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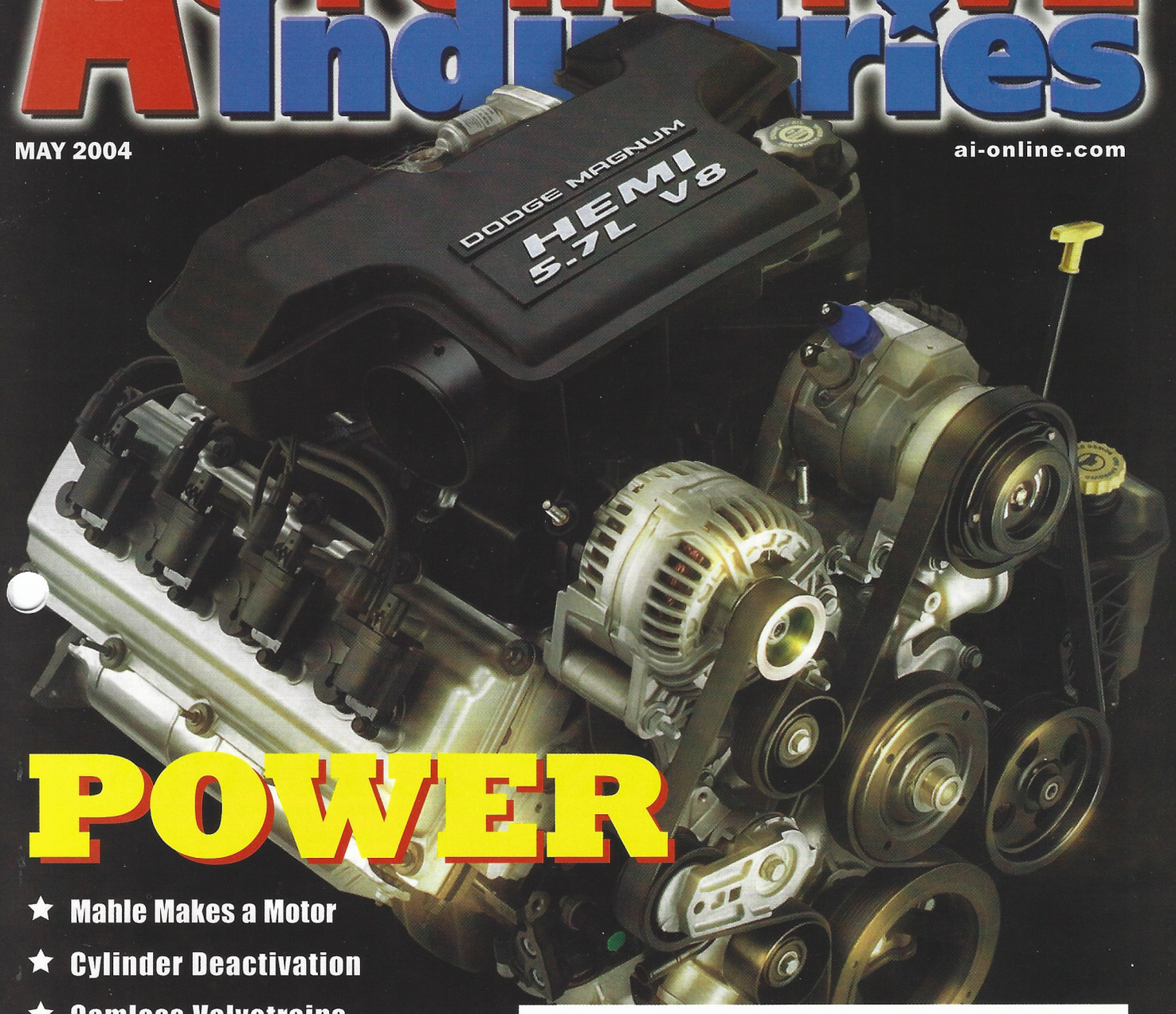

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Advanced Powertrains – What's Hot, What's Not

■ Hybrid, fuel cell, "clean" diesel, hydrogen ICE...and the winner is? We talk to advanced powertrain experts and leaders to find out.

by Gary Witzenburg

Most folks envision some wondrous new technology sweeping in and replacing the old faithful internal combustion engine (ICE) virtually overnight. Ain't gonna happen. Those in the know have long viewed the automotive powertrain evolution as a chart with market penetration up the vertical (totaling 100 percent) and calendar years along the horizontal axis.

Electric and steam were substantial segments in the industry's early years before gasoline ICE, for excellent reasons, grew to 100 percent. Following the fuel crises of the 1970s, a sliver of diesel ICE (long dominant in heavy-duty trucks and buses) began to grow within the passenger vehicle spectrum, then shrank again to barely visible in this country. Given different priorities, taxation and emissions requirements, however, diesel has grown in Europe and elsewhere to nearly 50 percent in some markets today.

You need a microscope to see any battery electric vehicle (BEV) share despite ill-considered laws attempting to force BEV sales in some U.S. states. Hybrid electric (HEV), while beginning to grow, remains barely visible as an emerging segment. And the promised land of affordable fuel cell electrics (FCEVs) seems perpetually 10 years away.

Where do industry experts and leaders see these and other "advanced" powertrain technologies a decade from now? We asked Ford Vice President, Research and Advanced Engineering, Gerhard Schmidt; GM Executive Director, Hybrid Powertrain, Larry Nitz; and Toyota Executive Engineer, Environmental Engineering, Dave Hermance for their thoughts.

Now that full-hybrid cars like the Toyota Prius and Honda Civic have introduced America to hybrid vehicles, the next step will be to bring the powertrains to popular SUVs like Ford Escape (above left, on sale this summer) and Lexus RH400.

Ford Hybrids

"Hybrids are not rocket science," Ford's Schmidt offers. Honda's Insight and Civic and Toyota's Prius HEVs have long been available, and more will arrive this year, including Ford's Escape Hybrid. "We are the first non-Japanese company offering a full hybrid," he says, "and first with an SUV. We are pioneering this technology in this type of vehicle."

Ford has designed and developed its own hybrid system, though it is similar to Toyota's Hybrid Synergy Drive (HSD) and incorporates a version of the Prius' Aisin two-motor transaxle, including its Toyota patents. "This is a no-compromise hybrid," Schmidt contends. "It's a four cylinder engine in combination with an electric motor with the performance of a V-6. We intend to expand the range of products with this technology."

Is a hybrid's extra cost worth its efficiency benefit, and can it be competitive with modern diesels offering similar efficiency with lower cost and complexity? "Should we have to go to a partial zero emission (PZEV) standard in California," Schmidt responds, "this could be an interesting competition. You have some really expensive parts in the hybrid, especially the battery, but you would also have added cost for the diesel's aftertreatment.

"If you drive in downtown Tokyo, a gasoline electric hybrid may be an excellent choice. But if you drive from Detroit to Chicago, a high-torque diesel is a better choice, because you set your cruise control and get no benefit from regen braking or start/stop. In Tokyo, you might see as much as 50 percent economy benefit with a hybrid, but with typical European driving, you won't see the same benefits. It depends on the customer profile and the driving cycle.

"The main benefits of a hybrid are regenerative braking and start-stop operation. You also get some benefit from downsizing the engine and making it a little more efficient, but you lose

towing capacity. And if you go uphill for half an hour, you won't have energy in the battery.

GM Hybrids

"We have a portfolio of systems to deploy where we think they make sense," says GM's Nitz. Two different GM systems are now in limited production. The first, in Chevy Silverado and GMC Sierra hybrids, the first full-size pickup HEVs, are available to fleets this year and retail customers for '05. "This is a flywheel/alternator/starter technology," Nitz says. "We've basically downsized the torque converter and wrapped a motor/generator around it, which keeps the transmission's length and diameter the same. It does decel fuel cut-off, engine stop/start and a mild amount of regenerative braking, and it gets about a 10 percent increase in fuel economy."

Because the 42V electric motor provides performance-boosting torque, regen braking and a 110V power takeoff, but not power to the wheels, this system is considered a "mild" hybrid. "Some people criticize that," Nitz says, "but it delivers the same hybrid capability that a strong hybrid does." Given the $2,500 premium, volumes will be modest — 500 for fleets this year and "several thousand" in '05. "The market will tell us how many it wants," he adds.

The second, Advanced Hybrid System II for urban buses, a joint development with GM Allison Transmission, is a "two-mode input compound split architecture," Nitz explains. "The power flow is split...part mechanically, part electrically. For a vehicle of that size with that amount of tractive effort and both city and highway speeds, we went with a compound split — two electric CVTs that select between each other. The starting mode is an input split; then, at a synchronous point around 20 mph, a fixed gear ratio of about 1.7, it shifts to a compound split. It gives you excellent balance of mechanical vs. electric power at the start and in the city and excellent balance of electric vs. mechanical power at higher speeds.

"The input compound split allowed us the bandwidth for low-speed in the city — this stop/go urban environment is perfect for hybridization — and 65 mph on the freeway. Lift-foot regen slows the vehicle to about 3 mph, then you step on the service brake. We're very excited about this system and have orders for it all over the country." The largest so far is

GM's Larry Nitz says that the 42V belt/alternator/starter system that will power a Saturn VUE in 2006 is as close as a hybrid could be to a bolt-on system.

235 from the city of Seattle, which Nitz says will get 60 percent improved economy in an "urban central business district" test and 35-40 percent better in their real-world environment.

This architecture, scaled to specific applications, will be the basis for all GM strong hybrids. "The input compound split offers the opportunity to size each vehicle's motor to do everything it needs to do," Nitz says, "yet not be so oversized that it doesn't package or that the added cost is extraordinary. For a sport utility, for example, we have to deliver uncompromised performance, and it's got to package in the same space as a conventional automatic transmission.

"Over time, we believe this architecture can be scaled further for fwd as well as rwd. Our objective is to be able to take an existing powertrain, remove the transmission, put this hybrid drive in that same volume and get similar tractive effort. Front drive is a huge packaging challenge, and you're not going to get there with a simple input split with huge electric machines. So we've chosen to increase the mechanical complexity of the input compound split, which gives us more direct-geared operation and gets our mechanical efficiency way up while still providing enough electric power to be a full hybrid. We think this is a watershed architecture and an improvement over what Toyota has done with the Prius."

The third GM system is a 42V belt/alternator/starter system slated to debut in a Saturn VUE and other applications beginning in 2006. "This is a very high value hybrid, as close as a hybrid could be to a bolt-on system," Nitz says. The objective is to provide 80-90 percent of the hybrid benefit at 10-20 percent of the cost. It delivers the hybrid promise — decel fuel cut-off, engine-off at idle, some regen and some acceleration assist — is seamless to the operation of the vehicle and gets 10 percent-plus fuel economy improvement."

Toyota Hybrids

With its second-generation Prius on the road and Highlander and Lexus RX hybrid SUVs coming soon, Toyota seems ahead of the game and plans more to come. "You will see from us next an all-wheel-drive that's really a front-wheel-drive with a rear motor," Hermance says. "Then, based on our concept vehicles, there will probably be a RWD vehicle that might be made AWD and additional front-drive packages down the road. Once we've done the architecture for the Prius small four cylinder, a larger four for the Camry-size vehicle and the V-6 for the RX and Highlander, that gives us most of the range of our product line by the time we add the RWD. So it could come in almost any platform, depending where we think the market is."

Where could hybrid market share be 10 years out? "Given our history with the Prius and where we think we're going with the Highlander and RX," Hermance says, "it's reasonable to figure you could do 10 percent of a product line. That doesn't suggest that all manufacturers are going to have mid-size hybrids, for example, or that 10 percent of mid-size cars will be hybridized, but we're hybridizing about 10 percent of our mid-size vehicles. I've seen J.D. Power numbers suggest-

ing that 10 percent by application is not an unreasonable number."

Given their extra hardware, software and development, what about the cost of hybrids? "We might disagree on how much the cost penalty is today, and what we could conceivably get it to," he responds. "There's the question of how much you write off against the platform and how much against R&D, but we agree that cost is the significant issue. Then the game becomes, what value can you bring? If all you can bring for that additional cost is improved fuel economy, that's a losing proposition. But if you can bring other value for that cost, you can start to change the equation. It is the one way to get fuel economy, emissions and performance improvement in the same package. We've managed to improve all three simultaneously with the last two generations of Prius, and the cost has come down each time. We're going to try a different tack with the RX and the Highlander by focusing on performance and not as much on fuel economy."

Rival Honda has two HEVs (Insight and Civic) on the road and more on the way, beginning with an Accord hybrid later this year. Honda's system is more like GM's in that the electric motor provides performance assist and regen braking but does not power the vehicle's wheels. The two-seat, ultra-aerodynamic Insight is the highest-economy HEV on the market, and the Civic last year was the first to earn certification as an Advanced Technology Partial Zero-Emissions Vehicle from California's Air Resources Board (CARB).

Fuel Cells

Fuel cell electric vehicles (FCEVs) have been a subject of intense R&D at most makers for many years. The notion of emissions-free, hydrogen-powered energy is highly seductive despite enormous challenges in system technology, cost and infrastructure. "We are on a technology path to prove the commercial viability of these systems," GM's Nitz asserts, "and we're a leader in fuel cell stack development.

"We believe in the hydrogen economy; hydrogen is where we want to go. But there have to be a couple of breakthroughs, not the least of which are on-vehicle hydrogen storage and the infrastructure. We can build vehicles and improve the [technology], but without the infrastructure and the storage medium, it really doesn't matter. Those are areas on which GM and others are spending a tremendous amount of resources. Right now, we've got a test going together in Washington with a fleet of six hydrogen fuel cell Opels. With Shell Hydrogen, we're building a hydrogen fuel station where politicians, lobbyists and others can check these vehicles out, drive them and refuel them. It's not just industry that can bring about a conversion to a hydrogen economy. I think it's going to take a national initiative to do that."

Doesn't hydrogen production consume more energy than conversion or combustion gives back? "The beauty of hydrogen is that your options for generating it are greater," Nitz says, "and those include a lot of renewable options. The great hope is to be able to remove the vehicle from the emissions agenda, and you would do that through renewables, so there's a lot of work on getting hydrogen not from natural gas or oil but from renewable sources."

"I don't think anybody has all the pieces put together yet or they would be making a lot more noise about it."

— Toyota Executive Engineer, Dave Hermance, on fuel cells

Hermance points out that Toyota and GM, and now Honda, are independent fuel cell developers, while most others are working with Ballard. "I don't think anybody has all the pieces put together yet or they would be making a lot more noise about it," he says. "There's a lot of engineering to be done over the next several years. The biggest thing is that we still don't know how to store hydrogen on a vehicle in any kind of efficient manner, and I'm not enamored with high-pressure gas storage."

What about Ovonics' hydride storage system? "That's pretty heavy," he replies, "and they're having trouble hitting the theoretical efficiencies they were talking about. We've done a couple of hydride systems and found the material heavy, very expensive and not as efficient as we thought it would be."

Ford's Schmidt seems more optimistic: "We are in a position to deliver fuel cell vehicles fairly soon," he says, "working with Ballard and DaimlerChrysler and partnering with British Petroleum (BP) on the energy side. We're waiting for an announcement from the Department of Energy. We expect to participate in a demonstration program where up to 30 fuel cell vehicles will be at three or four different locations nationwide. We already have more than 15 fuel cell vehicles running here in Dearborn, plus two in Sacramento with the California Fuel Cell Partnership. And we plan to have up to five in Vancouver for a demonstration program with the Canadian Fuel Cell Partnership."

Just this April 13, Honda delivered two Honda FCX fuel cell vehicles (for lease) to the city of San Francisco, bringing to 12 the number of Honda fuel cell cars on the road in the U.S. and Japan. Honda boasts that its FCX is the world's first commercial fuel cell vehicle and the only one certified by the U.S. EPA and CARB for everyday commercial use. Los Angeles, now with seven Honda FCXs in its advanced vehicle fleet and operates its own hydrogen refueling station. Honda has also recently established an experimental Home Energy Station (HES) that generates hydrogen from natural gas at its U.S. R&D headquarters in Torrance, Calif.

The FCX, which uses Honda's own unique fuel cell stack and an ultra-capacitor instead of a battery for energy storage, seats four passengers, has a range of "up to 170 miles" and recently demonstrated capability to start and run in below-freezing temperatures. "This is a tremendous breakthrough for Honda and everyone whose dream it is to make fuel cell power a reality," says Honda R&D Americas Vice President Ben Knight. In 2003, Knight said that the hydrogen fuel cell offers the greatest promise of any advanced technology but added that "any large societal gains from this technology are still a couple of decades away."

Hydrogen ICE

Ford is a strong proponent of hydrogen ICEs as a "bridging technology" to accelerate development of a hydrogen infrastructure while preserving the manufacturing base for ICE components. "We know that the gasoline ICE will be around for a long time," Schmidt

asserts," and we have the manufacturing facilities to make cylinder heads, crankshafts and all these things. Why not use them for a bridging technology? It allows you to build up the infrastructure using hydrogen for both fuel cell and ICE and not throw away all this investment. We already have pretty good experience with hydrogen IC engines. They are more expensive than gasoline ICEs but significantly cheaper than fuel cells, so I think it's more than 50 percent probable that we'll have a migration plan from today's fossil fuel economy to a hydrogen economy in which we'll continue to use internal combustion engines."

Toyota's Hermance disagrees. "The only way that's viable is if we're not successful in development of the fuel cell, if the infrastructure guys get out ahead of the fuel cell developers, which I don't think is likely. You can't burn hydrogen in a conventional ICE without making the engine specific to the application, or at least you won't get much efficiency out of it. Also, hydrogen production is significantly less energy efficient than gasoline production, so you're taking an inefficient fuel and consuming it in an inefficient conversion device, the worst of both worlds. I have significant confidence in the folks at GM and Toyota and others involved in development of the fuel cell technology that by the time they figure out how to make the fuel renewably, we'll be well down the road and ready for the fuel cell."

"Clean" Diesel

Ford's Schmidt is also optimistic on potential for advanced diesels in the U.S., despite the American consumer's negative perception, anti-diesel lawmaker bias in Washington and California and extremely tough new emissions standards arriving for '07. "I think diesel will get a chance in North America," he says. "The combustion process is 30-40 percent more efficient compared to competitive gasoline engines, we already have significant business in heavy-duty, and I see opportunity in the SUV and light truck arenas. But it's not just about being more fuel efficient, it's also about having more fun because of the diesel's high low-end torque and relaxed driving at low engine speeds."

Schmidt contends that the '07 emissions standards can be met, but at higher cost. "Will there be technologies to achieve these standards?" he asks. "I think the answer is yes. The question is whether our customers will be willing to pay for them. It's still a challenge to find affordable technologies. But this is a work in progress, and everything depends on fuel prices."

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What will make "clean" diesels so costly? "First, the diesel by itself is more expensive than a gasoline engine. Turbocharging [for competitive performance] adds more cost, and the fuel injection is more expensive because of the higher pressures required. But to fulfill these tough new emissions standards, I believe, will require a particulate filter and some aftertreatment to reduce NO_X. Depending on the engine size [these devices alone] could cost some thousands of dollars."

GM's Nitz believes that diesels will continue to play a role, at least in heavy-duty pickups. "Diesels are cleaner than they've ever been," he says, "and they're going to get cleaner. It's a huge challenge to meet '07 and beyond, but huge technology portfolios are being worked to improve diesel emissions. They have to be basically the same as gasoline, and as we look at the technologies to do that, the jury is out on how well we'll be able to clean up the emissions and keep them clean through the life of the vehicle."

Outlook

Ten years out, will any of these contenders threaten the long-reigning gasoline ICE?

"Fossil fuel is not forever," Schmidt says, "so it's very important to find efficient solutions and clean technologies that allow us not to be dependent on one single energy source or one single supplier. We have seen [some success for] hybrid electric vehicles, and when we look really long term, we see hydrogen fuel cells and we think, as a bridging technology, the hydrogen ICE. If you're optimistic and visionary, you may see a 100 percent fuel-cell landscape in the very long term. But as long as fossil fuels are available and affordable, the traditional ICE will continue to play a major role."

GM's Nitz also sees a portfolio of options: "Hybrids are not a silver bullet. Diesels are not a silver bullet. Some duty cycles make sense for hybrids, some make sense for diesels, and the preponderance of the rest will be conventional and advanced gasoline. Stop-and-go city driving is the right place for hybridization. Continuous highway driving is the right place for conventional powertrains. Heavy-duty will favor diesel, and light-duty will favor gasoline. As the emissions get proven on diesels, they may be able to expand into other applications, but that's a huge challenge. And we'll make additional tremendous advancements to gasoline engines."

"I'd guess hybrids in the 5-10 percent range," Toyota's Hermance adds. "And if our friends from General Motors are correct, you might see the glimmer of a slice for fuel cells, but I think that's optimistic."

Simply put, it's very difficult to compete with a tank of gas for carrying a large amount of energy in a package of reasonable size and weight at a very reasonable cost. Unless the cost equation changes substantially, something else comes along that can do it much better or the planet finally begins to run out of oil, there's no reason why it should not continue to dominate. ★