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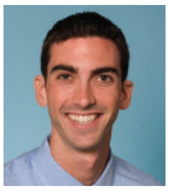
RAND PARDEE RAND GRADUATE SCHOOL

Policy Insight

New Engines and Fuels for Cars and Light Trucks



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Public concerns about fuel prices, energy security, and climate change are causing automakers to alter product plans for the new cars and light trucks ("light-duty" passenger vehicles) scheduled for introduction early in the next decade. Market pressure for innovation has been stimulated by rising fuel prices and forecasts for even higher oil prices, as well as demands from federal and state regulators that new vehicles achieve better fuel economy and emit fewer greenhouse gases.

Speculations about the long-term future of the transport sector include hopes for a variety of new and alternative fuels and technologies. However, the near-term future of propulsion systems for new cars and light trucks in North America involves a fierce competitive struggle between four practical systems: advanced diesel technology, gasoline-electric hybrid vehicles, corn-based ethanol, and improvements to the gasoline-powered internal combustion engine. In this issue of *Policy Insight*, we examine the advantages, drawbacks, and prospects of each alternative, recognizing that most automakers are hedging their bets by investing in more than one system for the next decade.

Advanced Diesel Technology

Advanced diesel technology offers some clear advantages over traditional gasoline engines. Fuel economy is usually 20–40 percent greater, partly because of the larger energy content of diesel fuel and partly because of the efficient operation of a diesel engine. Diesel fuel does contain more carbon than gasoline, but replacing gasoline with diesel fuel is projected to produce a net decline in greenhouse gas emissions. Diesel engines also offer an enhanced capability to haul heavy loads, and they tend to last longer (in terms of total vehicle miles of travel) than comparable gasoline engines.

In Europe, where fuel prices are higher and tax policies favor diesel fuel over gasoline, diesel engines have already captured more than 50 percent of the new-car market. In North America, diesels currently have only about 2 percent of the huge market for light-duty vehicles (now around 17 million vehicles per year), but there are good reasons to expect steady and sustained growth in diesel market share. The recent desulfurization of diesel fuel, combined with breakthroughs in emission control, have made it feasible for advanced diesel engines to comply with California's tailpipe emissions standards, the cleanest requirements in the world for particles and nitrogen oxides. The Mercedes E320 sedan is the first diesel-powered car to be certified for sale in California under modern tailpipe standards, despite uncertainty about the durability of clean diesel's new emissions controls.

The drawbacks of the modern diesel engine include a significant increase in the cost of the engine and the limited availability of diesel fuel, as only about one-third of refueling stations offer diesel. Most of these are near highways and interstates, where they sell diesel fuel for trucks; the availability of diesel fuel in residential areas is expected to grow along with demand.

Recent changes in public policy provide a competitive boost to clean diesel technology. Federal income tax law now offers a generous credit to taxpayers who purchase a light-duty vehicle with a clean diesel engine, though this is set to expire in 2010. From a vehicle manufacturer's perspective, more diesel offerings are also a potential compliance strategy, as new federal and state regulations require rapid advances in fuel economy and control of carbon dioxide emissions. However, the future stringency of tailpipe emissions standards is also a concern, since the decisions of environmental regulators can be unpredictable.

The number of automakers announcing new diesel offerings is growing rapidly and includes BMW, Daimler, Ford, GM, Honda, Toyota, and Volkswagen. A renaissance for the diesel engine has already begun in the U.S. light-duty market, and will likely continue as long as fuel prices remain

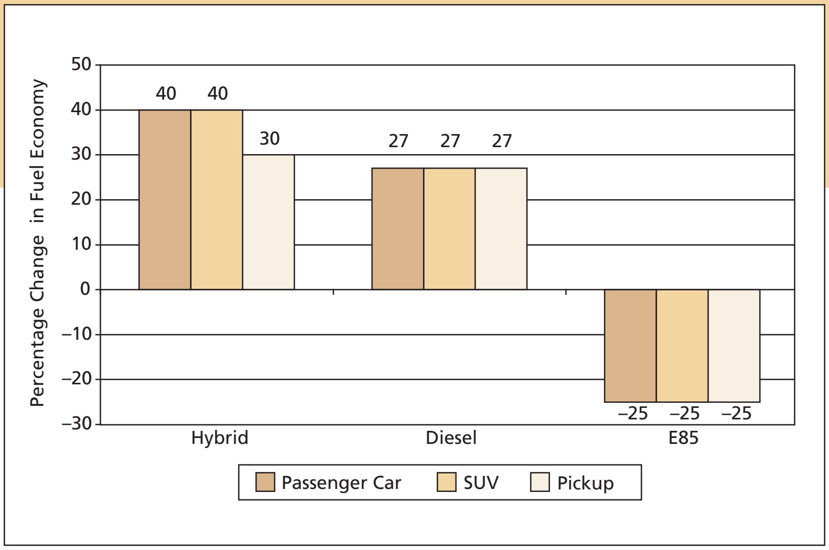

Figure 1. Changes in Fuel Economy Resulting from New Technologies

high and regulatory pressure for fuel economy and carbon control continues to intensify.

Gasoline-Electric Hybrid Technology

The commercial promise of hybrid technology has been a subject of sustained dispute within the automotive industry, but recent developments have turned many skeptics into cautious optimists. What cannot be denied is that hybrid technology offers substantial gains in fuel economy: as much as 40 percent for cars and medium-sized sport utility vehicles (SUVs) and 30 percent for large pickup trucks (see Figure 1).

Not all hybrids are equally fuel-efficient. There is a large difference between a "mild" hybrid, in which the electric motor may operate only at starts and stops, and a "full" hybrid, in which the electric motor does most of the work, with only occasional support from a small gasoline engine. Also, some manufacturers have chosen to allocate the gains from hybridization to increased power and acceleration instead of improved fuel economy.

Honda was the first manufacturer to offer gas-electric technology in the U.S. market (in 1999), but Toyota rapidly surpassed Honda in both volume of hybrid sales and number of hybrid offerings. The Prius accounts for a majority of Toyota's hybrid sales in the U.S. market (as of 2006), and Toyota plans to offer more dedicated hybrids like the Prius. Ford offered the first full hybrid in the U.S. SUV market. GM plans to offer at least eight hybrid models using three different systems (from mild to full) in 2008, and Chrysler is also taking determined steps toward more hybrid offerings.

Even with high fuel prices, the $2,000 to $10,000 premium for a hybrid engine has encountered consumer resistance. Honda discontinued two hybrid offerings due to limited sales, and in SUV applications, Ford, GM, and Toyota have found that less than 25 percent of buyers choose the hybrid option. The ultimate extent of the hybrid's penetration in the U.S. market may depend on how much the cost of battery technology can be curtailed.

Sales of hybrids have been boosted by favorable public policies. In some states, owners of hybrid vehicles have been granted access to high-occupancy vehicle (HOV) lanes, and government fleet purchasers have favored hybrid technology. Generous federal income tax credits were made available for full hybrids, though the volume cap has already been reached at Toyota, and Honda and Ford are nearing their caps. Congress will need to decide whether to extend the hybrid tax credits and remove the ceilings for specific manufacturers. As regulatory pressure on fuel economy and carbon emissions intensifies, the business case for large-scale commitments to hybrid technology will improve.

Overall, the penetration of gasoline-electric hybrid technology in the U.S. market has stunned some experts in the automotive industry. Hybrid sales continue to grow rapidly, stimulated by high fuel prices, favorable policies, and regulatory pressure. But the economics of hybrids, especially in large SUVs and pickups, may remain unfavorable for mass production unless there are breakthroughs in battery technology.

Blends of Ethanol and Gasoline

In 2006, more than 50 percent of the transport fuel sold in the United States was "gasohol": a blend of 10 percent ethanol and 90 percent gasoline (also called E10). It is expected that gasohol use will increase rapidly in the next few years as a competitive oxygen booster (MTBE) is phased out to protect water supplies and as refiners comply with new regulations to offer clean and renewable fuels.

A key competitive question is whether the market for E85, a blend of 85 percent ethanol and 15 percent gasoline, will grow rapidly in the next ten years. Vehicles require significant modification to run on E85, but Chrysler, Ford, and GM have found low-cost ways to modify new vehicles so that they can run on E10 or E85 ("flex fuel" vehicles). In model year 2007 alone, about 5 percent of the new light-duty vehicles in the United States were sold with flex-fuel capability, and it is expected that this percentage will increase rapidly over the next five years. For the consumer concerned about the volatility of fuel prices, a vehicle that can operate on either E10 or E85 has a versatility advantage.

E85 has some other advantages. In the United States, ethanol is made almost exclusively from corn. Although some petroleum is consumed in the process of making corn-based ethanol, the net effect of replacing E10 with E85 is a sharp reduction in petroleum consumption—an attractive outcome in the eyes of energy-security advocates. Whether using corn-based ethanol also leads to a net reduction in greenhouse-gas emissions is less clear. The climate impact of corn-based ethanol is very sensitive to exactly how it is produced, and some methods of production may increase greenhouse-gas emissions by as much as double the amount of emissions from a gasoline-powered vehicle.

The principal drawback of E85 is the high cost of producing the fuel, a cost that is above even high-priced gasoline. Since ethanol is not compatible with gasoline pipelines, high transport costs are a significant obstacle for E85. Ethanol also has a lower energy content than gasoline, which makes the cost comparison unfavorable on an energy-equivalent basis. Not surprisingly, only about 1,000 of the 170,000 refueling stations in the United States offer E85.

In addition, if the demand for corn-based ethanol continues to grow, higher prices for corn may cause food prices to rise further, since corn is a key input to the production of meat and other foods. Environmental scientists are also beginning to raise concerns about the impacts of corn-based ethanol production on the quantity and quality of water supplies.

Benefit-cost analysis does not support a rapid increase in corn-based ethanol production unless one places a high value on energy security or world

Table 1. Net Present Value (NPV) of Three Alternative Technologies, Compared with the Current Gasoline Baseline

Future Price of Oil	Hybrid	Diesel	E85
Passenger Car			
Low	–$1,205	–$374	–$2,110
Nominal	–$317	$288	–$1,045
High	$935	$1,219	$1,113
Sport Utility Vehicle			
Low	–$636	$264	–$2,936
Nominal	$477	$1,092	–$1,504
High	$2,044	$2,257	$1,368
Pickup Truck			
Low	–$1,007	$1,162	–$4,005
Nominal	$135	$2,207	–$2,046
High	$1,742	$3,679	$1,792

oil prices stay high (see Table 1). But policymakers appear determined to give a boost to E85. Vehicle manufacturers receive significant fuel-economy credits if they produce flex-fuel vehicles, and Congress has authorized generous tax credits for blenders that use ethanol and for refueling stations that add E85 pumps. Removing the 54-cent tariff on imported ethanol would make E85 more competitive by allowing Brazil—where ethanol is made cheaply from sugar cane—to export ethanol to the United States, but Congress is reluctant to expose investments in corn-based ethanol to competitive pressures.

In summary, the future of E85 is brighter than might be expected based on economics because policymakers appear to be determined to expand E85 use. Though technological breakthroughs in ethanol production from sources other than corn may lower costs, it is doubtful that large numbers of motorists will purchase E85 at the pump if the energy-equivalent price of E85 remains—as it is today—higher than the price of gasoline.

The economics of hybrids . . . may remain unfavorable for mass production unless there are breakthroughs in battery technology.

Benefit-Cost Analysis of New Engine and Fuel Technologies

We calculated the net present value of each technology from a societal perspective, accounting for a broad array of factors such as incremental technology costs, fuel savings, performance benefits, life-cycle pollution emissions, and reductions in oil use. Table 1 displays our results for each technology under different assumptions about future oil prices and for three different vehicle classes.

The results show that clean diesels consistently have the highest net present value. Hybrids look promising when gasoline prices are at or above our nominal assumption ($2.50 per gallon), except for passenger cars. The net present value of E85 is negative and generally the lowest of the three alternatives, except in the high oil price case (in which the long-run price of gasoline is $3.50 per gallon). These conclusions from the analysis hold across a broad range of assumptions about technology costs, pollution damage estimates, and the social costs of oil dependence.

Improved Gasoline-Powered Vehicles

In the history of automotive propulsion systems, the petroleum-based internal combustion engine has been declared obsolete many times. But creative engineers have found numerous ways to refine the gasoline engine to maintain its competitive edge and lengthen its life.

Future analysis should include modifications to the current gasoline engine. For example, Ford's "Eco-boost" program calls for turbochargers—a technology normally associated with diesel applications—to be added to gasoline engines, which could increase fuel economy by as much 20 percent. GM is also moving in this direction. Lightweight materials may also provide part of the answer. Honda is a leader in this area, as are steelmakers, who are offering new lightweight steel products designed to compete with aluminum.

Before the gasoline engine is again declared dead prematurely, it may be wise to account for promising refinements to the gasoline engine that are likely to be discovered by creative engineering.

Conclusion

From both a consumer and societal perspective, advanced diesels and gasoline-electric hybrids have a promising future. But policymakers appear to be favoring ethanol through a variety of regulations, subsidies, and tax incentives. A better approach might be to establish a level playing field for the propulsion systems, making sure that the net effects of public policies encourage innovation while not unduly favoring one technology over another.

Further Reading

Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne, "Land Clearing and the Biofuel Carbon Debt," *Science*, Vol. 319, No. 5867, February 29, 2008, pp. 1235–1238.

Farrell, Alexander E., Richard J. Plevin, Brian T. Turner, Andrew D. Jones, Michael O'Hare, and Daniel M. Kammen, "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, Vol. 311, No. 5760, January 27, 2006, pp. 506–508.

Greene, David L., K. G. Duleep, and Walter McManus, *Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market*, Oak Ridge, Tenn.: Oak Ridge National Laboratory, ORNL/TM-2004/181, August 2004.

Keefe, Ryan, Jay Griffin, and John D. Graham, *The Benefits and Costs of New Fuels and Engines for Cars and Light Trucks*, Santa Monica, Calif.: RAND Corporation, WR-537-PRGS, 2007. As of February 28, 2008: http://www.rand.org/pubs/working_papers/WR537/

Lave, Lester, Heather MacLean, Chris Hendrickson, and Rebecca Lankey, "Life-Cycle Analysis of Alternative Fuel/Propulsion Technologies," *Environmental Science and Technology*, Vol. 34, No. 17, 2000, pp. 3598–3605.

Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu, "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," *Science*, Vol. 319, No. 5867, February 29, 2008, pp. 1238–1240.

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