



Risk in Perspective

Fueling Heavy Duty Trucks: Diesel or Natural Gas?



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"The choice to use diesel or natural gas fuels in heavy duty trucks is not straightforward."

Last year heavy duty trucks accounted for about 30% of the 2 trillion vehicle miles of travel on US roads and highways. These vehicles include big rig freight carriers on interstate highways, smaller local delivery trucks, and buses. Most consumer goods in the US have at some point been shipped by heavy duty trucks, while buses remain critical to transportation of pupils to and from school in most regions of the US.

How should heavy duty trucks be fueled? Diesel fuel has dominated this market for decades, but recently regulators in California have begun actions that call into question the future of the diesel. Natural gas is touted as a clean alternative. Since the early 1990s, for example, several urban transit systems have used natural gas instead of diesel fuel to power part of their bus fleets. For these applications, the fuel is stored in the form of compressed natural gas (CNG), where it is compressed to several thousand pounds per square inch, or as liquified natural gas (LNG), which requires temperatures around -260° F.

One of the world's leading truck and engine manufacturers, Navistar International, has commissioned

HCRA to undertake an independent, comparative analysis of diesel and natural gas fuels for use in heavy duty trucks. A broader assessment might include other fuel options like liquid petroleum gas, alcohol fuels (methanol and ethanol), and hydrogen, but diesel and natural gas appear to be the most likely short run alternatives in the US. In phase 1 of the study, a qualitative analysis has been conducted that applies explicit evaluative criteria and identifies key tradeoffs. In phase 2 of the study, a more quantitative risk-tradeoff analysis will be undertaken based on the best available data. In this issue of **RISK IN PERSPECTIVE**, we offer preliminary findings from our qualitative analysis while urging readers to identify additional factors for consideration in phase 2.

AIR POLLUTION: PARTICULATES

A major concern about the diesel engines now on the road is that they pollute the air, which is a special concern in those areas that have difficulty meeting health-based outdoor air quality standards. In some urban areas, diesel-powered trucks are significant contributors to ambient levels of particulates, comprising 10%

to 30% of the emissions of fine particulate matter (particles less than 2.5 microns in size). Particulates reduce visibility and are associated with adverse health effects: excess mortality, aggravation of cardiopulmonary disease, exacerbation of bronchitis and asthma, and perhaps lung cancer.

The magnitude of the health risks induced by diesel emissions is a subject of continued scientific research and controversy. In particular, the scientific validity of California's quantitative estimates of cancer risk from inhalation of diesel exhaust has been questioned by the Health Effects Institute, an independent scientific organization. Major research programs are under way to enhance scientific knowledge of the health effects of diesel emissions. In addition, little is known about whether particulates from natural gas engines have the same effects as diesel particulates in terms of their possible carcinogenicity.

The big advantage of natural gas is that it burns cleaner than diesel fuel. Natural gas is primarily methane, a relatively simple molecule. It mixes more uniformly than diesel fuel in the ignition chamber, leading to more complete combustion and fewer emissions of several types of pollution. One study has compared emissions from diesel- and LNG-powered heavy duty trucks operated by a California grocery store chain, and it found that the LNG trucks had 90% fewer direct emissions of particulates by weight than the diesel trucks. These diesel trucks, however, were not equipped with innovative emission control systems.

Technological advances in diesel systems are leading to improved environmental performance and the creation of "green" diesels. Innovative particulate traps can capture significant quantities of particles, and engineers are developing better methods of trap

regeneration (removal of particulates accumulated in the trap). In addition, cleaner diesel fuels can be used. For example, Fischer-Tropsch diesel fuel contains no sulfur and can significantly reduce emissions of particulates and other pollutants.

Adverse health effects from inhaling particulates may depend not only on the mass of particles, but also on the size of the particles. Smaller particles penetrate deeper in the respiratory tract and can be more toxic. Some studies suggest that while natural gas engines emit a smaller mass of particulates, the number of "ultra-fine" particulates may be higher than for diesel engines.

AIR POLLUTION: NITROGEN OXIDES

Emissions of nitrogen oxides (NO_x) from heavy duty vehicles are another important concern. NO_x contributes to the formation of both ground-level ozone ("smog") and fine particulates. Many urban residents live in areas that exceed national air quality standards for ozone and face increased risks of impaired lung function, chest pain, and asthma. Heavy duty trucks comprise about 10% of NO_x emissions in the US.

Natural gas engines have an advantage over diesels with respect to NO_x emissions. The study of LNG trucks in California found that, compared to the diesels, they had 25% to 75% fewer emissions of NO_x. Advances in "green" diesel technology, such as exhaust gas recirculation (EGR), are likely to reduce NO_x emissions. Yet controlling NO_x emissions from diesels poses significant challenges to automotive engineers. Simultaneous reductions of both NO_x and particulate emissions are difficult to achieve since the control of one pollutant generally must be traded off with emissions of the other.

GREENHOUSE GASES AND GLOBAL CLIMATE CHANGE

Diesel engines are very efficient. They operate at high compression ratios and are able to convert into useable work a large fraction of the available energy in the fuel. Because natural gas engines operate at a lower compression ratio, diesel engines possess an efficiency advantage over natural gas, although this advantage may be reduced by advanced emissions control systems. All else being equal, higher fuel efficiency results in less fuel being burned and fewer emissions of carbon dioxide.

Carbon dioxide emissions contribute to the greenhouse effect, which may cause global warming, disruptions in agricultural production, and ecological harm. Road transport (including both passenger vehicles and heavy duty trucks) accounts for about 30% of emissions of greenhouse gases in the US, so fuel efficiency gains can play an important role in controlling potential impacts of global warming.

Carbon dioxide is not the only greenhouse gas of concern, however. The use of natural gas as a motor vehicle fuel may exacerbate the greenhouse effect because methane will escape into the atmosphere during refueling operations and at natural gas storage facilities. It is difficult to predict the precise magnitude of these methane emissions, but it is known that methane is approximately 20 times more "potent" as a greenhouse gas than carbon dioxide.

The apparent advantage of diesels with respect to greenhouse gas emissions is diminished somewhat when viewed from a life-cycle perspective. Although diesel engines offer greater fuel efficiency than natural gas engines, the energy used to extract, refine, and transport the fuels differs. The production of diesel fuel is a more energy intensive process and may entail more greenhouse gas emissions than

natural gas during the production step of the life-cycle. One study suggests that from a life-cycle perspective, the use of natural gas instead of diesel in heavy duty vehicles results in a 5% to 10% increase in greenhouse gas emissions.

European policy makers and vehicle manufacturers have taken the threat of global climate change more seriously than have the Americans. Europeans see "green" diesel technology as part of a comprehensive approach toward European compliance with the Kyoto agreements aimed at stabilizing greenhouse gas emissions. In designing strict emission standards for NO_x and particulates that could discourage the use of diesels, regulators in California do not appear to have taken into account the diesel's advantage in control of greenhouse gas emissions.

SAFETY

The relative safety of using natural gas or diesel fuel is important for policy makers to consider. Natural gas is highly flammable, and explosions are a common fear. The National Fire Protection Association, whose hazard rating system influences a wide range of safety codes, gives natural gas its highest hazard ranking for flammability, while diesel is designated as moderately flammable (on a scale of zero to four, natural gas is a four, while diesel is a two). Natural gas leaks and spills must be treated with great care. Natural gas is lighter than air and will become buoyant and disperse, but natural gas vapors at low temperatures (from leaks of cryogenic LNG or CNG cooled by thermodynamic expansion) are dense and can form clouds of flammable vapor concentrations. Diesel is less flammable since it generally does not form ignitable vapor mixtures unless the fuel is heated.

Natural gas also poses additional hazards related to its special storage characteristics. The extreme pressure and temperature

conditions involved in using CNG and LNG pose hazards not encountered with diesel. For example, LNG storage vessels must be equipped with pressure release valves to prevent an unsafe buildup of pressure that can occur when the LNG warms and changes to a gaseous state. Clearly, special care must be given to the transport, transfer, and storage of CNG and LNG to avoid leaks and tank rupture.

These characteristics of natural gas indicate that it poses potentially greater safety hazards than diesel. These hazards do not necessarily preclude its viability as an alternative to diesel. Training for people who handle natural gas, as well as careful design and manufacture of natural gas storage tanks, can reduce the potential for leaks and tank ruptures. In some ways, natural gas may be safer than diesel. For example, the current natural gas pipeline distribution system transports natural gas to many locations, reducing the hazards associated with using tanker trucks to haul fuel on roads and highways. In addition, natural gas does not pose the toxicity hazards of diesel fuel, which may leak into the environment and expose workers to toxic chemicals.

Additional empirical analysis and experience with natural gas vehicles will provide a better picture of the relative risks of natural gas and diesel. Nevertheless, policy makers should be aware that the public is likely to demand special care in the widespread use of natural gas in vehicles because of the relative novelty and lack of familiarity with this technology. Safety concerns about siting fueling stations may be an obstacle to the implementation of natural gas as a replacement for diesel fuel in heavy duty trucks.

PERFORMANCE

Diesel engines offer performance benefits that have made them the favored option in heavy duty truck applications. Diesel engines are

powerful enough to haul heavy loads and climb steep hills. In addition, their high fuel economy allows long-range operation between refuelings.

A frequent complaint from drivers of LNG heavy duty trucks is a noticeable loss of power compared to diesel engines. In addition, natural gas vehicles have a limited driving range. One reason for this is the limited current infrastructure for refueling CNG and LNG trucks. Natural gas vehicles typically have to return to a central facility each time they need to refuel. The establishment of more refueling stations would alleviate this limitation. A second reason for the limited driving range is that natural gas trucks have poorer fuel economy. Fuel economy (miles per gallon) is influenced by both the energy density (BTU/gallon) of the fuel as well as the engine efficiency (the fraction of available energy in the fuel that can be converted to useable work). One gallon of LNG contains about 60% of the energy in a gallon of diesel fuel, and CNG contains even less energy per unit volume. The relatively low energy density of natural gas can be addressed by using larger fuel tanks, but this imposes a fuel economy penalty due to the added weight and may reduce the amount of useable space in a vehicle.

The performance limitations of natural gas engines suggest that they may be a viable option only in certain niches, at least in the short run. Local delivery trucks and transit buses are the most frequent application of natural gas in heavy duty vehicles because natural gas is more difficult to implement for use in long-haul freight carriers.

COST

The capital costs of purchasing a heavy duty natural gas vehicle vary widely, but in general they cost more than diesels. The study of LNG trucks in California found that a conventional

diesel truck may cost somewhere around \$70,000, and a natural gas truck costs an additional \$35,000. Another study found that the incremental cost of a natural gas transit bus is on the order of \$45,000 to \$75,000 per bus, taking into account the installation of special fuel tanks, fire suppression systems, and other devices. It is not surprising that the cost of natural gas vehicles is high, since the scale of production is quite small and the technology is still relatively new. Prices would likely decrease if the market for natural gas vehicles increased substantially, but by how much is unclear. In addition, the cost of diesel vehicles is likely to increase with the adoption of "green" diesel technologies.

Fuel cost is another consideration. The average big rig logs about 70,000 miles a year, and the purchase of fuel is one of the biggest costs for trucking companies. While a gallon of LNG is generally less expensive than a gallon of diesel, a comparison of fuel cost should be made on an energy equivalent basis (since natural gas contains less energy per unit volume). In this regard, neither fuel has a clear advantage. The extensive natural gas distribution system in the U.S. may offer a convenient and inexpensive supply of CNG. However, this supply may not provide the purity of natural gas that is sought to maximize engine performance (e.g., impurities can cause engines to "knock"). LNG also can be readily produced at competitive rates, but the total costs of supplying LNG often depend heavily on transportation costs. For example, existing gas processing plants in Wyoming can produce LNG inexpensively, but the demand for LNG in heavy duty trucks tends to be located in distant regions. At the same time, costs for diesel fuel fluctuate widely; for example, the national average price of diesel fuel has increased around 30% in the last year. Therefore, the price of natural gas may be higher or lower than diesel, depending on the particular circumstances.

A transition to natural gas also entails capital

costs related to special facilities used for refueling and maintenance. The incremental costs for installing natural gas facilities can be substantial. For example, the study of the LNG fleet in California found that the construction of an on-site refueling station for eight LNG trucks cost \$350,000. Maintenance facilities may also need to be upgraded to include ventilation improvements and leak detection systems. Compliance with fire safety codes and local siting concerns may also increase incremental costs. One study has found that a typical 200-bus fleet of CNG vehicles may require capital costs on the order of \$2 million above that for a conventional fleet of diesels.

If environmental regulations make new heavy duty trucks more expensive, the short run effect on pollution may be adverse. The existing fleet of heavy duty trucks is typically used for many years, and these vehicles are subject to the less stringent environmental standards in place when they were originally purchased. If replacement costs for purchasing new natural gas or "green" diesel vehicles are very high, this may have the unintended consequence of prolonging the life of a fleet of comparatively dirty vehicles.

CONCLUSION

The choice to use diesel or natural gas fuels in heavy duty trucks is not straightforward. These fuels have different effects on environmental quality, health, safety, truck performance, and economics. Decision-makers should recognize that fuel choice involves trade-offs between competing policy goals. The table below summarizes the relative advantages of the fuels with respect to different criteria considered in this qualitative assessment.

There are competing environmental considerations. On the one hand, use of natural gas could lead to fewer emissions of particulates and NOx. Such a conclusion is

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FURTHER READING

Health Effects Institute. Diesel
Emissions and Lung Cancer:
Epidemiology and Quantitative Risk
Assessment, A Special Report of the
Institute's Diesel Epidemiology
Expert Panel, June 1999.

National Research Council
Transportation Research Board.
Guidebook for Evaluating, Selecting,
and Implementing Fuel Choice
Options for Transit Bus Operations,
Transit Cooperative Research
Program Report 38, Sponsored by the
Federal Transit Authority,
Washington, D.C.: National
Academy Press, 1998.

Organization for Economic
Cooperation and Development.
Choosing an Alternative
Transportation Fuel: Air Pollution
and Greenhouse Gas Impacts, Paris:
OECD, 1993.

U.S. Department of Energy, National
Renewable Energy Laboratory.
Raley's LNG Truck Site Final Data
Report, July 1999.

U.S. Department of Transportation,
Federal Transit Agency. Summary of
Assessment of the Safety, Health,
Environmental and System Risks of
Alternative Fuels, FTA-MA-90-7007-
95-1, DOT-VNTSC-FTA-95-5,
August 1995.

Walsh, Michael. Global Trends in
Diesel Emissions Control-A 1999
Update, Society of Automotive
Engineers, SAE Technical Paper
Series 1999-01-0107, 1999.

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DIESEL VS. NATURAL GAS IN HEAVY DUTY TRUCKS

Criterion	Relative Advantage	
	Diesel	Natural Gas
Pollution		
Fine particulates		X
Ultra-fine particulates	?	?
Nitrogen oxides		X
Greenhouse gases	X	
Safety	X	
Performance	X	
Economics		
Short run cost	X	
Long run cost	?	?

complicated by the fact natural gas may increase "ultra-fine" particulate emissions. On the other hand, diesel engines appear to have fewer greenhouse gas emissions (carbon dioxide and methane). A quantitative tradeoff model is required to determine which of these pollutants creates the greatest harm.

Diesels appear to have a safety advantage over natural gas. Additional analysis and experience with natural gas could provide a better sense of the relative safety risks. Performance considerations also appear to favor the diesel engine in heavy duty trucks, though natural gas may perform acceptably well in less demanding applications.

Economic considerations weigh in favor of the diesel, particularly in the short run. Substantial capital investments throughout the transportation system would be required to make natural gas a feasible option for use in heavy duty trucks. Yet the long run prices of diesel fuel and natural gas are big unknowns, since both are influenced by unpredictable forces in worldwide energy markets.

Public policies toward diesel fuel in Europe and the US appear to be diverging. This dichotomy is most apparent in the passenger car market, but similar forces may also apply to heavy duty trucks. European vehicle manufacturers, in collaboration with regulators in the European Union, appear to be increasing their commitment to "green" diesel engine technology by expanding the use of the diesel in passenger vehicles as well as in heavy duty trucks. Europe encourages the use of diesels through differential fuel taxes and by imposing less stringent emission standards for diesels, compared to gasoline. This "pro-diesel" strategy is part of a larger European commitment to enhance fuel efficiency and reduce greenhouse gases from the transportation sector of the economy. American policies toward the diesel are less clear, but it appears that policies being devised in California are discouraging the use of the diesel. Such policies apply the same emission standards to both gasoline- and diesel-fueled cars, which may lead to greater reliance on natural gas in the heavy duty truck market.