mode operation.

Assanis predicts the NOx aftertreatment burden for HCCI/PCI will be minimal if advanced combustion can be sustained in all operating modes—but only if emissions standards remain as currently predicted. He reckons that hydrocarbon-SCR systems will be sufficient to handle NOx control.

However, he warned that high HC and CO levels combined with low exhaust temperatures "will make oxidation catalysts very difficult and require extensive invention of low-temperature catalysts." To optimize catalyst operating efficiency, rapid warmup and heat-conservation controls will be needed.

If HCCI/PCI cannot handle the full range of high-load and cold-engine operating conditions, an alternative is mixed-mode combustion—a combination of controlled auto ignition and spark ignition. Mixed-mode operation will require additional aftertreatment to handle high NOx conversion at high-load conditions—likely some combination of lean-NOx traps, HC-SCR, and/or urea-SCR catalysts. And high HC and CO emissions at lighter-load HCCI/PCI conditions will remain an issue, Assanis said.

A diesel particulate filter with low-temperature passive regeneration and durable active regeneration will be required for stratified and diesel combustion modes, he explained. And even more stringent emissions standards could force NOx aftertreatment on full-time HCCI/PCI combustion modes, Assanis said.

But in the short-term, aftertreatment suites will undergo an extreme makeover, explained Dr. John Pinson, Vice President of Light & Heavy Duty Diesel Development at **Ricardo North America**.

"First, we'll see aftertreatment elements which are currently discrete being integrated into a single can—for example, the merging of the particulate filter and the NOx trap, especially as we look to SCR-urea injection," he said. "We'll also see more sophisticated and lower-cost sensors for meeting onboard diagnostics (OBD)—and in some cases, elimination of some of those sensors."

Pinson noted that as engines and their aftertreatment are designed clean-sheet as a total system, the result is fully optimized—"and that's precisely what's happening in the industry right now," he said. ***aei***