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cover story ➤ BY BILL KENNEDY, CONTRIBUTING EDITOR

EVOLUTION of the species

The trend toward 'green' vehicles drives changes in automotive manufacturing materials and processes.

Hulking dinosaurs once ruled the Earth. Eventually, climate change and other forces did the big fellows in. Petrified bones and fossils trace the evolution of today's species.

Similarly, gas-guzzling vehicles have long ruled U.S. roads. Now climate change and the desire to minimize consumption of fossil fuels are driving the evolution of new vehicular species.

Manufacturing technology and materials are part of that evolution. Building components for vehicles that burn less fuel presents manufacturing opportunities and challenges. This article focuses on four "green" technologies that may help reduce gasoline use or eliminate it altogether.

Ethanol Efficiency

From headlight housings to exhaust pipes (see "Exhaustive Effort" on pages 121-122), automakers are examining every element of their products to boost efficiency and cut costs. On the power train side, a range of technologies aim to reduce fossil fuel consumption. Many alternatives, such as hybrid arrangements and fuel cell systems, are complex, expensive or in the early stages of development. One approach that uses existing technology involves adding ethanol to gasoline.

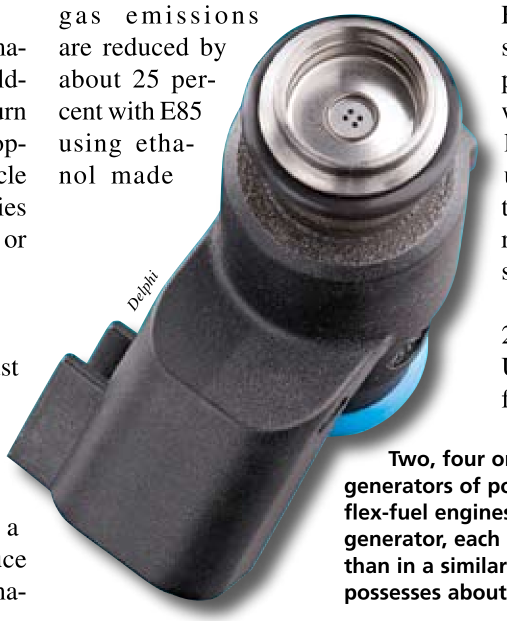
Since the 1970s, gasoline blends featuring 10 percent or less ethanol—gasohol/E10—have become common. Most gasoline-engined vehicles designed since the 1980s are engineered to handle E10 blends.

Next came blends with as much as 85 percent ethanol. The higher proportion further cuts consumption of hydrocarbon-based fuel and reduces pollution. Gary Herwick, president of Transportation Fuels Consulting Inc., Milford, Mich., said greenhouse gas emissions are reduced by about 25 percent with E85 using ethanol made from corn, and up to 70 percent using cellulose-sourced ethanol.

E85 uses existing internal-combustion gasoline engine technology but requires significant modifications. Ethanol conducts electricity and absorbs water, making it a catalyst for corrosion of some materials. Also, ethanol acts as a solvent on rubber and some plastics. So fuel-handling components must be made of ethanol-compatible materials, and engine-management systems must be engineered to adjust combustion parameters to burn the various blends efficiently.

The U.S. government created incentives for automakers to produce flex-fuel vehicles that can run on ethanol blends from E0 (gasoline alone) to E85. Herwick said the federal measures offer credits to vehicle makers to produce flex-fuel vehicles. The intent was to solve the chicken-and-egg problem of which comes first: vehicles that use ethanol or ethanol outlets to fuel them. After the vehicles were on the road, then "they'd work on the infrastructure for the E85," Herwick said.

As a result, out of a total of about 240 million passenger vehicles in the U.S., roughly six million are flex-fuel capable. This spring, E85 was



Two, four or six holes are common in the spray generators of port fuel injectors for conventional and flex-fuel engines. However, in a flex-fuel injector's spray generator, each hole's area is about 30 percent larger than in a similar gasoline injector because E85 fuel possesses about 30 percent less energy than gasoline.

available in about 1,200 of 180,000 U.S. service stations. Jim Zizelman is chief engineer for air and fuel control and director of the Rochester, N.Y., technical research center for Troy, Mich.-based Delphi Corp. He said the number of E85 vehicles and sources "is obviously likely to grow pretty substantially as more and more OEMs become interested in being green."

Regarding E85's suitability for unmodified engines, Zizelman said, "You do not want to put E85 into a vehicle not identified as flexible fuel." The differences from a nonflex vehicle are "primarily on the wet side of the control system," he said, including the fuel tank, fuel pump, fuel lines and injectors. "All the things that would be exposed to ethanol must be compatible."

Materials that are not compatible with ethanol include steel, brass, zinc, lead and aluminum; the detritus of corrosion will travel through a fuel system and damage or clog it. Rubber and some plastic components also degrade when exposed to ethanol and must be replaced with alcohol-resistant composites or elastomers.

Materials are specified according to use. "Stainless steel resists corrosion," Zizelman said. "The specific grade you choose depends on the application. A fuel rail that simply contains the fuel would have perhaps a different callout of steel than a moving component in an injector where you have some frictional characteristics." Stainless alloys used in moving parts, for example, may have higher chromium or nickel content for greater wear resistance.

Delphi provides specific material specifications to its Tier 2 and 3 suppliers, but the materials usually are not new or uncommon. "The materials we are talking about using for E85 are not space-age materials that are difficult to find or difficult to manufacture," Zizelman said. "They may be different in an E85 injector versus a non-E85 injector, but these materials have been used for a long time."

Transportation Fuels Consulting

This insignia appears on GM vehicles that have been modified to handle gasoline/ethanol blends up to E85 (85 percent ethanol, 15 percent gasoline).

Besides compatibility issues, a flex-fuel engine must be able to run efficiently on E0, E85 and all blends in between. Also, E85 possesses about 30 percent less energy than gasoline, so a higher flow of E85 is required to produce performance equivalent to pure gasoline. Considering that a flex-fuel vehicle may be filled with pure gasoline one day and E85 another, "you have to be able to provide the small amounts of fuel associated with the pure gasoline operation in the idle condition, but also the high flow conditions required for the wide-open throttle condition in E85," Zizelman said.

Fuel injector technology solves the problem. An injector has two major elements: a valving device that turns the fuel on and off, and a spray generator that converts the high-pressure fluid into an atomized spray. “You regulate the amount of fuel that comes out of an injector by how long you keep it open,” Zizelman said. “In the case of an E85 injector, you have to have a higher linear range, i.e., the maximum flow has to be higher, [than in a standard injector, but] the lower flow has to remain the same.”

The coil and electromagnetic solenoid that open and close the valve are optimized to work quickly. Zizelman added: “We add a director plate or spray generator with larger holes to provide that increase in maximum flow. You end up changing two variables. When the injector is running completely open it runs more fuel, but it also can operate more quickly so it can offer a smaller amount of fuel for the idle condition.”

He said two, four or six holes are common on port fuel injectors for conventional and flex-fuel engines. “There is no real reason to have a different number of holes for E85; you would just increase the size of whatever number you have chosen for your application.” For E85, the holes must flow 30 percent more fuel. So, roughly, the hole area must be about 30 percent larger. Common holemaking techniques are stamping and EDMing, with stamping being the more modern method.

Diesel Details

Another approach to reducing fuel consumption involves implementation of high-tech diesel power trains. According to engineering consulting organization Ricardo plc, an advanced diesel engine offers upwards of 20 percent fuel economy improvement over a comparable gasoline engine. Improvements in emissions, startup behavior, noise and drivability (as well as government incentives) have increased diesel automobile market share in Western Europe from 22 percent to almost 50 percent over the last decade. Acceptance is growing in the U.S. and should increase as manufacturers find ways to meet this country’s stringent nitrogenoxide limits.

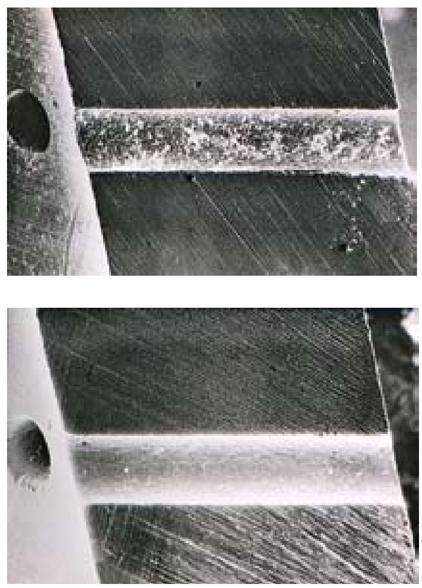
Jim Bower, diesel injector specialist at surface finishing products provider Extrude Hone Corp., Irwin, Pa., said the company has been dealing with diesel performance issues since the early 1970s, when manufacturers of large truck engines sought ways to achieve consistent emission performance in response to tightening government regulations.

The truck makers found that engine emissions increased significantly after about 80,000 miles. The problem was with the holes in diesel injectors, manufactured via EDMing; the holes featured edge roughness and small burs, which were removed by the flow of fuel. “The fuel actually eroded the holes bigger,” Bower said.

Extrude Hone applied its abrasive-flow treatment to the injectors. The process forces a polymer medium containing abrasive grains through a part. The company treated new injectors to radius the holes and remove the ragged edges. Erosion over the long term was minimized, and emissions remained consistent after more than 500,000 miles.

Extrude Hone continues to address changes to diesel engines resulting from stiffer emission regulations. "The biggest thing we see is the industry going to not only more holes but smaller holes," Bower said. While an injector might previously have had six holes 0.006" or 0.007" in diameter, "some of them will have as many as eight or 10 holes, but they are down to 0.004" in diameter," Bower added. "They have found that increases the atomization. If you make a smaller mist, it burns much cleaner."

Bower added that "there is a lot of development going on right now. The next big step is 2010, when they've got to meet the next step of the emissions requirements." Regarding light vehicles, Bower said Extrude Hone has

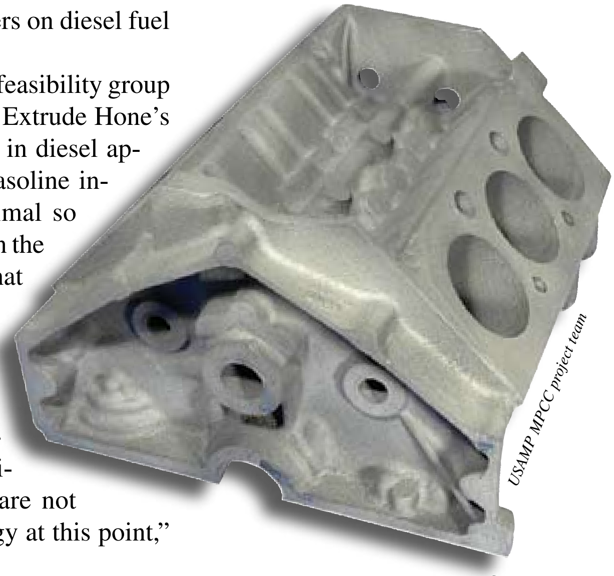


Extrude Hone

Extrude Hone's MicroFlow AFM (abrasive flow machining) process forces a polymer medium containing abrasive grains through a part. The company treats new diesel injectors (micrograph at top) to smoothly radius fuel delivery holes and remove ragged edges. The treated injectors (micrograph at bottom) exhibit minimized flow variability due to wear and improve fuel atomization for better emissions control.

worked with automakers on diesel fuel system issues.

Bill Walch, process feasibility group manager, said most of Extrude Hone's work to date has been in diesel applications. Work on gasoline injection has been minimal so far. There are "plates on the end of the injectors that we have done some work on. They punch the holes, typically at an angle. We've done some work for a number of OEMs with positive results, but they are not pursuing the technology at this point," Walch said.



This engine block was manufactured to determine the castability of a magnesium alloy applied in a magnesium power train cast components project being carried out by the U.S. Automotive Materials Partnership of the United States Council for Automotive Research.

Green Team

General Motors recently announced it hired 500 technical experts to work on fuel-saving technology. Ford listed its "Top Ten Green Initiatives" in recognition of Earth Day. Chrysler has begun a number of programs aimed at improving its vehicles' fuel efficiency. Also, the Big Three automakers work together on green issues through an umbrella organization called the United States Council for Automotive Research.

USCAR's goal is to strengthen the technology base of the domestic auto industry through cooperative R&D. USCAR coordinates partnerships addressing specific areas, including materials, emissions, safety, power trains, energy storage and recycling.

Dick Osborne, a staff development engineer at GM, works in the Automotive Metals Div. of USCAR's U.S. Automotive Materials Partnership. In November, USAMP released a report, "Magnesium Vision 2020—A North American Automotive Strategic Vision for Magnesium." The report contends that by 2020, an average vehicle's magnesium content could increase from about 12 lbs. today to as much as 350 lbs., with corresponding benefits in fuel economy. The study examined the market infrastructure and manufacturing considerations involved in increasing the use of magnesium and indicated that magnesium parts offer cost-effective ways to reduce vehicle weight and improve efficiency. Converting steel or cast iron parts to magnesium typically reduces weight by 50 to 55 percent; converting aluminum parts cuts weight by 33 percent. Moving less weight requires less fuel.

USAMP recently concluded a structural cast magnesium development (SCMD) project whose findings were applied to an actual production part: a magnesium engine cradle for Chevrolet's high-performance Z06 Corvette.

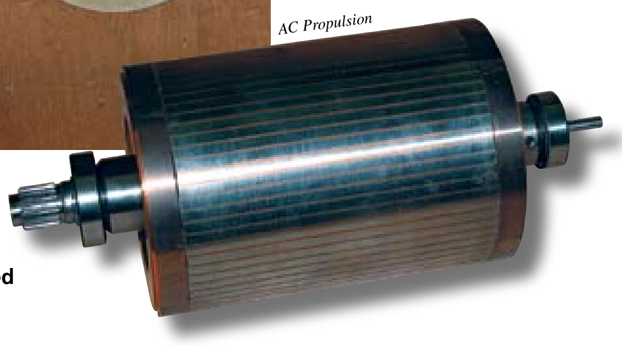
"We were looking for a tough application," Osborne said about the project. "We wanted to push our team to work on something that people thought would never be possible." An engine cradle is challenging because it is subject to high mechanical stress, a corrosive environment and high temperatures.

The baseline cradle was an A356 T6 aluminum permanent mold casting. A356 T6 is a stable, relatively corrosion-resistant alloy used widely in the automotive industry. The magnesium alloy cradle was manufactured via high-pressure die casting, which is fast and offers good replication of detail, providing a near net-shape product that requires minimal machining.

Osborne said choosing the right

magnesium alloy was key to the project's success. It had to be easily castable, have high strength, exhibit good corrosion resistance and offer high creep resistance. Good castability was important for the fast cycle times and consistency needed to contain manufacturing costs. Strength and corrosion resistance were crucial because a cradle must support the engine and is exposed to the under-car environment. Creep occurs when elevated temperatures allow a material's internal grain boundaries to slide past each other. In extreme cases, creep will cause a fastener to lose its clamp load on a part. The alloy chosen "had to have all those things, and also be cost effective," Osborne said. Magnesium alloy AE44, with 4 percent each of rare earth metals and aluminum, met all the requirements.

Project participants also dealt with magnesium's sensitivity to galvanic corrosion. "A magnesium component is anodic," Osborne said. "Most other metals are cathodic. When you put magnesium parts up against most metals with an electrolyte such as salt water [found on winter roads], you basically have a battery. Then you have a current flow and a loss of material on the magnesium side."



The 6"-dia, 10"-long rotor for the AC Propulsion motor, an assembly of copper and iron laminations, turns 13,000 rpm at the eBox electric vehicle's top speed of 95 mph.

Iron and copper are among the strongest cathodes relative to magnesium. To isolate the cradle from dissimilar metals, USAMP applied aluminum isolating plates. "If you have an aluminum alloy that is relatively pure, when it lays up against magnesium, it doesn't create that highly intense current flow and acts as a barrier between magnesium and steel," Osborne said. The isolators were attached with epoxy.

The project's research immediately benefited the manufacture of the Corvette cradle. The relatively low production volume (about 7,000 a year) permitted multiple processes to be set up at the casting facility. "We had the supplier set up the machining operation right next to the casting operation," Osborne said. "We were casting, X-raying the parts, machining them and applying the isolators to mitigate the galvanic corrosion."

The magnesium cradle weighs 22 lbs., about a 35 percent savings over the aluminum part's 35 lbs. Also, before the expense of fitting the aluminum isolators, material cost of the magnesium cradle was actually less than the aluminum part. "In terms of the pricing of the aluminum alloy per pound versus the magnesium alloy per pound, there's not that much difference. When you knock off 35 percent of the mass, you can get a per-piece cost savings. Isolation is one of the areas we have to focus on, to drive those costs out," Osborne said.

Osborne emphasized the collaborative nature of USCAR, citing the current Magnesium Powertrain Cast Components Project (MPCC), in which the project team has developed a cast magnesium engine block, oil pan, front engine cover and rear seal carrier, based on the architecture of the Ford 3.0-liter Duratec V-6. "Again, the idea is to resolve the issues with the particular application," he said. Issues include redesign of the cylinder block from aluminum to a magnesium alloy, compatibility of coolant, dissimilar metals, fastener considerations and machining concerns. "The project started in 2001, and we have engineers from all our companies working on it. What's unusual is that it is a Ford engine block, but the Big Three OEMs developed the design collaboratively and the project is being led by a GM scientist," Osborne said.

Earlier this summer, cylinder blocks were cast and machined, and engine assembly began. Initial runs were anticipated for October. "We should have the final report sometime during the first quarter of next year," Osborne said.

Electric Energy

Another approach to green vehicle manufacturing is the all-electric car. AC Propulsion Inc., San Dimas, Calif., converts the gasoline-powered subcompact Scion xB into an electric vehicle it calls the eBox, which uses no gas at all. ACP president Tom Gage said, "When we got into this business, it was all about clean air. And the new cars are very clean indeed. But what has changed is that people are starting to realize we use too much gasoline."

The eBox's AC induction motor is an integrated drive and charging unit that puts out 161 hp at 5,000 rpm and 165 ft.-lbs. of torque beginning at 0 rpm. The boxy hatchback weighs 2,970 lbs. (about 570 lbs. more than the stock Scion xB), accelerates to 60 mph in 7 seconds and has a range of 120 to 150 miles.

"Our main business is the drive system itself," Gage said about ACP's AC-150 Gen-2 EV power system. "Conversions are not that easy to do. By showing how it can be done, we are helping to produce a market for our product."

ACP has been in business for 15 years, fitting its power units into Hondas, Volkswagens, electric buses and its own tzero electric sports cars. Over that time, "our drive system has actually changed only a little," Gage said. What has changed significantly is the batteries. "We started out with lead-acid batteries. A car's worth weighed about 1,200 lbs.," Gage said. Today's lithium-ion battery pack weighs about 500 lbs. and doubles the range of its predecessors. Connected in a series of 48 units that produces 400v, the batteries are in an enclosure that isolates them from the rest of the car and eliminates a shock hazard for the driver.

The battery's cost currently is a large percentage of the $55,000 conversion price. In a mass production situation, Gage said, the cost of the battery and conversion expenses will decline. "Right now, we are building about one car a month and are sold out through the end of year."

Gage said ACP believes there is "a pretty big niche" for purely electric vehicles. "So much driving is done locally that there is definitely a place for a limited-range vehicle." A 200-mile intraurban day is quite doable, Gage said, considering that a car is usually parked for a fair amount of time,

The following companies contributed to this report:

AC Propulsion Inc.
(909) 592-5399
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Delphi Corp.
(248) 813-2000
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Extrude Hone Corp.
(800) 367-1109
www.extrudehone.com

General Motors Corp.
(313) 556-5000
www.gm.com

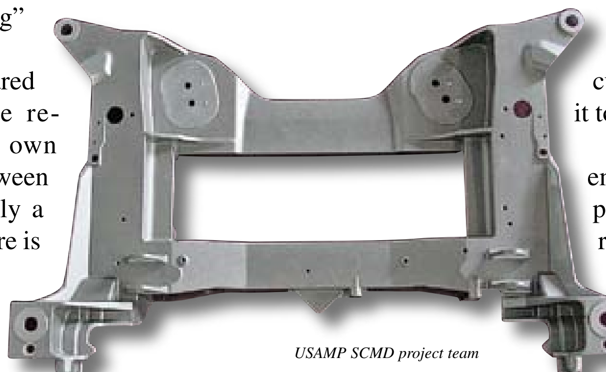
Transportation Fuels Consulting Inc.
(248) 887-1666

United States Council for Automotive Research
(248) 223-9000
www.uscar.org

enabling "opportunity charging" throughout the day.

The eBox has no multi-geared transmission. The gears are removed, and "we put in our own custom ratio, a ratio right between first and second gear, basically a speed reducer," Gage said. There is no clutch, and 0 speed is 0 motor rpm. Top speed, about 95 mph, occurs at 13,000 motor rpm.

ACP does about half the machining required for the conversion in-house, subcontracting the rest. "We build our own motors," Gage said. "The housing, end plates, shaft and various other small parts are all made in the machine shop." Some unique operations and materials are required. The power plant's rotor is an assembly of copper and iron laminations.



USAMP SCMD project team

This AE44 magnesium alloy engine cradle manufactured via high-pressure die casting weighs 35 percent less than a permanent-mold-cast A356 T6 aluminum cradle.

Because the motor turns up to 13,000 rpm, ACP machines a step in the outer ring of copper and presses on a special beryllium-copper retaining ring to control centrifugal expansion of the soft copper rotor. "The beryllium copper comes in tube form, and we cut slices off the tube and machine it to fit," Gage said.

The eBox's charging method employs the same electronic components that drive the motor and requires the motor to be isolated electrically from the rest of the vehicle. "So both at the torque coupling and where it is adapted to the transmission, we use insulating components," Gage said. "Some are machined out of plastic and some out of phenolic."

Also, Gage summarized the evolution of green vehicles. "We need to do everything we can, both in terms of improving efficiency of cars that use gas and finding alternatives so some cars don't have to use any gas at all." △