feature article

FEATURE FOCUS: *Fuels & Combustion*

a new dawn for diesel

Will Americans pay the price to put light-duty diesels on U.S. highways?

by John DeGaspari, Associate Editor

Trucking is the lifeblood of the freight business in this country and diesel engines are its beating heart. Each year some 2.6 million trucks—nine out of 10 of which are diesel-powered— haul nine billion tons of goods along U.S. highways. That being said, it is the conventional gasoline engine that still rules the American road. It is the power plant of the lion's share of small pickup trucks, sport utility vehicles, and passenger cars. And it can consume a great deal of fuel.

Hybrid electric-gasoline vehicles have recently gained the spotlight as one way to boost fuel economy in light-duty vehicles and stem the rise in fuel consumption in the United States. But that is still an exotic solution. When it is available, it is costly. A fuel-efficient alternative—the diesel engine—has largely been overlooked as a means of curbing American cars' appetites.

This 2.8-liter diesel engine, being manufactured in Cento, Italy, as part of a joint venture between DaimlerChrysler and VM Motori, will power Chrysler's 2005 Jeep Liberty.

A number of factors have come into play in recent years that make light-duty diesels a viable alternative to conventional gasoline engines. Modern direct-injection diesels are different engines from the smoky, noisy, and smelly diesels of 30 years ago. Taking advantage of electronic controls and advances in fuel injection, today's light-duty diesels are quiet and clean, and they provide excellent low-end torque and superior fuel economy, proponents say. Ultra-low sulfur fuel, set to become available in the United States in 2006, will enable emissions control technologies to reduce particulates and nitrogen oxides, the two main pollutants of diesel engines.

Enough pieces are in place, in terms of engine performance and the ability to meet emissions standards, that light-duty diesels are finally getting some serious consideration in the American market. Few people believe that diesels will sweep gasoline engines off the road in the United States any time soon. Yet car manufacturers are beginning to test the waters.

This month, the Chrysler Group is introducing in the United States a version of its midsize sport utility vehicle, the Jeep Liberty, powered by a 2.8-liter turbo diesel engine. Mercedes-Benz reintroduced its sleek E-class diesel sedan in North America last year, after a four-year hiatus. Other carmakers think that light-duty diesels could form niches in specific markets as well.

A New Generation

In addition to their role in powering heavy vehicles, diesels have long been an important segment of the medium-duty business, for instance, in large pickup trucks. Manufacturers have also tapped into light-duty diesel markets for small trucks and passenger cars in Europe and Asia.

The technology of light-duty, direct-injection diesel engines has advanced tremendously in the last decade or so. Engine manufacturers have succeeded in producing refined engines, to the extent that the people in Europe are willing to pay $80,000 for luxury cars with four-liter direct-injected diesel engines in them. According to

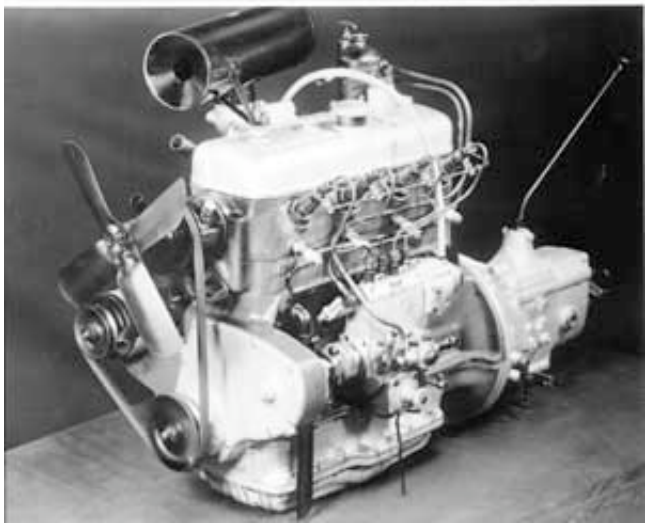
Ricardo Consulting Engineers, a British firm, there were 6.5 million diesel cars sold in Western Europe in 2003, nearly double the amount of five years earlier. Diesels have greater range on a tank of fuel and better fuel economy than traditional gasoline engines, and provide better torque, so that smaller engines could be used without sacrificing acceleration or towing capacity. With the use of emissions control devices, car manufacturers have been able, so far, to meet the tightening emissions controls in Europe.

Many of the improvements have been driven by higher fuel prices in Europe and a gap between the price of diesel and more expensive gasoline. Diesel engines are more expensive than gasoline engines and the lower fuel prices in the United States make buying decisions based on fuel economy alone unlikely. Many of the advancements have gone largely unnoticed by U.S. drivers, who still view diesels as workhorses for large trucks. But some proponents of diesel say that a combination of higher torque, better fuel economy, and smooth, quiet engine performance could sway a significant number of drivers here to consider diesels for smaller, personal-use vehicles.

Chrysler decided approximately two years ago to offer its new diesel Jeep in the United States, according to Jim Weidenbach, the senior manager of small vehicle applications. The company has been selling light-duty diesels in Europe for the past five years.

The 2.8-liter diesel that will power the Jeep Liberty is based on a similar engine that has been sold in Europe, but with a few improvements, including a system that offers more control over fuel injection and helps control noise. It also generates more torque and power than the diesel engine in the European Cherokee. Weidenbach said the Liberty would have a fuel economy rating of 22 miles per gallon city and 27 mpg highway. The comparable gasoline engine is rated at 17 mpg city and 21 mpg highway.

(Above) General Motors' 1.9-liter diesel engine powers small vehicles in Europe; DaimlerChrysler claims to have made the world's first diesel production car in Berlin in 1936 (below).



Historically, light-duty diesel engines have been given short shrift, from a technology standpoint, compared to gasoline engines, said Weidenbach. "If you look at engines of 25 years ago, they are very similar to what you would have found in the 1930s," he said. That changed in the 1990s. Today diesels for small vehicles are equipped with microprocessor controls just as gasoline engines and have sophisticated fuel injection systems.

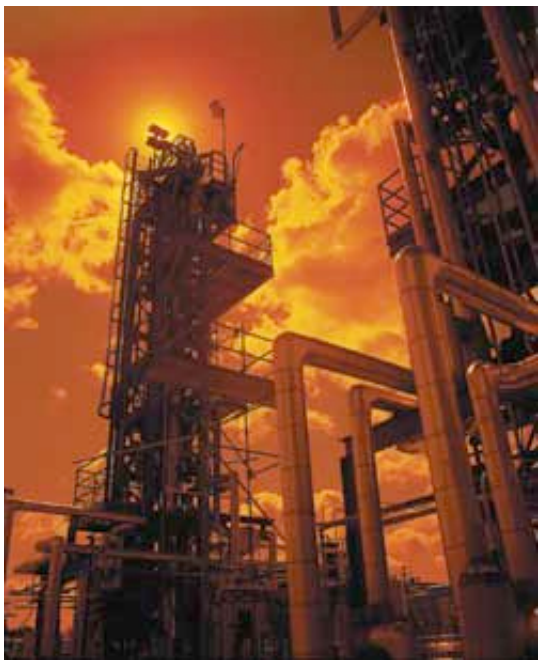
Dick Baker, a technical specialist in combustion and emissions who works on advanced diesel systems at Ford's powertrain and advanced engineering organization in Dearborn, Mich., said that electronic controls have arrived for diesels, and next-generation fuel systems offer precise control to soften the combustion process.

"Diesel clatter is a thing of the past," he said. "Now you have all the torque you can handle and deliver 30 percent to 40 percent better fuel economy while you are doing it."

The fuel system puts several different injection pulses into the combustion process in one revolution. It uses a pilot injection in addition to the main injection, which helps to soften the rate of pressure rise.

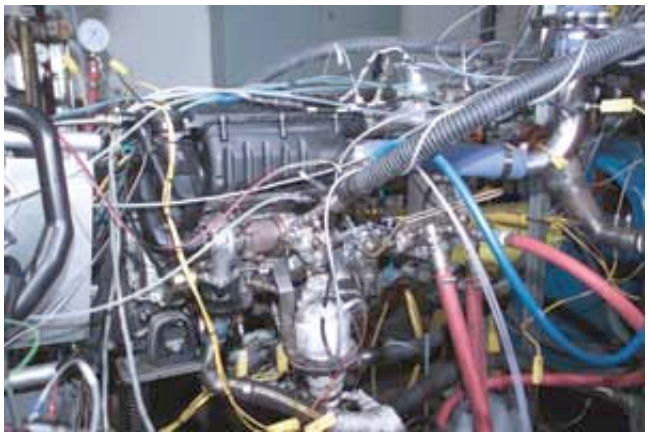
Many of the advanced technologies in fuel economy were spurred in Europe and Japan, where fuel prices have long been higher than in the United States, according to Gary Rogers, president of FEV Engine Technology Inc. in Auburn Hills, Mich. The cost at the pump led to a preference for smaller, lighter vehicles to conserve fuel, and to diesel engines for the same reason, he said.

Charles Freese, executive director of diesel engineering at General Motors Corp., noted that diesels are a key part of GM's passenger car business in Europe. Diesels provide better fuel efficiency than gasoline engines do, he said, and are well-suited to heavy loads and continuous driving. Hauling a heavy load up a steep grade, the difference in fuel economy could be as high as 75 percent compared to conventional gasoline engines, he said.



Refineries are setting up to produce cleaner diesel fuel (above); a 1.7-liter Mercedes engine, equipped with diesel oxidation catalyst and a lean NO_x trap, is coupled to a motoring dynamometer at Oak Ridge National Lab's Fuels, Engines, and Emissions

Research Center (below).



While the Big Three automakers here are betting that the interest in diesels will filter down from medium- to light-duty trucks and sport utility vehicles, others think that there may be some appeal in passenger cars as well. The potential for diesel and hybrid powertrains on the U.S. market is the subject of a report completed in August for the U.S. Department of Energy by Oak Ridge National Laboratory, in collaboration with Energy & Environmental Analysis Inc. of Arlington, Va., and J.D. Power & Associates of Troy, Mich.

The report is an economic analysis that looks at attributes including fuel economy, range, and torque, over three model years: 2008, 2012, and one not specified, but beyond 2012. Near-term scenarios were based on announced introductions; farther-off scenarios were more hypothetical. For the longest-range scenario, the report estimates that diesels could capture 31 percent of the light-duty truck market and 11 to 12 percent of the passenger car market.

David Greene, a corporate fellow at Oak Ridge National Laboratory and one of the report's authors, noted that high fuel prices, as well as the considerable gap between diesel fuel and gasoline prices, helped drive diesel sales in Europe. Greene acknowledged that few buyers would be willing to lay out extra money for diesels on the basis of fuel prices alone in this country. He believes that the combination of torque, range, and fuel economy will be enough to sway a substantial number of light-duty diesel buyers in the United States.

"In smaller vehicles, there is a market for fuel economy," he said. "That is the market where people who really care about fuel economy are." Plus, it is easier for small cars than for big ones to meet fuel emissions standards, which are measured in grams per mile. "The less engine-out

NO_x you have to deal with, the less effective your NO_x removal system has to be," he said.

Cleaning Up

Regardless of its benefits in fuel economy or performance, the diesel must meet emissions standards, which are tightening both in the U.S. and in Europe. Rogers of FEV Engine Technology noted that techniques to reduce NO_x and particulates in diesel exhaust have been effective enough to meet present European standards. Emissions standards are more restrictive in the U.S than in many European countries, and will tighten further in 2007 and 2010. That will likely require putting more emissions control devices onto already expensive engines, Rogers said. Meeting emissions standards is difficult, and is often a balance of tradeoffs among efficiency, noise, and emissions, he said. But the cost of meeting emissions standards is a key challenge to the future of light-duty diesels in the United States.

Removing particulates is furthest along, according to Ford's Baker. "Particulates are being resolved, and in the 2007 model year, anyone who wants to sell a diesel is going to have to have a particulate filter in the U.S.," he said. Particulate filters accumulate soot to be burned, removing visible smoke and much of the odor from the exhaust.

Nitrogen oxide is a tougher nut to crack. NO_x comes from efficient combustion and results from oxidation at high temperatures in the atmosphere. The fundamental problem is that reducing NO_x formation requires a chemical reaction that reduces available oxygen. Taking NO_x out means working with a rich mixture of fuel to oxygen. Diesels run efficiently with an excess of oxygen, or lean.

A schemetic drawing of a diesel particulate filter for Opel engines shows the removal of soot from the exhaust. 1. Pretreated exhaust emissions enter filter. 2. Cross-section of filter element. 3. Function of filter element. 4. Pressure sensors. 5. Temperature sensor. 6. Filtration cycle showing (a) filter phase and (b) regenerating phase. 7. Filtered exhaust emissions.

One NO_X treatment is selective catalytic reduction, which uses an oxygen-stripping chemical, such as ammonia, in the presence of a catalyst. Urea, which contains ammonia, can be stored as a fluid and squirted into the exhaust system for the reduction reaction. It works well, but fluid must be replenished periodically and the system must be actively maintained.

Another method, a lean NO_X trap, requires the engine to alternate between running in lean and rich modes. The trap collects and stores NO_X when the engine runs lean and removes the NO_X when the engine runs rich. The strategy calls for the engine to switch back and forth between rich and lean conditions about once a minute, and requires tight control of the air/fuel ratio.

GM's Freese noted that the diesel will have to meet emissions requirements to be a player in the States. In the United States, where vehicles tend to be larger, emissions requirements will be tougher to meet than they are in Europe. Larger engines burn more fuel to move mass and are going to have greater emissions out of the tailpipe. Freese predicts that meeting future emissions standards can be a challenge and beyond the reach of some technologies. "The standards of today are different than the standards we will have in 2007," he said. And they add cost to the vehicle. In Europe, GM supplies diesel engines that use two particulate filters.

Baker at Ford, however, said he is optimistic that technical solutions will be found to meet emissions standards in the U.S. Those standards will tighten in 2007, and add to the complexity and cost of the engine. Refineries are putting equipment in place to remove sulfur.

The Right Price?

Overall, diesels will always be more expensive than gasoline engines, Rogers said. They operate at higher pressures and are heavier, requiring bigger and stronger pressure vessels. Adding to the cost are turbochargers, intercoolers to keep the temperature down in the engine, and high-pressure fuel injection systems. Rogers said that diesel engines, equipped with emissions control devices, could cost $1,000 to $2,000 more than conventional gasoline engines that are not turbocharged.

According to John Heywood, the Sun Jae Professor of Mechanical Engineering at the Massachusetts Institute of Technology and director of its Sloan Automotive Laboratory, cost is a key issue. Diesels have cleaned themselves up, and in Europe, car companies have learned how to make very attractive diesel driving vehicles, he said. In Europe, vehicle and fuel taxes, and fuel prices have been high enough to make diesels attractive to consumers. In his view, the cost increment and tightening emissions standards will determine how well light-duty diesels play out in this country.

Emissions control devices are not cheap. Heywood estimates that they will add perhaps $1,500 per vehicle. They could also reduce efficiency by at least 5 percent, he added. "We have not yet got robust enough technologies to know how well they will be able to really clean up diesels and how much it is going to cost," he said.

Others think that the cost of emissions control may come down in time. K.G. Duleep, managing director of Energy & Environmental Analysis Inc., is a co-author of the Oak Ridge National Lab report. He said that particulate filters and lean NO_x traps were quite expensive a couple of years ago; associated engine controls and configuration requirements could add $1,000 in manufacturing costs, he said. More recently, work has been done to integrate particulate filters and lean NO_x traps. The integrated approach could potentially cut manufacturing costs by almost half, to the $500 to $600 range, he said. He sees the integrated approach becoming available in some car models in 2008.

Sulfur Out

Removing sulfur from diesel fuel in 2006 will enable the use of various emissions treatment technologies. Sulfur

contributes to particulate formation and it can poison certain catalytic sites, such as those used on NO_x traps, Rogers said. The Environmental Protection Agency mandates that as of 2006 on-road diesel fuel have sulfur concentrations of no more than 15 parts per million. In years past, allowable sulfur levels have been 200 ppm or higher.

Allen Schaeffer, executive director of the Diesel Technology Forum, an industry group in Frederick, Md., said, "For the first time, diesel fuel is on par with gasoline in terms of emissions. Cleaner fuel enables manufacturers to use advanced emissions control technology, opening up the possibility for more products to come out." And cleaning up diesel fuel also has costs, with estimates ranging from a few cents to several cents a gallon.

Cost and tightening emissions standards will determine how light-duty diesels play out.

Peter Lidiak, fuels and refining manager of the American Petroleum Institute in Washington, D.C., said that the availability of low-sulfur diesel fuel is likely to boost demand somewhat for small diesel-powered vehicles. One question is how much of the product from refineries will be low-sulfur fuel intended for the highways and how much will be lower-grade stock destined for other applications, such as heating oil. There is also some question about how many refineries will decide to remain in the transportation end of the diesel fuel business.

"Whoever decides to do it will meet the standards," Lidiak said. "The question is, will there be enough domestic suppliers or will we have to look to imports to make up the shortfall that might appear in the supply picture."

In 2003, the United States consumed an average of 1,022.9 million barrels of diesel fuel and imported 49.4 million barrels, according to American Petroleum Institute figures. That year, it consumed 3,261 million

barrels of gasoline and imported 189 million barrels. According to the Energy Information Administration of the U.S. Department of Energy, in late November of last year, average on-highway diesel fuel cost about $2.11 at the pump; gasoline cost about $1.94. Diesel imports are likely to rise under the clean diesel requirement because domestic suppliers are not going to make enough to meet demand, Lidiak said.

More Miles Per Gallon

Diesels could make a bigger impact on fuel consumption from a fleet perspective in this country, where people favor larger vehicles, than in Europe, Rogers said. Diesels deliver higher torque at lower speeds than gasoline engines, allowing drivers to get away with a comparatively smaller, lower-horsepower diesel without sacrificing acceleration or towing capacity, Rogers said. Large vehicles need big gasoline engines to deliver that kind of performance, but don't require that kind of horsepower under normal driving conditions; fuel consumption is poor under low-speed city driving or normal highway driving. Diesel engines provide better fuel efficiency under those conditions and bigger improvements in larger vehicles than in small ones. Smaller engines are also more efficient because they have less friction than large engines, Rogers said.

In Europe, replacing a gasoline engine with a diesel in a 3,000-pound car could result in a 30- to 40-percent improvement in fuel efficiency. Putting a diesel in a large sport utility vehicle could provide a 40- to 50-percent improvement in fuel efficiency, he said.

Sooner or later, people are going to have to try to rein in fuel consumption in the United States, Heywood said. "Projections over the next 25 years show our consumption of petroleum in light-duty vehicles going up 60 to 70 percent, if we just carry on the way we are now." To solve that problem, the auto industry needs to look at many technologies, especially those we can get into the marketplace quickly, he said. Diesel is one tool among many, including continuing developments in conventional gasoline engines and hybrids.

While it is too early to know how any of these technologies will play out in the long run, it is good that diesels, hybrids, and a range of fuel-saving technologies are being worked on and implemented in the early stages,

Heywood said.

Incremental advances in seemingly mundane areas—reduced engine friction, better cooling, the completeness of burning fuel—could make significant differences in fuel economy. "We don't have to have brand-new technology. We can just spend a bit more money, be smarter, and improve standard gasoline and diesel technology significantly," he said. "That is really what is going to make a difference over the next 15 to 25 years."