Diesel Fuel in the United States

In the 1970s, Diesel technology had a poor image in the United States owing to the inadequate performance and reliability observed in certain models. The 1990s brought increased awareness of greenhouse effect issues. Greater Diesel penetration of the American automobile market could represent a short-term solution for reducing CO_2 emissions, along with the use of hybrid vehicles, but the impact on American refining plant would be substantial.

In the early 1970s in North America, Diesel technology was only marginally present in automobiles. Even today, it is applied exclusively to heavy trucks. Only 0.1% of the light vehicle fleet in the United States is equipped with Diesel engines. Until recently, this situation seemed unlikely to change, because American public opinion seemed reluctant to reintroduce Diesel engines for reasons of low performance and a poor environmental image.

In spite of this handicap, national and local public authorities and the industry seem to be reviewing their position on Diesel, in light of recent technical advances and the lessons to be learned from the European experience. There is increasing concern in the United States about greenhouse gases (GHGs) and, to a lesser extent, about national energy dependence, and there are a few indications that the Diesel engine might make a comeback.

Environmental Considerations

According to the US Energy Information Administration (EIA), the US is responsible for about one quarter of global CO_2 emissions, which could reach 1.7 billion metric tons in 2005.

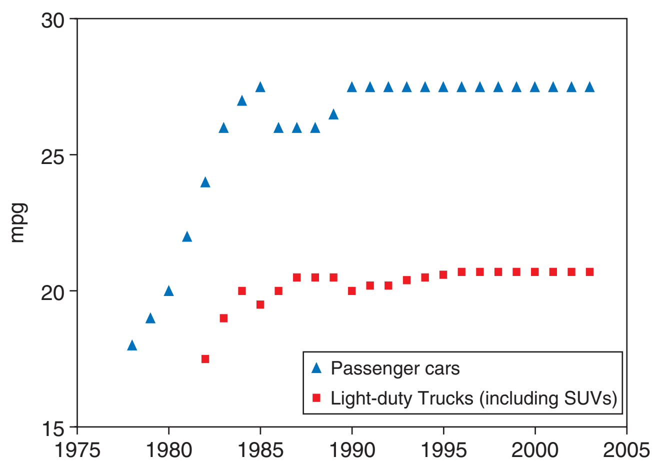
There are several reasons why emissions are up by nearly 400 million metric tons compared to 1990. In the wake of the oil shocks of the 1970s, considerable energy gains were made, but this trend slowed considerably when the crude price collapsed in 1986. As a result, energy consumption rose, also driven by strong economic growth in the 1990s and, more recently, by a sharp rise in the use of "gaz-guzzlers" (sport-utility vehicles, vans and pickups). Given this situation, and despite the fact that the United States is unwilling to ratify the Kyoto Protocol, the Bush Administration launched an alternative program in 2002. The main thrust of this "Clear Skies Initiative" was to reduce GHG emissions by 18% over the next 10 years, as well as the NO_x and SO_x emissions.

The transport sector, which accounts for the bulk of American oil consumption (about 70% in 2002) and one-third of American GHG emissions, will be required to do its share. That is why Clear Skies not only promotes alternative energies and motors (with hydrogen and bifuels as long-term solutions), but also encourages the transport sector to make progress on conventional gasoline and Diesel engines, thus furthering the aims of the Environmental Protection Agency (EPA).

Created under the Clean Air Act of 1970, the EPA is vested with the authority to regulate and inspect the energy efficiency of vehicles and their local polluting emissions (HC, CO, NO_x and particles), fuel efficiency and GHGs (CO_2).

After issuing the Corporate Average Fuel Economy (CAFE) standards, which have applied since 1975 to all cars put on the market by each manufacturer, the EPA introduced range-specific vehicle emissions standards then revised them, along with the motor fuel specifications, within the framework of low-sulfur motor fuel programs.

Fig. 1 CAFE standards in the US (miles per gallon)



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In the Clean Air Act Amendments of 1990, the EPA imposed a reduction of the sulfur content in road Diesel to 500 ppm, effective 1993. This was to facilitate compliance with emissions standards applicable to Diesel buses and trucks that were drafted in 1985 and enforced in 1994. Also dating to this period were the reformulated gasoline programs (RFG) and Tier 1 emissions standards for light vehicles (gasoline or Diesel) for sale, which, at the time, fell into three categories (proceeding from the most to the least strictly regulated):

- Passenger vehicles (like sedans) and light-duty vehicles weighing less than 3750 pounds;
- Light-duty trucks weighing less than 5750 pounds, including sport utility vehicles (SUVs), vans and pickups;
- Light-duty vehicles weighing over 8500 pounds.

In this way, the EPA sought to bring emissions standards and motor fuel characteristics into convergence. Today, this objective motivates its actions to increase the efficiency of advanced vehicle emissions control technologies, and its projects to develop very low sulfur motor fuels. California's air pollution regulations are a good example, under the authority of the California Air Resources Board (CARB).

In October 2002, the EPA completed its Tier II program, reducing the sulfur content in gasoline (30 ppm on average and 80 ppm maximum, effective 2005), and imposing emissions standards stiffer than those established under Tier I. For the first time, all "light-duty" vehicles (< 8500 pounds), from sedans to SUVs, were included in the same category. **Focusing on NO_x emissions, the EPA also made the emissions standards applicable to Diesel vehicles tougher, and set a target for road Diesel of 15 ppm of sulfur, effective June 2010. This "ultra low sulfur Diesel" (ULSD) is expected to represent 80% of the market by 2006.**

Some of these measures were implemented as part of the National Low Emission Vehicle (NLEV) program negotiated in 1998 by the EPA, the states and automobile manufacturers. Among other things, NLEV used limit values for certain emissions—non-methane organic gas (NMOG), NO_x, CO, particulate matter and HC—that had been implemented by the LEV program developed by the California Air Resources Board (CARB) and taken effect in 1994. At the same time, the National Highway Transportation Safety Administration, part of the US Department of Transport (DOT), proposed gradually raising the CAFE standards for light-duty trucks (including SUVs) from 20.7 to 22.2 miles par gallon by 2007, while keeping standard for passenger cars constant at 27.5 mpg.

In 2002, the EPA also introduced emissions standards for non-road engines (Tier 3), some of which burn Diesel fuel. Non-road Diesel fuel may also, like road Diesel, be subjected to more stringent specifications (regarding sulfur content, for instance).

The Automobile Market

Diesel sedan sales have always represented a very low proportion of vehicle sales in the United States. In the last 15 years, they accounted for 20,000 to 40,000 private cars, or 0.2% to 0.4% of car registrations on this segment.

Early in the 1980s, following the two oil shocks, the sales of Diesel sedans rose to nearly 100,000 units. At that time, the Department of Transportation forecast that Diesel sedans would account for 20% of the market by 1990. But the fluctuating Diesel fuel price and the falling price of gasoline, not to mention disappointing technological results (the solutions developed were insufficiently reliable) led to a rapid decline of the Diesel vehicle on the US automobile market.

In theory, the CAFE standards ought to have prompted manufacturers to develop their Diesel offering in the United States, but these standards were not very strict in the 1980s and '90s. So the American and Japanese motor companies dominating the market, which had not made the same technology advances as European manufacturers, continued to focus on producing gasoline vehicles. Then came an upsurge in the popularity of SUVs and pickups, characterized by per-unit consumption.

Today, there are indications that Diesel engine might make a comeback in the United States. Some motor companies are banking on a 10% penetration of the private car segment by early in the next decade. The main reason is that the Diesel engine has an edge in terms of consumption and reducing GHGs. American automakers are likely to manifest this interest by putting Diesel engines in the "gas guzzlers" to which American consumers are so partial.

Furthermore, Diesel is compatible with a number of NO_x and particulate emissions aftertreatment technologies: $DeNO_x$ catalysis, NO_x traps, particle filters and selective catalyst reduction based on urea (trucks only).

Under these circumstances, automakers present in the United States are starting to develop their Diesel vehicle offering. In 2004, Daimler-Chrysler expects to roll out a Liberty Jeep running on Diesel fuel. The German carmaker Volkswagen, the only company currently selling Diesel vehicles in the United States, intends to renew its product range with models

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featuring the TDI engine. Mercedes plans to bring out one of its models in a Diesel version.

But these manufacturers are going to run into specific problems relative to the Diesel situation in the US:

- The price of gasoline is slightly lower than that of Diesel fuel (37 versus 39 cents/gallon).
- Diesel engines have a poor image (noisy and polluting).
- The extra cost generated by bringing Diesel vehicles into compliance with the 2007 emissions standards (NO_x and particles) should come to $1,500 to 2,000 per vehicle, depending on the manufacturer.
- The quality of Diesel motor fuel is inferior to that observed in the European Union.

Fig. 2 Diesel fuel specifications in the US and Europe

	Europe		United States	
	2000	2005	1993	2006
Cetane number	51	51	40	40
Aromatics (% vol.)			35	35
Polyaromatics (% weight)	11	11		
Sulfur (ppm)	350	50 & 10	500	15

On the other hand, they may derive some benefit from the latest version of the energy bill passed in November 2003 by the House of Representatives, which provides tax incentives for new-generation Diesel engines. This provision had already been added for hybrid vehicles.

Can American Refiners Meet Increased Demand for Diesel Fuel?

Not only has the EPA established new emissions standards for different vehicle ranges, but it also advocates a drastic reduction (97%) in the sulfur content of road Diesel. By 2006, Ultra Low Sulfur Diesels (ULSD) must represent 80% of the market. They must contain 15 ppm de sulfur versus 500 ppm today.

Recent industrial experiments in Europe (Scanraff in Sweden, BP in the United Kingdom) and in the United States (Arco in California) have shown that producing a very low sulfur Diesel fuel is technically feasible if existing technologies are modified in some respects: reactor size, more severe operating conditions (temperature, pressure), higher level of hydrogen consumption, use of higher performance catalysts, optimized selection of the feedstock treated (obtaining a light Diesel by distilling lower-sulfur crudes).

Given the present configuration of American refineries, it might be difficult to bring these solutions into general use in the United States. Gasoline currently represents 45% of production at American refineries, versus 25% to 35% in Europe. For the most part, they present conversion schemes based on fluidized catalytic cracking + coking. The middle distillate cuts produced are low-grade, which means that it might be necessary to build new high-pressure desulfurization units. The EIA projects that half of all American refineries (i.e. 63% of the 2 Mbbl/day of ULSD that will theoretically be produced by 2006, according to an EIA forecast) may simply revamp existing desulfurization units. These refineries can count on moderate quantities of conversion distillates-base stocks, a supply of relatively low sulfur crude oils and modern hydrotreatment units of large capacity built in the early 1990s to meet the 500 ppm sulfur standards. The EPA is more optimistic: it thinks that the revamping of 80% of production plant is possible, assuming lower costs and more dynamic investment behavior.

Granted, all US refiners will be investing to ensure on-time compliance with the sulfur content standards for gasoline. But their decision is less clear-cut for ULSD, of which they produce three to four times less than gasoline, their star product. Some refiners might exploit other distillate segments (non-road) with less exacting regulations to sell off a portion of their high sulfur base stocks and distillates, which would postpone or obviate the need for innovation in the area of Diesel fuel hydrotreatment. According to a study carried out for the American Petroleum Institute by Charles Rivers Association/Baker and O'Brien, this could show a ULSD deficit of about 320,000 barrels per day by 2006.

This wise approach to capital investment goes back to the early 1990s, when American refiners had an unpleasant experience with surplus capacity induced by the RFG program. Today, however, they are even more hesitant due to the difficulty to accurately evaluate their capability to adapt to new standards with regards to uncertainties about future trends, such as:

- **The real level of demand for ULSD (2 to 3 Mbbl/day, depending on the source) and the impact of standards imposed on other distillates on non-road markets.** These factors will determine price differentials on the various Diesel fuel markets and the degree to which it is necessary to desulfurize "difficult" Diesel base stocks. The latter is a key component in the cost of hydrodesulfurization, knowing that more economical solutions (adsorption or oxidation) are still at the research stage.
- **The performance levels and real commercial potential of advanced catalytic technologies used to limit NO_x and particulate emissions.** These are decisive in

determining the amount of sulfur actually required in road Diesel fuel (given that the technologies under consideration can be distinguished in particular by their sensitivity to sulfur).

- **The availability of engineering/construction resources.** Refineries will all have to meet gasoline standards (2005) and Diesel fuel standards (2006) at the same time. Moreover, there could be a shortage of specific critical equipment produced by a small number of manufacturers worldwide.

In this context, it remains difficult to evaluate the impact of ULSD regulations on the future capex budgets of American refiners.

This is obvious when one observes the variance in published ULSD capex estimates: they range from \$3 to \$13 billion. For example, based on the EIA's long-term equilibrium analyses (National Energy Modeling System, May 2001), refining investment should amount to \$6.3-9.3 billion during 2006-2010, including \$4.2 billion by 2006. The EIA also estimates that the selling price of road Diesel will rise by between 6.5 and 10.7 cents par gallon over this period. These ranges are based on assumptions close to those used by the EPA (lower limit) and the oil industry (National Petroleum Council, upper limit). The NPC calculates that it will take \$4.1 billion just to meet the 30 ppm requirement by 2006.

Taking more optimistic assumptions, the EPA forecasts that ULSD regulations will induce total capital expenditure of \$5.3 billion (including \$3.6 billion by 2006). The EPA estimates the full cost to the refining industry of Diesel desulfurization (capex + operating costs) to be \$50 million, whereas it would cost an estimated \$44 million to satisfy the Tier 2 standards alone (sulfur content in gasoline). Therefore, the EPA deems that the refining industry can bear the cost, which only corresponds to two-thirds of total environmental spending between 1992 and 1994 to satisfy the market for reformulated gasolines and Diesel fuel containing 500 ppm of sulfur.

In the final analysis, the EPA does not anticipate any major changes in the ULSD supply-demand equilibrium by 2006.

The EPA anticipates that some refiners will invest as early as possible to exploit temporarily high margins or to sell credits to those that invest late in the game.

It is also counting on imports from Canada, whose regulations are gradually coming into alignment with US environmental regulations, as well as imports from Europe, which currently supplies about 5% of US road Diesel imports. According to the EIA, the latter assumption is not very realistic. For one thing, the European specification on the sulfur content in road Diesel only sets a 50 ppm limit for 2005 (with the percentage increasing of 10 ppm quality from 2007). Secondly, all that Europe is doing to promote the production of a 10 ppm sulfur Diesel fuel is offer tax incentives. Finally, any ULSD produced in Europe will only be "diverted" to the American market if the price differential is superior to the tax benefit plus the cost of transport.

Diesel Technology *versus* Other Alternative Solutions

Diesel technology can be viewed as a today available solution to help curb the progression of GHGs, especially the CO_2 emissions given off by the American motor fleet. However, this solution can only be effective if it meets environmental standards (particles, NO_x) and if the American refining sector upgrades the average quality of the Diesel fuel that it produces (sulfur content, cetane number).

The motor industry is also exploring other alternatives. The gasoline hybrid vehicle offers continuity with today's internal combustion vehicle, as well as good opportunities to reduce vehicle energy consumption and CO_2 emissions by 20% to 40% compared to the existing conventional motor.

In this area, Japanese carmakers, especially Toyota, are out in front. They offer hybrid sedans in Japan, Europe and the United States, where they dominate a marginal market. In the late 1990s, Toyota was the first to add a gasoline hybrid vehicle to its product range; today, the second version of the Toyota Prius is making its debut. The company plans to extend its hybrid offering to pickups and to the high-end segment of its range. Honda and Nissan are also coming out with a hybrid vehicle.

Until recently uninterested in this type of motor, the American manufacturers are making a timid but real effort to penetrate the hybrid vehicle segment. The most dynamic is General Motors. Initially, it set ambitious goals: it wanted to launch three different versions of hybrid engines by 2007 to equip a dozen models. In the end, it concentrated on its "gas guzzlers" (4 × 4s and SUVs). Ford is a year behind schedule in developing its only hybrid vehicle, while Chrysler has scaled back its plans to only one hybrid pickup.

The use of hydrogen in a fuel cell (FC) to supply an electric motor is presented as a long-term solution worth considering in the effort to reduce GHGs. But several technical issues (hydrogen storage and on-board production) and the cost of FC production (about 100 times greater than a

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conventional thermal motor today) are inhibiting a rapid and large development of this solution.

In conclusion, Diesel technologies can be viewed as an effective solution to reduce GHGs in the United States, provided that they conform to EPA emissions standards. Whether Diesel engine penetrates the US automobile market will deeply depend on the US government policy for transport GHG control, the industrial choices made by the motor companies present in the US, on the level of acceptance by consumers (who recall their negative impressions of the 1970s) and on refiners capacity to modify plant to meet the 2006 specifications and beyond to improve a diesel fuel quality (e.g. cetane index...).

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